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Pollutants Removal by Vegetative Filter Strips Planted with Different Grasses

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Abstract. Over the last few years, increasing occurrence of deadly pathogens and presence of various pollutants (nutrients, pesticides, other chemicals, and sediments) above the prescribed limit in water systems, clearly indicate alarmingly deteriorating quality of water resources. As a result, farming systems that are known to be the main non-point or diffuse pollution source are being reviewed microscopically. Vegetative Filter Strip (VFS) is considered to be one of the best management practices (BMPs) for effective control sediment and nutrient transport over agricultural lands. Many laboratory and field scale studies have also indicated the limited usefulness of VFS to control movement of bacteria in surface runoff. However, design of VFS under field conditions still remains a challenge due to variation in upland hydrological parameters and factors effecting movement of pollutants through VFS such as type of vegetation cover and density, width of strip, and land slope. Determination of trapping efficiency of VFS for bacteria is more complex due to the complex interaction of various factors governing the die-of and re-growth of bacteria under field condition, and release of bacteria from soil reserve. An extensive field experiment is being conducted at the research farm of University of Guelph in Southern Ontario, Canada, to evaluate to effectiveness of VFS under different vegetation cover, ground slope, width of filter strip, and in various seasons. Concentration of sediment reduced an average by 88.3% and almost 94.3% sediment mass was trapped in various filter strips. Higher trapping efficiencies for mass were observed for sediment bound nutrients (94.5% and 93.9% for N and P, respectively) compared to soluble forms (57.0% and 77.3% for N and P, respectively). Results for bacteria (*Total Coliforms, Fecal Coliforms, and E. Coli*) through VFSs were encouraging but not conclusive. In the present paper, experiment and results of the study are presented and discussed in details.

Keywords. *Vegetative Filter Strips, Pollutants, Nitrogen, Phosphorous, Bacteria, Manure, BMP*

Introduction

Environmental concern related to nutrient loss and appearance of various pollutants (sediment, nutrients, pathogens, and others) in water systems at a higher than the recommended level, could only be addressed by holistic nutrient management for crop production and by adopting strategies that limit pollutant generation and their transportation. Impact on water quality from excessive manure and other waste products from industrialized and concentrated livestock operations have added new dimension to environmental issues. Further, after the 2000 Walkerton tragedy that killed seven people in Canada, federal and provincial regulating agencies are desperately looking ways and means to plug potential pollution sources responsible for deteriorating drinking water sources. Huge investments are being made to identify, and control point and non-point pollution sources. Sediment, nitrogen, phosphorous and microbes are primary pollutants associated with surface runoff from areas of confined livestock activity and agricultural fields receiving manure (Western et al., 1980; McLeod and Hegg, 1984; Edwards et al. 1983).

During recent past, vegetative filter strips (VFS) have become an important best management practice to control pollutant transport (Boyd et al., 2003; Williamson et al, 1999; Patty et al., 1997; and Mickelson and Baker, 1993). Vegetated filter strips also known as buffer strips, buffer zones, and grass filters/strips or filter strips (Chaubey et al. 1995). Numerous studies have clearly advocated the effectiveness of vegetative filters strips as the first defense mechanism in the multi-tier approach of reducing pollutant transport from agricultural fields applied with manure. VFS along streams are recommended widely in Ontario to protect and enhance the quality of stream ecosystems. However, effective tools for designing VFS under field conditions based on the quality and quantity of pollutants in upstream runoff are unavailable.

