Efficacy of vegetative filter strips (VFS) installed at the edge of feedlot to minimize solids and nutrients from runoff

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Abstract: Runoff from open animal feeding operation is a major source of non-point pollution. Vegetative filter strips (VFS) are one of the effective ways in controlling non-point source pollution. In this study, performance of a vegetative filter strip situated at down slope end of a beef feedlot was evaluated under eastern North Dakota climatic conditions. Two automatic ISCO samplers were installed to collect runoff water entering and leaving the vegetative filter strip. Runoff samples were analyzed for solids, nutrients, pH, and conductivity using standard methods. Results indicated that VFS was effective in reducing concentration of total solids (TS) by 33.7%, total suspended solids (TSS) by 68.0%, total phosphorous (TP) by 29.9%, ortho-phosphorous (OP) by 19.3%, ammonium nitrogen (NH_4-N) by 31.8%, total Kjeldahl nitrogen (TKN) by 35.6%, and potassium (K) by 19.8%. Nitrate nitrogen (NO_3-N) concentrations at the outlet samples increased as expected, and the buffer was not effective in reducing soluble nutrients. Performance of the VFS indicated that a VFS can be used for reducing runoff pollution that comes directly from feedlots into VFSs without passing through the settling basins. Longer buffer lengths might be required for reducing soluble pollutants.

Keywords: feedlot, nutrients, runoff, solids, vegetative filter strip

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1 Introduction

With expanding livestock facilities, animal agriculture is facing increasing environmental concerns, i.e., water and air pollution due to increasing manure volumes from these expanding livestock facilities. Although manure is an excellent source of nutrients for plants and a good soil conditioner, improper manure management, especially from feedlots, can negatively influence water quality. For example, runoff from feedlots may carry significant amount of manure borne nutrients (e.g., nitrogen and phosphorous) to surface water (Swanson et al., 1971) and may cause water pollution. According to Koelsch et al. (2006), runoff from feedlots is a major contributor and will continue to be a contributor to surface and groundwater impairment.

Typically, feedlot runoff is collected and stored in a holding pond or lagoon and usually emptied by pumping and applying to crop land. For an instance, beef cattle feedlots often use a lagoon or settling basin with vegetative filter strips to reduce runoff pollutant concentration and migration to surface water bodies (Mankin et al., 2006). However, holding pond or lagoon construction is expensive, requiring large land area and regular maintenance. Moreover, seeping water from the containment structures possesses the risk of contamination of the potential drinking water (Parker et al., 1999). On the other hand, vegetative filter strip (VFS) systems involve spreading and infiltration of runoff, thereby this system do not require any containment

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structure. The challenge of an effective VFS is to maintain the sheet flow, the systems fail if channelization occurs (Lorimor et al., 2002). While the cost comparison between VFS and settling basin is difficult due to location, topography, and climatic conditions for both systems, but in general the cost involves in a VFS system is lower than other structures due to capital investment and maintenance (Kizil, 2010; Barrett, 1999). As a result, producers are often not interested to construct holding ponds due to high capital investment.

The US Environmental Protection Agency (EPA) has recommended vegetative filter strips (VFS) to minimize the adverse impact of feedlot runoff to surface and groundwater bodies (USEPA, 2001). Vegetative filter strips are a band of planted and/or indigenous vegetation installed at the down slope end of non-point source pollution areas before runoff reaches a water body (Dillaha et al., 1988). Vegetative filter strips provide an environment to reduce pollutants by reducing sediment carrier energy (Webber et al., 2010). In addition, pollutant reduction in the buffer also occurs due to infiltration, adsorption, and plant uptake of nutrients.

During the past three decades, many studies have been conducted, both at field and plot scales, to show the buffer's effectiveness in removing pollutants in runoff from feedlot (Woodbury et al., 2002, 2005; Edwards et al., 1983; Dickey and Vanderholm, 1981; Mankin and Okoren, 2003; Paterson et al., 1980; Young et al., 1980), simulated feedlot (Dillaha et al., 1988; Robinson et al., 1996), simulated pasture (Lim et al., 1998), manure applied pasture (Chaubey et al., 1994, 1995), livestock stockpile (Fajardo et al., 2001), and cropland runoff (Dillaha et al., 1989). In most of these studies, the VFS received runoff either after passing through the settling basin or field applied manure. A wide variability in the VFS effectiveness to remove sediments and nutrients was noticed in all of these studies. Typically, buffer performance depends on soil type and condition, vegetation type and condition, buffer strip length, buffer slope, flow type, influent solids concentration, and particle size distribution (Mankin et al., 2006). Depending on the geographical region, some of these buffer design criteria varied significantly. Recently, significant interest has grown in using VFS without sediment settling basin because of low installation and maintenance costs, as well as eliminating the acreage required for a settling basin. As a result, buffer performance without settling basin needs to be evaluated based on local and regional climatic condition and design criteria. Very limited studies have been conducted to assess the VFS performance at the down slope end of a beef feedlot in mitigating solids and nutrients from feedlot runoff.

The objective of this study was to evaluate the performance of a vegetative filter strip without settling basin in minimizing solids and nutrients concentrations in runoff from a feedlot under eastern North Dakota climatic conditions and management practices.

2 Materials and Methods

2.1 Study site

The study site was located at Richland County, about 65 km south-west of Fargo, North Dakota. The average annual rainfall in the study area is 468 mm. Feedlot soil type is sandy loam and classified as hydrologic soil group A. This feedlot was designed for 500 head of beef cattle with two pens, but only one pen was operational, and runoff samples were collected from that pen only. The length and width of the pen were 76 and 62 m, respectively, and overall aggregate slope of the feedlot about 5% was achieved by incorporating mounds in the pen, with a perception that liquid component will be separated quickly from solid component at a steeper slope, and buffer effectiveness at the end of pen surface will be increased as a result. A 12 m long (in the direction of flow) grass buffer strip was installed down slope of the feedlot with an assumption that runoff from the feedlot will pass through the buffer strip and maximize pollutant retention and then be dispersed evenly throughout the water spreading area. The VFS consisted of mixed vegetation including barnyard grass (*Echinochloa crus-galli*), ladysthumb smartweed *Polygonaceae persicaria*), common lambs quarter grass (*Chenopodium berlandiery Moq.)* mares tail hoarse weed (*Conyza canadensis),* common ragweed (*Ambrosia artemisiifolin*), yellow foxtail (*Setaria glauca*), and white clover

(*Melilotus alba*) and had uniform slope of 2%. The water spreading area was graded with an average slope of less than 1% for the water flowing downslope as is shown in Figure 1. The wastewater is contained in a holding area within a dike system (Figure 1), so that no pollutant or runoff is discharging from the feedlot area. This system was designed to contain the runoff event of 25 y 24 h from rainfall event as state regulations required (NDDoH, 2005).