During the past few decades, researchers (Wilson, 1967; Neibling and Alberts, 1979; Overcash et al., 1981; Wall et al., 1982; Hayes et al., 1984; Rudra and Wall, 1986; Lalonde, 1998; Oblermann and Gordon, 2000; Gharabaghi, et al., 2000 & 2001; Abu-Zreig et al., 2003; Boyd et al., 2003) have focussed to evaluate the effectiveness of VFS for removal of sediments nutrients and pathogens from from runoff originating from crop land and from feedlots. The literature reveals that in certain vases VFS can remove up to, or even more than, 80% of nutrients, sustended solids and pathogens in surface runoff (Doyle et al., 1977; Bingham et al., 1980; Overcash et al., 1981). The removal efficiency depends upon the length of filter strips, type of vegetation and soil type because the removal mechanisms include sedimentation, infiltration and entrapment by the vegetation. Young et al. (1980) reported to to 92% reduction in sediments, 64% reduction in TN, 59% reduction in TP and 80% reduction runoff) by 24 m long cropped area receiving runoff from feedlot. Dickey and Vanderholm (1981) studied feedlot runoff and found that VFS can remove upto 95% (on mass basis) of nutrients and oxygen-demanding materials from the incoming runoff with concentrations reductions of up to 80%. Livingston and Hegg (1981) used terraced pasture to treat dairy yard runoff with some success. Edwards et al. (1983) and Dillaha et al. (1986b) studied the effectiveness of VFS to treat beef feedlot runoff and also obtained similar results for removal of solids, TP and TN. Dillaha et al. (1985, 1986a, 1987, 1989); Hayes and Hairston (1983) and Mickelson and Baker (1993) assessed the effectiveness of VFS in controlling pollutants from manured cropland runoff. These researchers found that VFS were up to 84%, 79% 73% and 56% effective in removing incoming masses of suspended solids, TP, TN, and atrazine, respectively. Dillaha et al. (1988) observed significant reduction in trapping efficiency when flow regime changes from uniform to concentrated flow. Lammers et al. (1991) also observed similar results in a survey of actual buffer strips in Virgina and concluded that buffer strips were not very effective when water collects in natural drainage ways prior to crossing the buffer strips.

Generally, pollutant removals efficiency of vegetative filter strips varies directly with the length of filter strip, and inversely with the magnitude of runoff rate entering the filter strip. Chaubey et al. (1994) observed a mass reduction of TSS, TN and TP in surface runoff by 66%, 0% and 27%, respectively with a 4.6 m long filter strips. They also observed an improvement in the ammonia and P removal from swine lagoon effluent with an increase filter strip length. Such reductions can be attributed to a significant decrease in flow velocity and the retadrng effect of vegetation, however, the reductions in the concentration of soluble pollutants is not as significant (Edwards et al., 1996; Srivastava et al., 1996; Lim et al. 1998). Increases in filter strip length results in a first–order exponential decline in pollutant concentration in the runoff generated from manure treatred crop land area. According to Ikenberry and Mankin (2000) vegetated filter strips can reduce pollutant concentrations from 70 to 90% in runoff from open animal feedlots. Variations in removal efficiency is due to site-specific characteristics of vegetation, slope, soil type, size and geometry of filter strip, and incoming pollutant concentrations. Young et al. (1980) concluded that 10-m wide grass filter strips could reduce up to 70% of the amount of fecal coliforms bacteria in runoff. Fajardo et al. (2001) that with filter strips up to 99% nitrogen removal efficiency and up to 87% fecal coliforms removal efficiency is possible from runoff originated from stockpiled manure.

Although it is apparent that VFS are generally capable of reducing non-point source pollution by reducing pollutants entering water bodies through surface runoff, further studies are still needed to establish the principal physical, chemical and biological mechanisms that regulate the transport, transformation, deposition and re-entry of bacteria and nutrients during lateral movement of overland runoff through vegetative filter strips, differing in vegetation and width in Ontario conditions. There is a need to quantify the changes with input patterns and season in the mechanisms and processes affecting bacteria and nutrient passage through vegetative filter strips; to establish design procedures useful for the selection of vegetation type and the lateral width of filter strips effective for protecting stream water quality for specific site characteristics of runoff, geomorphology and soil.

Realizing the fact that very limited knowledge is available on the effectiveness of vegetative filter strips in controlling pollutant transport, especially on bacteria, in Ontario conditions an extensive project is currently in progress at the University of Guelph. One of the focus of this research has been to evaluate the effectiveness of vegetative filter strips for the removal of sediments, nutrients (nitrogen and phosphorus) and pathogens (*Total Coliforms, Fecal Coliforms, and E. Coli*) from runoff originating from the cropland treated with manure in Ontario conditions.

Material and Method

The experiment was conducted in the year 2003 at Elora Research Farm, University of Guelph, Ontario, Canada located at 43°38.75' North Latitude and 80°24.5' West Longitude. Twelve filter strips of 5, 10, and 15 m length and 1.2 m width, and four vegetation covers with an average slopes of 3 % were prepared for this study. The experiment site has a clay brunisolic gray brown Luvisol-London (Guelph loam) soil type, and the soil texture is silty loam. Four vegetation treatments include perennial rye grass (A), sod (Kentucky blue grass) (B), mixed grass species, and no vegetation (D). After grass plantation filter strips were irrigated daily for about half an hour using a sprinkler system to establish grasses. Lateral surface runoff flow from the surrounding areas to these filter strips was prevented by inserting galvanized plates (240 cm X 15.2 cm) into the ground to a depth of 10 cm along both sides of the strips.

A flow stream of known flow rate and concentration of pollutants (sediment, bacteria, and nutrient) was introduced at the upper end of the buffer strip for a selected period of time. The concentration of sediment, bacteria, and nutrients at the bottom of the strip were monitored to assess the quality of water leaving the filter strip. The soil used for creating artificial runoff was Brookston clay. The soil collected from the field was dried, grounded, and sieved using US Standard sieve no. 40 (45 micron). A plastic mixing column of 29.5 cm diameter was used to mix soil, dairy cattle manure, and water to prepare slurry. A sump pump was used in the mixing column for continuous stirring of slurry during the experiment. To simulate upland runoff, the prepared slurry was mixed with clean water and was delivered at the upper-end of the filter strip at a rate of about 1.2 L/s. A peristaltic pump was used to deliver slurry, at a constant rate (1 L/min), with clean water. The experiment was conducted under unsaturated moisture conditions. During the experiment runoff samples at inlet and outlet were collected at different time intervals. Collected samples were analyzed for total suspended solids, phosphorus, nitrogen, and bacteria concentration. Standard analytical procedures were followed for the analysis of the samples. Oven dried filter membranes (0.45-micron) were used to determine total suspended sediment (TSS) concentrations. Sediment samples were digested to determine total N and P by following the method suggested by Thomns et al. (1967). Digested samples were then analyzed by QuickChem Method 13-107-06-1-A and Method 15-115-01-1-B to determine total Kjeldahl Nitrogen and total Phosphorous (Lachat Instruments, Milwaukee, WI). Industrial method # 824-89 and method # 780-89 of Techniocn Instruments Corporation (Tarrytown, New York) were used to determine NO3-N to NH4-N concentrations in the runoff samples. To count Total Coliforms, Fecal Coliforms and E. Coli, membrane filtration technique was used (American Public Health Association (APHA), 1989).

Results and Discussion

Total Suspended Solids (TSS): The average concentration of TSS in the incoming and exiting synthetic runoff ranged between 1.5 to 2.0 mg/l and 0.13 to 0.23 mg/l in incoming and outgoing runoff, respectively (Table 1). This indicated a substantial reduction in TSS concentration was observed between the inlet and outlet of filter strip. On an average 5000 mg of TSS entered into the strip during each run, and the total mass exited from various strips ranged from 28 to 523 mg (Table 2). Longer filter strip with sod cover retained most of the sediment. The average trapping efficiency in terms of concentration of TSS over various filter strips varies between 85.9 to 91.3 %, the highest being observed for sod grass strip and 10 m filter strip length (Table 3). However, when trapping efficiencies were considered in terms of the mass, average efficiency was 94.3%, and virtually all the incoming sediment (99.5%) was retained by 10 m long strip with filter strip (Table 4). Further, observation on changes in TSS concentration with time in the outgoing runoff indicated no significant variation. Thus, VFS trapping efficiency remain more or less constant during the entire 40 minutes duration of the experiment on a particular filter strip. The results of the study confirm the findings of earlier studies (Lee et al., 2000) where different vegetations were found to be effective in trapping different amount of sediment. They concluded that switchgrass buffer are effective in trapping coarse sediment and sediment bound nutrients whereas switchgrass-woody plants are effective in trapping clay and soluble nutrients from cropland runoff.