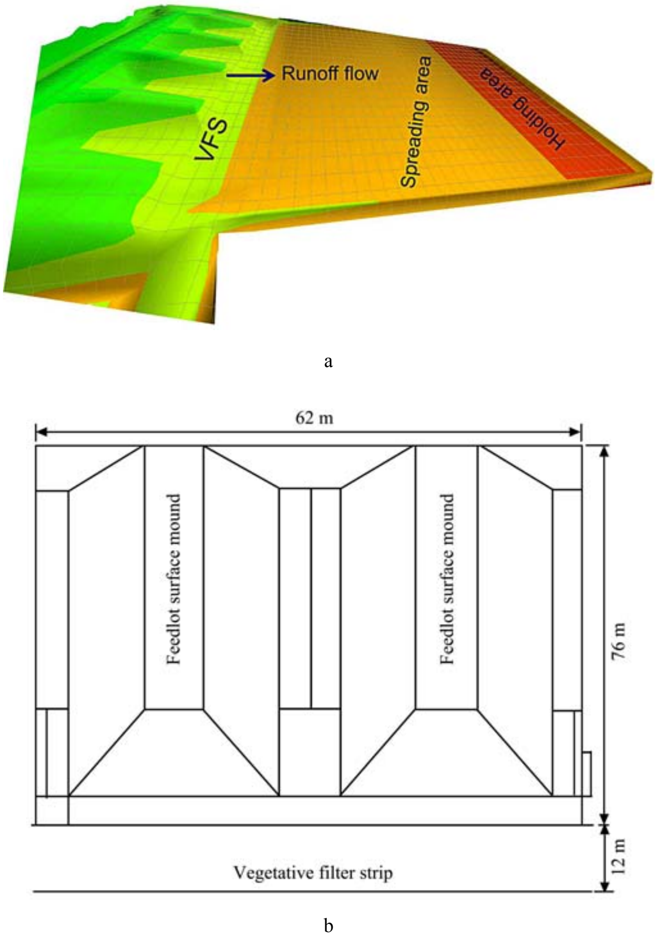

Figure 1 Layout of the feedlot, buffer, and water spreading area (a) and plan showing dimensions (b)

2.2 Experimental procedure

In this study, a section of buffer was selected, and earthen borders were established to collect incoming runoff from the feedlot pen surface to the buffer area and from the buffer to the runoff spreading area (Figure 1). The earthen borders were established to separate and prevent mixing of runoff from outside of the buffer areas. Automatic ISCO 6712 samplers (Teledyne ISCO, Inc., Lincoln, NE) were installed to collect feedlot runoff entering into the VFS (hereafter inflow) and to collect runoff leaving the VFS area (hereafter outflow) to spreading area. ISCO samplers were operated with a heavy duty marine battery, which was charged by using a solar panel. A 60 L bucket was installed at each runoff collection locations to accumulate the flow, and samples were collected from the bucket using the ISCO samplers, which was activated through using a float. The float was installed inside the bucket at a height from the bottom of the bucket to make sure that the bucket had enough water to collect specified sample volume (750 mL). After the first sampling, subsequent samples were collected hourly as programmed. When the ISCO sampler malfunctioned, grab samples were collected. After a runoff event, runoff collection buckets were emptied and reinstalled to collect runoff from next rainfall-runoff event during the study period. Immediately after collection, samples were brought back to laboratory and kept refrigerated until analyses were done. Temperature and precipitation data were downloaded from a nearby weather station (<2 km) of North Dakota Agricultural Weather Network (NDAWN) during the study period.

2.3 Sample analysis

Using standard methods (APHA, 2005), runoff water samples were analyzed for nutrients, solids, pH, and electrical conductivity (EC). pH and conductivity were analyzed using a hand held meter (YSI Pro Plus, YSI Inc., Ohio, USA). Solids and nutrients were analyzed at Soil Testing Laboratory, North Dakota State University. Data were pooled and pairwise means were compared between inflow and outflow using Duncan’s multiple range tests at $P < 0.05$.

3 Results and discussion

3.1 Background information

Runoff samples from seventeen rainfall events were collected during the monitoring period. The effectiveness of the VFS was measured as a function of its capacity to reduce solids and nutrient concentrations. As was mentioned previously, all runoff samples were not collected using automatic sampler due to instrument malfunctioning. In that case, grab samples were collected from runoff collection buckets. Total precipitation during each sampling events are presented in appropriate figures. Table 1 provides average key soil properties of the VFS area.

Table 1 Key soil parameters of the study site

Parameters	Value
pH	7.02±0.34*
Electrical conductivity (EC)/μS cm^{-1}	64.7± 39.0
Vertical hydraulic conductivity/cm s^{-1}	4.34×10^{-4}± 4.08×10^{-4}
Bulk density/g cm^{-3}	1.14± 0.11

Note: *Standard deviation.

3.2 pH

Average pH of runoff samples for the different sampling events are shown in Figure 2, and overall averages during the entire sampling period are reported in Table 2. The pH values found were in the range observed by others (Miller et al., 2004; Gilley et al., 2007). As is shown in Figure 2, the pH of the inflow and outflow samples varied slightly, but the differences were not statistically significant. Figure 2 shows that pH increases after each rainfall and its magnitude varies with rainfall. An apparent increasing trend of pH was observed from the beginning to the end of this monitoring period likely due to $CaCO_3$, which is used with feed ration (Gilley et al., 2007). High pH noticed at the beginning and at the end of runoff period was also reported by Hay et al. (2006). In addition, nitrification and denitrification process may have some effects on the variation of pH, although they were not measured. Overall pH values at the inflow and outflow sampling locations were similar.