Nutrients: Observations of the concentration of sediment bound nutrients (N and P) are, in general, expected to follow similar trend as of TSS. The average concentration of various nutrients in the runoff entering and exiting filter strips are summarized in Table 1. Since NH_4-N is the unstable form of nitrogen, lab analysis of collected runoff samples indicated very less concentration in most of the samples, and thus trapping efficiency could not be calculated for this form of nitrogen. Earlier studies have indicated that vegetative filter strips are relatively less effective for the concentration reduction of pollutants in soluble form as compared to sediment bound pollutants. The results presented in Tables 1 and 3 for soluble form of nitrogen and phosphorous further confirm this phenomenon. However, substantial reduction was observed in the total amount of dissolved or sediment bound nutrients (Table 2). For concentration reduction, highest trapping efficiency for sediment bound nitrogen and phosphorous for all the treatments were 95.4% and 92.4%, respectively, which were again observed for sod grass filter strip of 10 m length (Fig. 1). However, when total inflow and outflow amounts were taken into account, highest efficiencies for both nitrogen and phosphorous were more than 99% which indicated that most of sediment bound nutrients were retained in the filter strips (Table 4 and Fig. 2). Generally, for present study, mass trapping efficiencies were higher than 90% for sediment bound nutrients for filter strips of different length and vegetation covers. Results presented in Tables 1 and 2 show high trapping efficiency for nitrogen as well as for phosphorus.

Concentrations of NO_3-N in incoming and outgoing runoff were not substantially different (Table 1). However, amount of NO_3-N exited from various strips was significantly lower (Table 2). Details of total amount of nutrients entered and exited from strips are summarized in Table 2. For NO_3-N, trapping efficiency for concentration reduction for different filter strips ranged from 13.1% (sod-5m strip) to 35.2% (mixed-10m) (Table 3). However, no definite trend indicating the impact of filter strip length or vegetation cover was found (Figure 2). Trapping efficiency of 10 m mixed grass strip was lower than that of 5 m strip, while for sod grass it was vice versa. Large variation in NO_3-N mass trapping efficiency was observed, the highest (96.3%) being again for long strip with sod grass, and lowest (3.1%) for shorter rye grass strip (Table 4). It should be noted that total amount of dissolved nutrients entered into the strips were much higher than the amount of corresponding pollutant entered in the dissolved form.

Concentration of soluble phosphorous (PO_4-P) ranged from 107 to 186 µg/l in the incoming runoff and for outgoing runoff values were from 58 to 78 µg/l for different filter strips (Table 1). Average trapping efficiency for concentration reduction of filter strips for soluble phosphorous was 49.1%, and for all the treatments efficiencies were higher compared to soluble nitrogen (20.9% for NO_3-N) (Table 3). Filter strip of 10 m length with sod grass was found to be most effective for soluble phosphorous (trapping efficacy = 58.1%). Trapping efficiencies for soluble phosphorous were slightly higher for longer strips for sod as well as mixed grass cover, however; for rye grass it was vice versa. The results presented in Table 4 for trapping efficiency based on the mass reduction suggested that longer sod strips was most effective (97.2%) and shorter rye strips was least (63.7%). Infiltrations being the main mechanism for reduction of outgoing runoff in filter strip, higher trapping efficiencies were observed for soluble form of both nutrients. Schmitt et al. (1999) also observed VFS are more effective in reduction of particulate pollutant concentration but have less effect on the concentrations of soluble pollutants. They studied the performance of different filter strip lengths and type of vegetation on several contaminants and concluded that filter strips of 7.5 and 15 m in length can result in 76% and 93% reductions, respectively. Inamdar et al. (1999) concluded that VFS are effective in reducing the losses of some forms of nutrients, such as ammonium-N and particulate-P in a watershed, but additional BMPs are necessary to achieve significant reductions in all forms of N and P. In this study, among different vegetation treatments, filter strip with sod grass were found to be most effective for particulate nutrients followed by rye and then mixed grass. However, in case of TSS, sod and mixed grass strips were equally effective.

Bacteria: To study the pattern in the effectiveness of filter strip with time, concentrations of different types of bacteria were also measured at the inlet and outlet of the strip and at different time intervals. Concentrations of different bacteria in the incoming and outgoing runoff are presented in Table 1. The results of average trapping efficiency presented in Tables 3 and 4 for