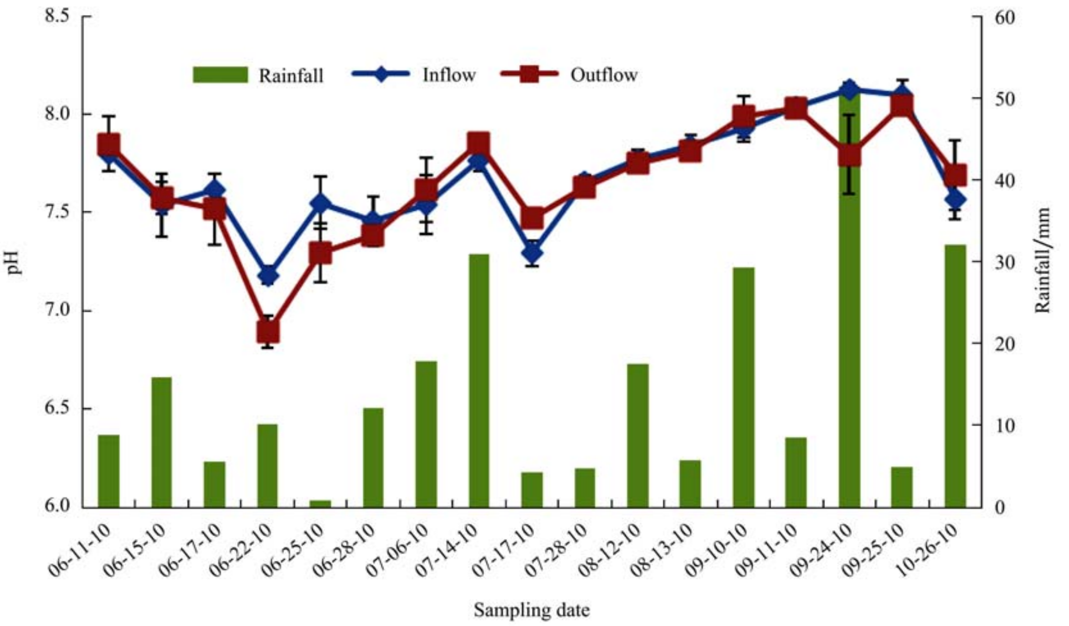

Figure 2 pH trend in runoff water samples at different sampling events (Error bars represent standard deviation of mean)

Table 2 Overall averages and standard deviations of different parameters measured during the entire sampling period at inflow and outflow runoff samples

Variable	Inflow	N**	Outflow	N	% reduction
pH	7.69^{a*}±0.29	187	7.69a±0.29	216	-
Conductivity/μS cm^{-1}	2084a±782	187	1761b±956	217	-
TS/mg L^{-1}	3703a±1937	187	2454b±1422	218	33.73
TSS/mg L^{-1}	1252a±1704	181	401b±686	218	67.97
TP/mg L^{-1}	25.1a±8.8	177	17.6b±10.4	215	29.87
OP/mg L^{-1}	17.2a±7.4	173	13.9b±8.0	196	19.27
NH_4-N/mg L^{-1}	13.8a±11.4	173	9.43b±10.1	216	31.76
TKN/mg L^{-1}	112a±56.1	177	72.5b±57.1	215	35.56
K/mg L^{-1}	5074a±237	177	406 b±281	216	19.80

Note: * Averages within a row followed by different letters are significantly different at $P \leq 0.05$ according to Duncan multiple range tests.

N** - number of samples

3.3 VFS effectiveness in solids transport reduction

Average concentrations of total solids (TS) and total suspended solids (TSS) at the inflow and outflow during sampling events are shown in Figures 3 and Figure 4, respectively. Overall average concentration and concentration reduction of TS and TSS are presented in Table 2 and Figure 5, respectively. Total solid concentrations in the inflow and outflow samples fluctuated with rainfall as is shown in Figure 3. Vegetative filter strip was effective in reducing TS and TSS concentrations between inflow and outflow samples, except for a few occasions, when inflow and outflow could not be clearly separated due to excessive runoff from specific rainfall events. A similar trend is also observed for TSS (Figure 4). Typically, runoff amount and pollutant concentration depend on the antecedent soil moisture condition prior to a rainfall (Duchemin and Hogue, 2009). In this study, following a significant rainfall event (>5 mm), TS concentration in the runoff samples increased significantly as compared to previous concentrations, which was expected. It is likely that decreased surface water flow resulted in deposition of sediment and absorbed potential pollutants (Stout et al., 2005). Overall, outflow TS and TSS concentrations were significantly lower than the inflow concentrations (Table 2). This means that the VFS at the end of feedlot pen surface was effective in intercepting sediment. From these observations, it appears that VFS without settling basin might be effective in minimizing sediment-bound nutrients in runoff transport.

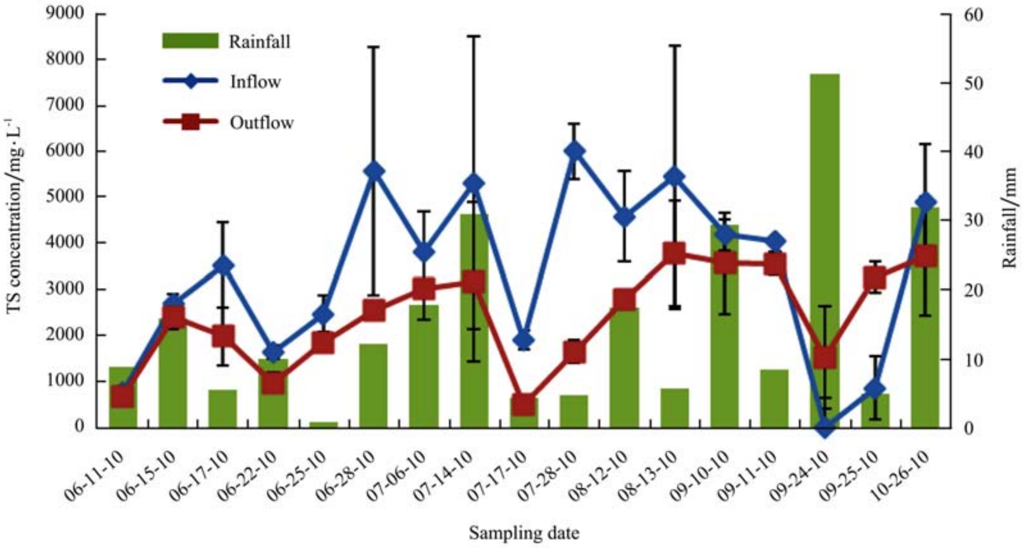

Figure 3 Variation in average TS concentration during different sampling events (Error bars represent standard deviation of mean)