Total Coliforms, Fecal Coliforms, and E. Coli indicate, in general, that filter strips are beneficial for trapping bacteria also. However, in some samples, concentration of bacteria (Table 1) was higher at the outlet than inlet, and thus, indicated negative trapping efficiency. This could be either attributed to sudden release of bacteria in flowing water trapped in the strip or presence of a larger group (clump) of bacteria in the collected sample. *Fecal Coliforms* concentration trapping efficiency for different vegetation and filter lengths ranged from 15.4% for mixed grass 5-m strip to 74.3% for sod grass strip of 10 m length (Figure 1). Quite a bit of variation was observed in the trapping efficiency of *Total Coliforms* and *E. Coli.* Even negative trapping efficiency for sod 5-m strip for *E. Coli* and sod 10-m strip for *Total Coliforms* were observed which indicated more release of bacteria at outlet as compared to number actually entering into the filter strip. The results for *Total Coliforms* and *E. Coli* were inconsistent. Coyne et al. (1998) based on the results of a filter strip experiment with mixed vegetation of Kentucky bluegrass and a tall fescue reported an overall *Fecal Coliforms* trapping efficiency ranged from 55 to 95%. In their experiment although overall mass was reduced but concentrations of fecal bacteria were still higher than acceptable for stream discharge. However, for the present study, the results presented in Table 4 on the trapping efficiency based on incoming and outgoing mass were more consistent for *E. Coli* and *Fecal Coliforms*. Average mass based trapping efficiency for *E. Coli* and *Total Coliforms* were 68.2% and 84.0%, respectively. Chaubey et al 1994 conducted an experiment on 24 m X 1.5 m filter strips of fescue grass with a slope of 3%. Their results showed that after 3 m in the buffer strip FC concentrations were reduced by 58% and that additional length did not increase the removal of FC. However, in the present study, longer sod grass were found to be the most efficient by trapping more then 98% of *E. Coli* and *Fecal Coliforms* entered into the filter strip. Further, efforts were also made to account the number of bacteria in soil pool before and after the run on each filter strip, results did not support any trend. The results on concentration reduction of bacteria were somewhat not conclusive; however, filter strips were definitely found to be effective in the reduction of the total mass of bacteria in runoff leaving the filter strip.

Conclusions

The results of the present study corroborate earlier similar work indicating the effectiveness of filter strip in reducing the concentration of various pollutants in runoff leaving the filter strips. Filter strips, as expected, were found to be very effective in reducing the concentration of total suspended solids and total mass with average trapping efficiency 88.3% and 94.3%, respectively. Trapping efficiencies were higher for sediment bound nitrogen and phosphorous as compared to dissolved form corresponding nutrient. Since, for the dissolved form of nutrients, increased infiltration is the primary mechanism for reduction of nutrient total mass in runoff exited through vegetative filter strips, change in concentration of soluble nutrients were not very high. *Fecal Coliforms* concentration decreased in the runoff leaving the filter strip suggested that filter strips were effective in trapping bacteria. However, for other types of bacteria (*E. Coli* and *Total Coliforms*) results were not very conclusive. The mass based trapping efficiencies were higher than concentration based efficiencies. AS expected, generally, denser vegetation and longer filter strips were found to be more efficient in trapping of different pollutants. Variation in trapping efficiency of various pollutants suggested that different processes/mechanisms are involved in trapping. More detailed experimentation at University of Guelph is underway to better understand the trapping mechanism of vegetative filter strips for different pollutants, especially, for bacteria.

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Table 1. Concentration of pollutants in runoff

Type of filter strip	Soluble nutrients				Sediment bound n nutrients				Bacteria						TSS (mg/L)	
	NO_3-N (mg/l)		PO_4-P (µg/l)		Total P (mg/l)		Total N (mg/l)		E. Coli (cfu/ml)		Total Coliforms* (cfu/ml)		FC (cfu/ml)			
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Rye-5m	0.8711	1.1364	110.33	55.01	0.0013	0.002	0.0023	0.0002	26	12	0	1	41	16	1.724	0.233
Rye-10m	1.1158	0.9855	111.61	62.04	0.0013	0.0002	0.0022	0.0002	15	11	0	0	44	21	1.514	0.214
Mixed-5m	1.2686	0.9459	106.69	59.68	0.0016	0.0002	0.0031	0.0004	21	27	177	159	76	65	1.780	0.229
Mixed-10m	1.2830	1.0753	110.62	57.80	0.0014	0.0002	0.0024	0.004	16	7	56	12	17	8	1.983	0.186
Sod-5m	1.3703	1.1908	144.76	72.01	0.0014	0.0002	0.0024	0.0002	44	102	402	254	90	29	1.663	0.190
Sod-10m	1.5936	1.0331	186.38	78.08	0.0014	0.0001	0.0024	0.0001	32	7	85	107	45	11	1.523	0.133