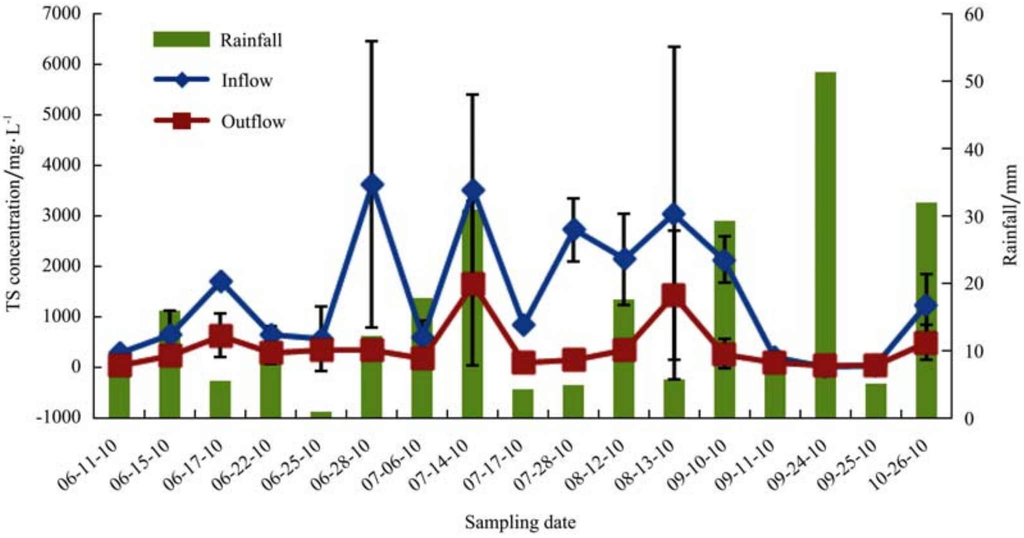

Figure 4 Variation in average TSS concentration during different sampling events (Error bars represent standard deviation of mean)

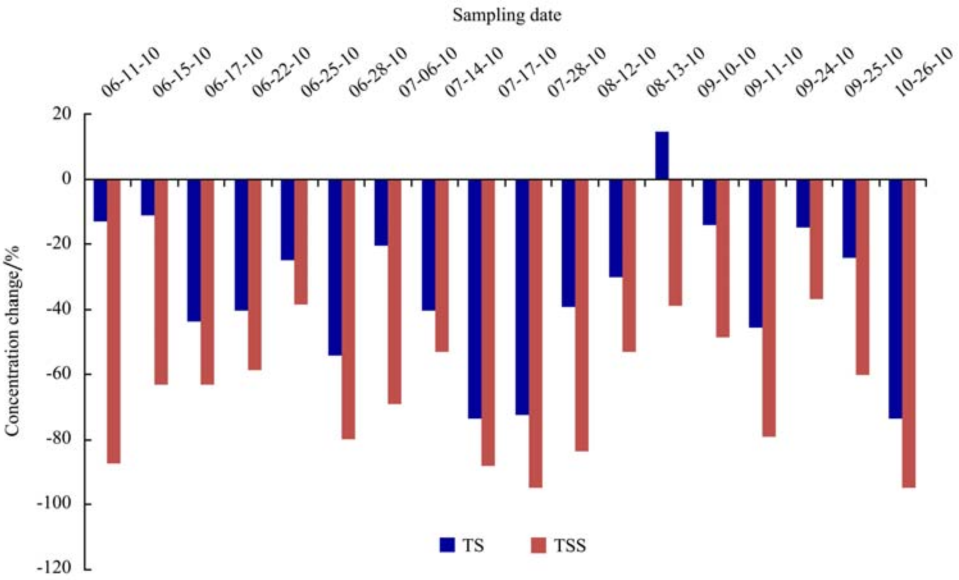

Figure 5 Transport reductions of runoff TS and TSS in different runoff events (negative sign indicates reduction)

Total solids (TS) concentration ranged from 781 to 6,017 mg L^{-1} and 501 to 3,803 mg L^{-1} in the inflow and outflow, respectively. The results of this study are consistent with other studies. Dickey and Vanderholm (1981) measured TS in effluent runoff from a VFS with dairy facility and a beef feedlot and values reported 996 and 4,710 mg/L, respectively. Similarly, TSS concentrations in runoff samples ranged from 61.9 to 3,618 mg L^{-1} at the inflow and 35.5 to 1,658 mg L^{-1} at the outflow samples.

When concentration reduction was averaged over the entire sampling period, TS concentration reduction (33.7%) was not as effective as the TSS concentration reduction (68.0%). This might be due in part to concentrated flow and physical obstruction provided by the vegetation because buffer is effective in removing suspended solids than dissolved solids. Other researchers observed 73% and 63% TS concentration reductions from a 91 and 61 m long VFS for dairy facility and beef feedlots (Dickey and Vanderholm, 1981), respectively, and 76.5% TS concentration reduction from a 26 m long VFS (Schwer and Clausen, 1989). In our study, TSS concentration reduction ranged from 37.0% to 94.7%, which agreed with others' findings. Schellinger and Clausen (1992) and Schwer and Clausen (1989) observed a 3.6% TSS concentration reduction from a dairy farm barnyard runoff and a 92% reduction from VFS with a milk house wastewater, respectively. It is important to note that in other studies, effluent was captured in a settling basin prior to the runoff entering into a VFS, whereas in this study, runoff from the feedlot directly ran through the buffer. Similarly, Andersen et al. (2009) observed 26% to 95% reduction of TSS concentration in runoff from six beef feedlots in Iowa, USA where settling basins were used for solids separation. Although, in this study, no settling basin was used before the VFS, a 12 m buffer strip itself was effective to retain significant amount of solids within the buffer area. It is likely that the buffer provides a means of physical separation of suspended solids, reduces transport energy and deposits sediment, and increases infiltration of dissolved constituents into the buffer as was also concluded by Hay et al. (2006).

3.4 VFS effectiveness in nutrients transport reduction

Variations in total phosphorous (TP) and ortho-phosphorous (OP) concentrations in runoff samples are shown in Figures 6 and Figure 7, respectively. Total phosphorus concentration-trends followed the same trend as TS. Total phosphorus concentrations ranged from 5.98 to 36.1 mg L^{-1} and 0.28 to 29.1 mg L^{-1} in the inflow and outflow samples (Figure 6), respectively. Similarly, OP concentrations varied from 2.25 to 27.3 mg L^{-1} at the inflow and 0.48 to 23.2 mg L^{-1} at the outflow from buffer (Figure 7). Other researchers also found that TP concentration in incoming runoff into the buffer varied from 20.0 to 81.5 mg L^{-1} from a dairy facility, whereas

OP concentration varied from 16.2 to 54.6 mg L^{-1} (Schwer and Clausen, 1989; Schellinger and Clausen, 1992). Andersen et al. (2009) observed 53 to 222 mg L^{-1} TP and 28 to 101 mg L^{-1} OP concentrations in influent runoff to the VFS. The relatively lower concentrations of TP and OP observed in this study may be due to the differences in feedlot soil types and diet. On an average, both in the inflow and outflow samples, the ratio of OP/TP ranged from 0.21 to 0.94 and 0.65 to 1.68, respectively, which mean that a significant portion of TP was soluble phosphorus. It is noted that the ratio of OP/TP was increased in the outflow compared with inflow for most of the runoff events indicating that particulate bound P was retained in the VFS with settled sediments. A small portion of soluble P tended to be captured by the buffer during low runoff flow rates with reduced concentrations at outflow.

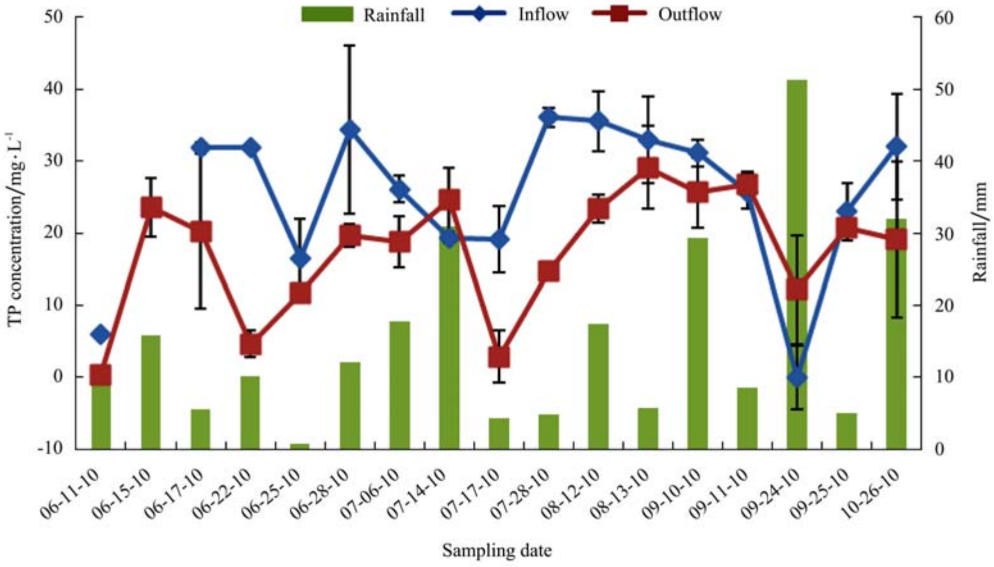

Figure 6 Variation in average TP concentration and standard deviation at different sampling events

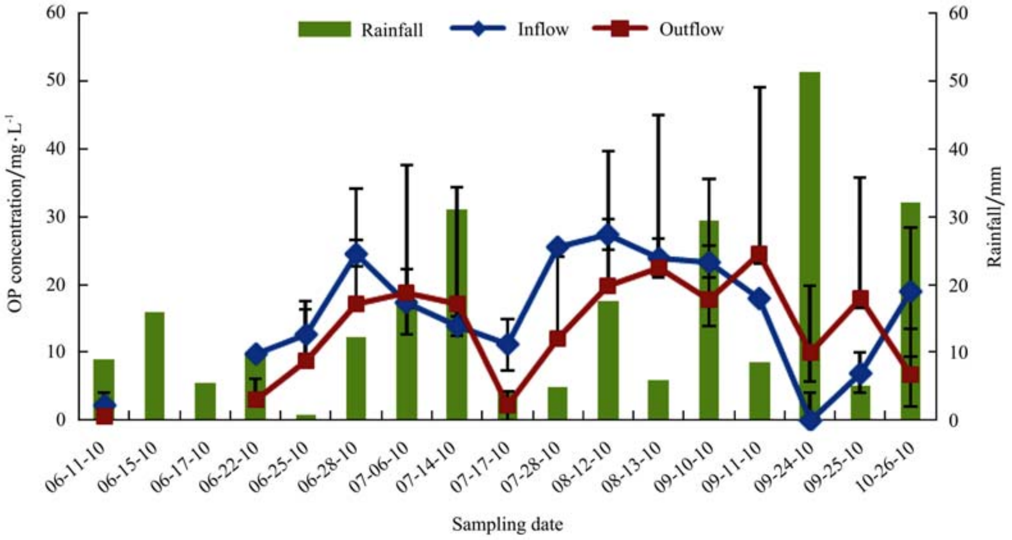

Figure 7 Variation in average OP concentration and standard deviation at different sampling events

It was observed that outflow concentrations of TP on 14 July (Figure 6) and OP on 6 and 14 July and 26 October (Figure 7) were higher than the inflow. This was likely due to grab sampling, as well as flushing effect. For those dates, the buffer area was inundated due to high runoff contributing to flushing that might result in a greater nutrient concentration at the outflow. As waste settled and was retained in the buffer areas, the organic phosphorus mineralized to inorganic phosphate compounds (Spellman and Whiting, 2007).