* *Total Coliform* was too low to count in the incoming synthetic runoff for filter strips with rye grass

Table 2. Total amount of pollutants entered and exited from different filter strips during run

Type of filter strip	Soluble nutrients				Sediment bound n nutrients				Bacteria						TSS (mg)	
	NO_3-N (mg)		PO_4-P (mg)		Total P (mg)		Total N (mg)		E. Coli (cfu*1000)		Total Coliforms* (cfu*1000)		FC (cfu x 1000)			
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Rye-5m	2517	2439	329	119	4.0	0.3	7.0	0.4	98638	32172	-	-	14438	41705	5305	523
Rye-10m	3703	1230	331	77	3.9	0.2	6.8	0.3	42745	15460	-	-	134343	30645	4791	286
Mixed-5m	2938	1513	289	100	4.1	0.4	7.8	0.8	76480	32234	607338	201084	217067	96389	4802	432
Mixed-10m	3007	1436	295	72	3.3	0.3	5.8	0.5	50382	8999	221460	17448	44292	11264	4815	261
Sod-5m	4185	1055	421	62	4.1	0.1	7.3	0.2	158426	96281	1677456	235734	284236	26670	5045	168
Sod-10m	6106	223	622	17	4.6	0.0	7.9	0.0	119279	1307	383563	34679	189910	2323	5199	28

* *Total Coliform* was too low to count in the incoming synthetic runoff for filter strips with rye grass

Table 3. Sediment, particulate and soluble nutrients concentration trapping efficiency (%)

Type of filter strip[¥]	Soluble nutrients		Sediment bound n nutrients		Bacteria			TSS
	NO_3-N	PO_4-P	Total P	Total N	E. Coli	Total Coliforms*	FC	
Rye-5m	-	50.14	87.75	91.17	66.38	-	61.11	86.47
Rye-10m	14.66	44.41	87.84	89.98	35.71	-	52.50	85.88
Mixed-5m	25.44	44.06	86.87	87.40	-26.32	10.00	15.36	87.14
Mixed-10m	16.19	47.75	85.57	83.88	57.93	78.00	52.33	90.64
Sod-5m	13.10	50.26	88.88	92.33	-130.48	49.47	67.53	88.57
Sod-10m	35.18	58.10	92.40	95.36	77.00	-26.25	74.29	91.26
Avearge	20.91	49.12	88.22	90.02	13.37	27.81	53.85	88.33

* *Total Coliform* was too low to count in the incoming runoff for filter strips with rye grass
[¥] Type of vegetation cover followed by the length of the strip represents the type of filter strip

Note: Negative trapping efficiency indicate higher concentration of pollutant in the runoff exiting from the filter strip

Table 4. Trapping efficiency based on mass reduction of filter strips for sediment (TSS), soluble and sediment bound nutrients, and bacteria (%)

Type of filter strip	Soluble nutrients		Sediment bound n nutrients		Bacteria			TSS
	NO_3-N	PO_4-P	Total P	Total N	E. Coli	Total Coliforms*	FC	
Rye-5m	3.10	63.73	91.28	93.82	67.38	-	71.11	90.13
Rye-10m	66.78	76.68	94.66	95.38	63.83	-	77.19	94.03
Mixed-5m	48.53	65.57	89.66	89.42	57.85	66.89	55.59	91.00
Mixed-10m	52.26	75.48	91.73	90.84	82.14	92.12	74.57	94.57
Sod-5m	74.78	85.20	96.73	97.75	39.23	85.95	90.62	96.67
Sod-10m	96.34	97.24	99.52	99.72	98.90	90.96	98.78	99.47
Avearge	56.96	77.32	93.93	94.49	68.22	83.98	77.98	94.31

* *Total Coliform* was too low to count in the incoming runoff for filter strips with rye grass
[¥] Type of vegetation cover followed by the length of the strip represents the type of filter strip

Note: Negative trapping efficiency indicate higher concentration of pollutant in the runoff exiting from the filter strip