Mineralization processes may convert TP into soluble P which mixes with outflow runoff and increased the soluble P contribution in the outflow samples (Dillaha et al., 1988). Moreover, outflow P concentration might be increased due to desorption from the already moist soil, which was previously P enriched. During a low rainfall situation, as runoff passed through the buffer, sediment-bound P is likely to be deposited and soluble P is likely to infiltrate into the buffer soil thereby reducing concentration at the outflow. Other researchers (Schellinger and Clausen, 1992; Hawkins et al., 1998) also observed increased soluble phosphorous concentrations at the outflow sampling location as compared to inflow concentration. Usually, runoff-pollutants dissolved in rainwater is a significant transport mechanism for water soluble pollutants (Spellman and Whiting, 2007) resulting in increased concentration in the outflow.

On an average, TP and OP concentrations reduction ranged from 4.02% to 95.3% and 5.91% to 80.9%, respectively (Figure 8). A similar TP reduction trend has also been observed by other researchers. Andersen et al. (2009) measured buffer performance from six beef feedlots in Iowa State, USA and observed TP concentration reductions ranged from 38% to 94% and OP concentration reductions ranged from 33% to 92%. Overall, the buffer was effective in reducing TP and OP concentrations by 29.9% and 19.3%, respectively.

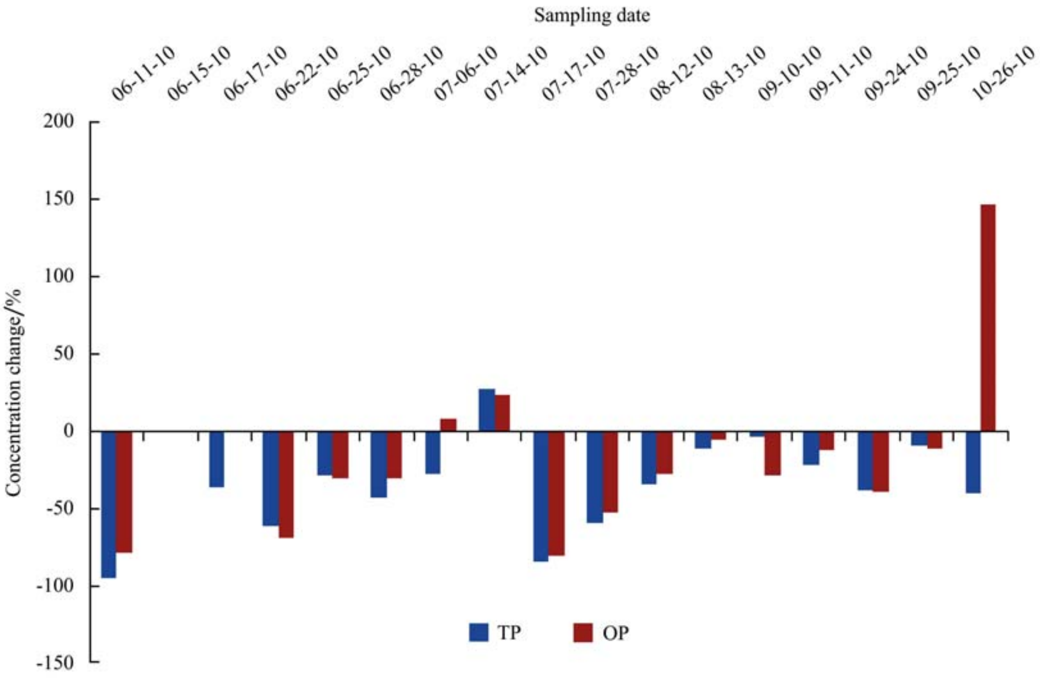

Figure 8 Variation in TP and OP concentration reduction averaged over each sampling event (negative sign indicates reduction)

Figure 9 shows the variation in NH_4-N concentrations. Significant variation in NH_4-N concentration was observed between inflow and out flow samples (Table 2). The NH_4-N and NH_3-N are pH dependent. Under acidic condition, the uptake will be NH_4-N and under alkaline condition that of NH_3-N. Although plant biomass samples were not collected and analyzed during the monitoring period, the uptake of NH_4-N by plants and adsorbed in soil might (Koelsch et al., 2006) have contributed to lower NH_4-N concentrations in the outflow runoff, since pH during the monitoring period was slightly alkaline (Figure 2).

Figure 10 shows the variation in NO_2-N + NO_3-N concentrations. Except for an anomaly on 11 and 17 June, NO_2-N + NO_3-N concentrations between inflow and outflow were consistent and followed the same trend. The Anomaly on 11 and 17 June was unknown. Outflow NO_2-N + NO_3-N concentrations were slightly higher than the inflow concentration, but the differences were not statistically significant. Increased nitrate nitrogen at the outflow has been observed in many studies (Dillaha et al., 1988; Mendez et al., 1999; Andersen et al., 2009; Young et al., 1980), which are likely due to mineralization of particulate organic N that is trapped and accumulated in the buffer resulting in increased soluble N over time (Mendez et al., 1999). In this study, except for a few occasions, NO_3-N concentrations were lower than the EPA threshold value (10 mg L^{-1}), meaning that NO_3-N concentration in runoff was not a concern. For soluble nutrients, a longer VFS might be required to enhance infiltration volume within buffer because NO_3-N reduction primarily occurs due to dilution and infiltration.

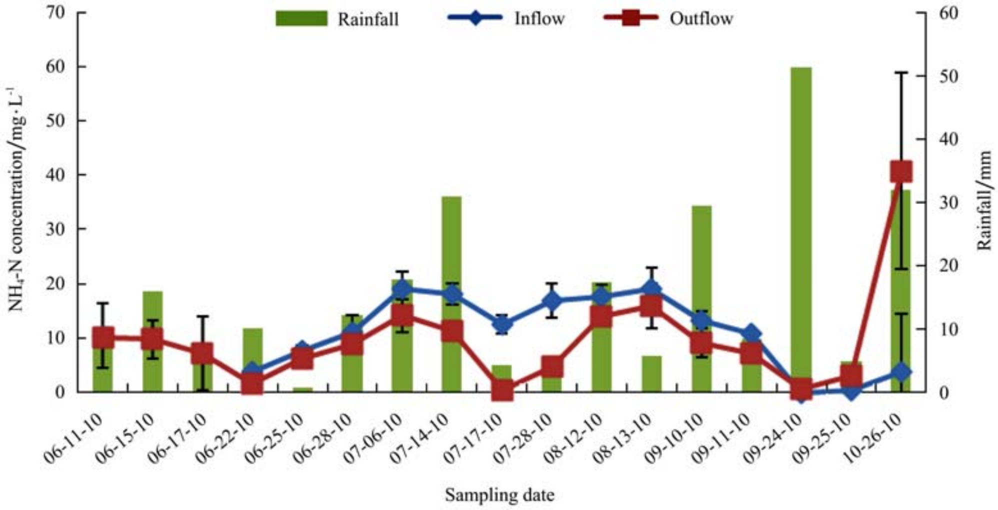

Figure 9 Variation in average NH_4-N concentration and standard deviation of mean at different sampling events

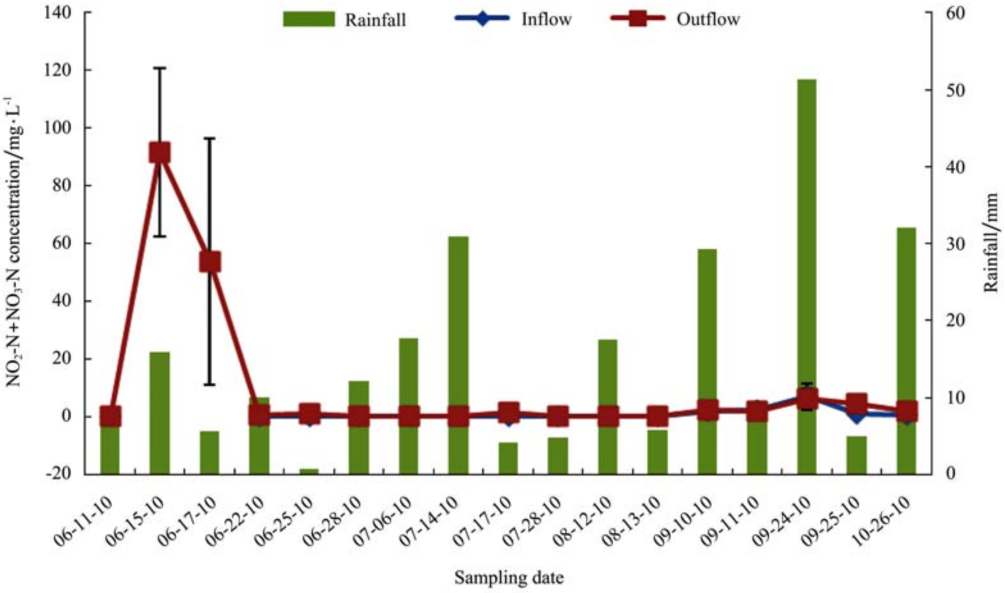

Figure 10 Variation in average NO_2-N+NO_3-N concentration and standard deviation of mean at different sampling events

Average concentrations of TKN during sampling events are presented in Figure 11, and overall concentrations across all sampling events are presented in Table 2. Total Kjeldahl nitrogen concentration varied significantly between inflow and outflow samples, and outflow samples had lower concentration than the inflow except for a few occasions. Total Kjeldahl nitrogen is also strongly correlated with total solids (R^2 = 0.70) indicating that reduction of sediment would result in sediment-bound nutrients reduction. Overall, VFS effectively reduced TKN by 35.6%. During the runoff sampling events, the concentration reductions for NH_4-N, NO_2-N + NO_3-N, and TKN are shown in Figure 12.

Potassium concentration at the inflow and outflow samples ranged from 43.3 to 854 and 20.7 to 713 mg L^{-1}, respectively (Figure 13). It is also evident in Figure 13 that the potassium concentration at the outflow was higher as compared to inflow on 10 September, which

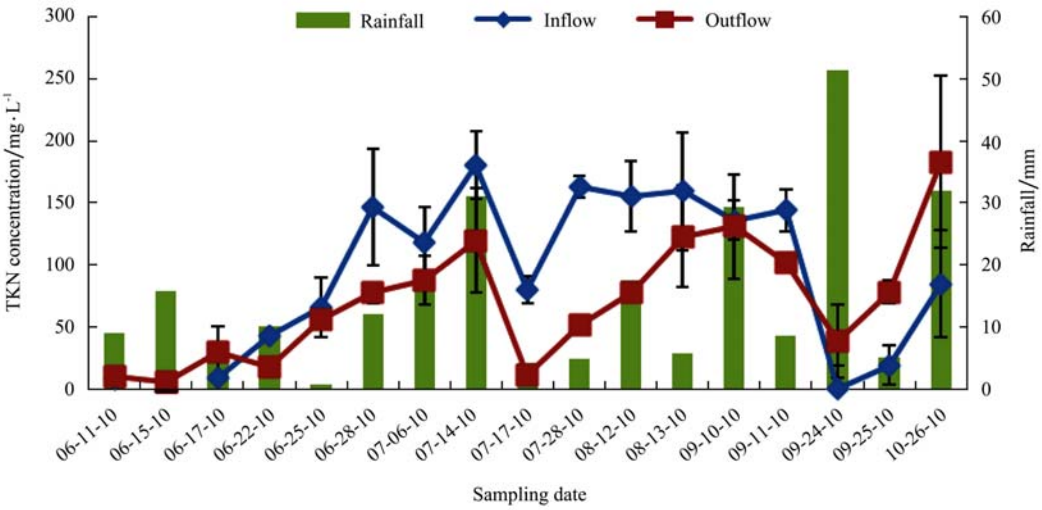

Figure 11 Variation in average TKN concentration and standard deviation of mean at different sampling events and corresponding rainfall