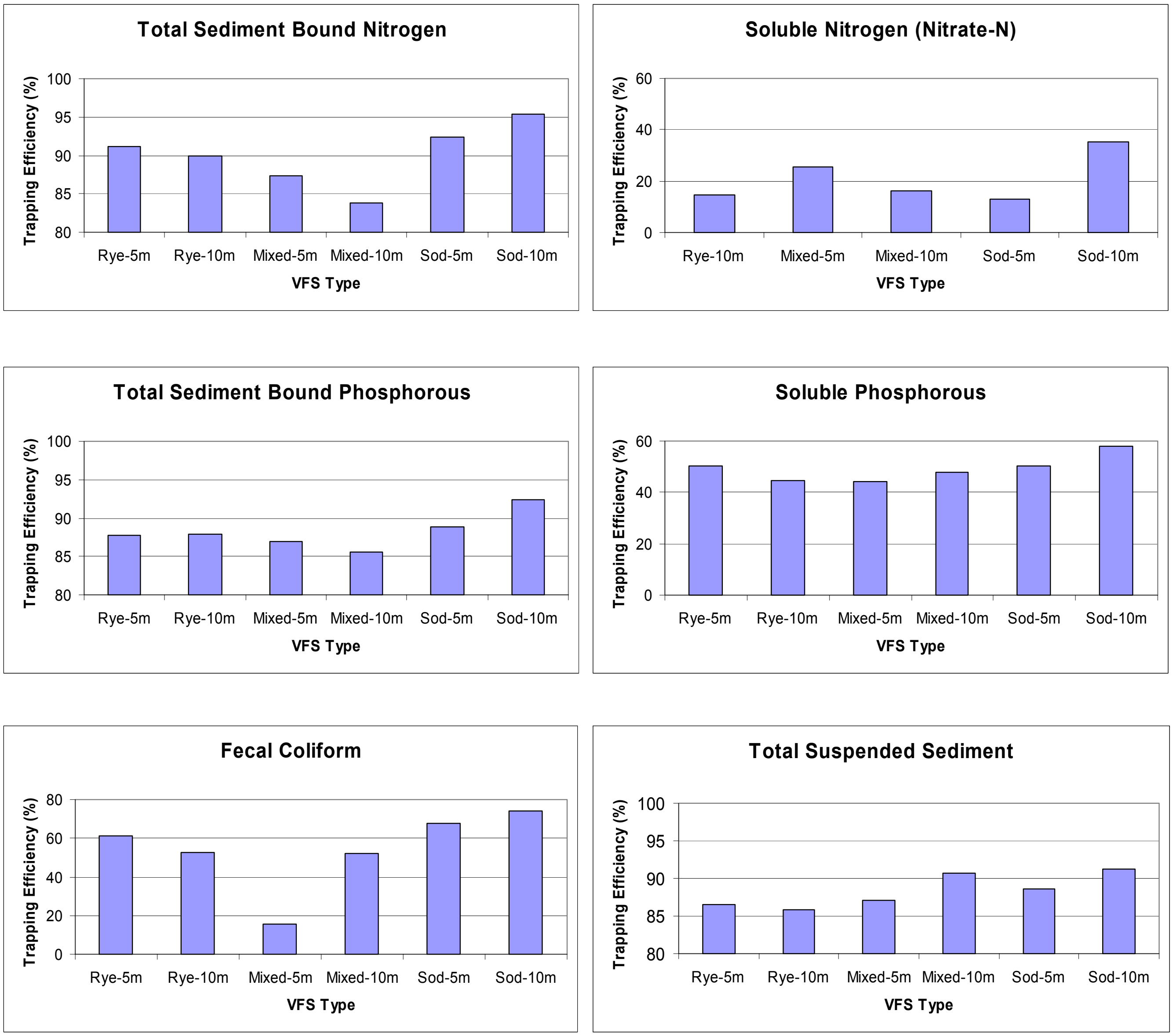

Figure 1. Trapping efficiency based on concentration reduction of filter strips for soluble and sediment bound nutrients, total suspended sediment (TSS), and *Fecal Coliforms*

Figure 2. Trapping efficiency based on total mass reduction of filter strips for soluble and sediment bound nutrients, total suspended sediment (TSS), and *Fecal Coliforms*