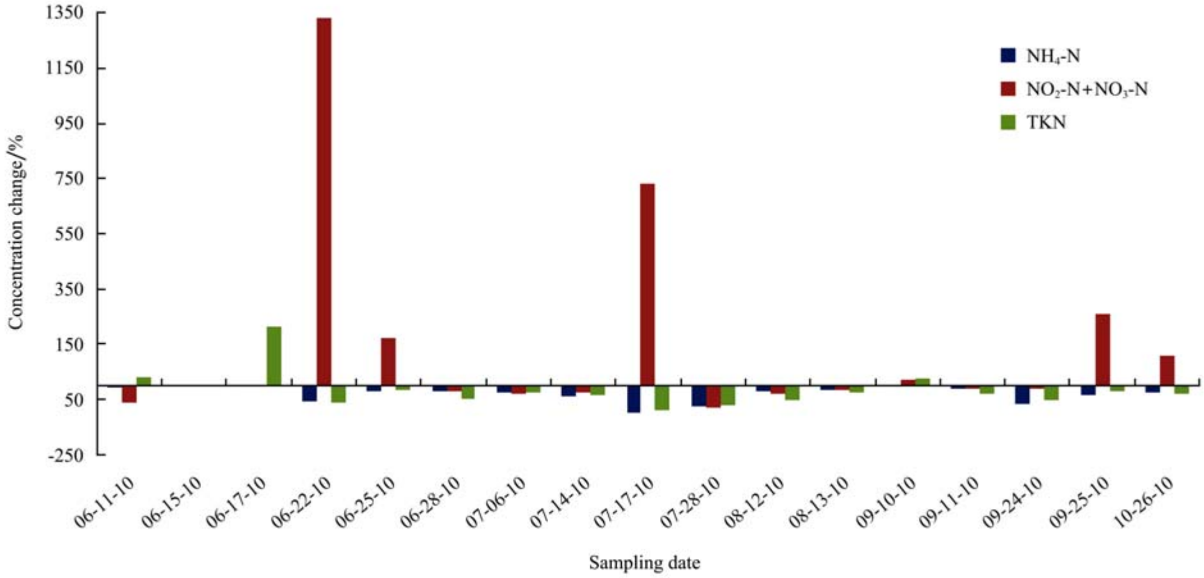

Figure 12 Concentration reductions of NH_4-N, NO_2-N + NO_3-N, and TKN at different sampling events (negative sign indicates reduction)

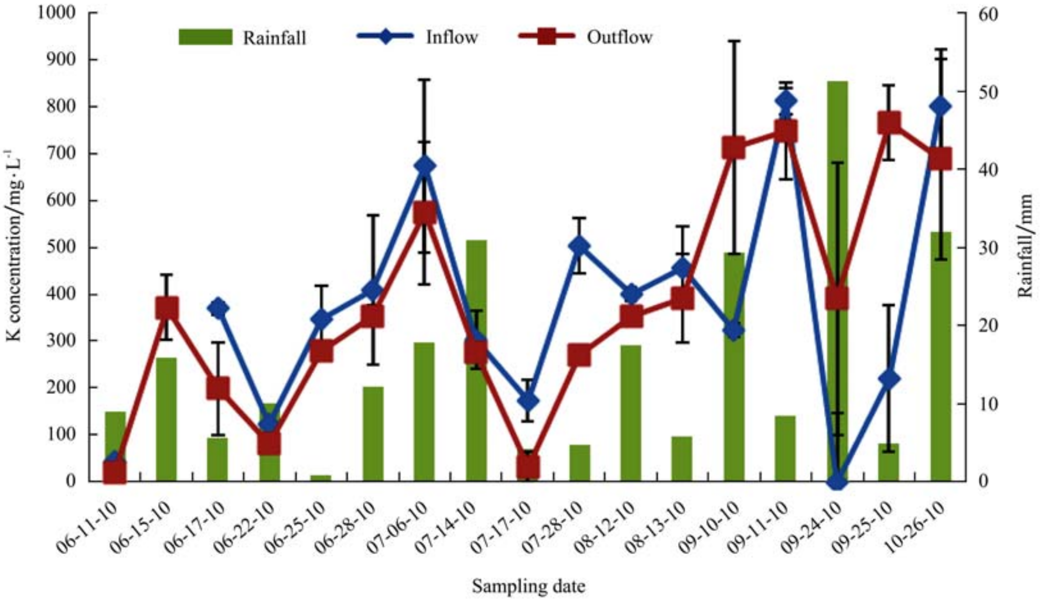

Figure 13 Concentration of potassium during different sampling events (Error bars represent standard deviation of means)

may be due to variation of sampling technique, i.e., grab vs. automatic sampling by the sampler. Dickey and Vandeholm (1981) reported K concentrations at the entry and exit of a VFS were 665 and 168 mg L^{-1}, respectively, and K values in this study were consistent with other studies. Hawkins et al. (1998) conducted VFS studies with swine lagoon wastewater on 11% and 5% buffer slopes and observed K concentration reductions by 5% and -17%, respectively. Since potassium is highly soluble, its concentration reduction potential is usually low. Overall, in this study, K concentration reduction was 19.8%, which was lower than other nutrient concentration reductions.

3.5 Conductivity

The average conductivity at inflow and outflow samples of VFS is presented in Figure 14, where conductivity fluctuated throughout the monitoring period, and the buffer appeared to cause a slight reduction in EC levels. A sharp increase in EC concentration was observed during 6 July and 11 and 25 September, which was likely due to greater amount of nutrients present in runoff at that time compared to the previous sampling since dissolved mineral salts (Stevens et al., 1995; Scotford et al., 1998; Yayintas et al., 2007) change conductivity. Typically, when dissolved matter in soil increases, conductivity increases. Conductivity and K exhibited a fair correlation at inflow (R^2=0.52) and outflow (R^2=0.78) sampling locations. Scotford et al. (1998) observed a stronger correlation (R^2=0.80) between K and EC. Overall conductivity was reduced by 16.3%. Again, the buffer was not very effective in reducing soluble constituents. Probably, buffer length should be increased to enhance infiltration of soluble constituents within buffer; eventually, better buffer performance can be achieved.

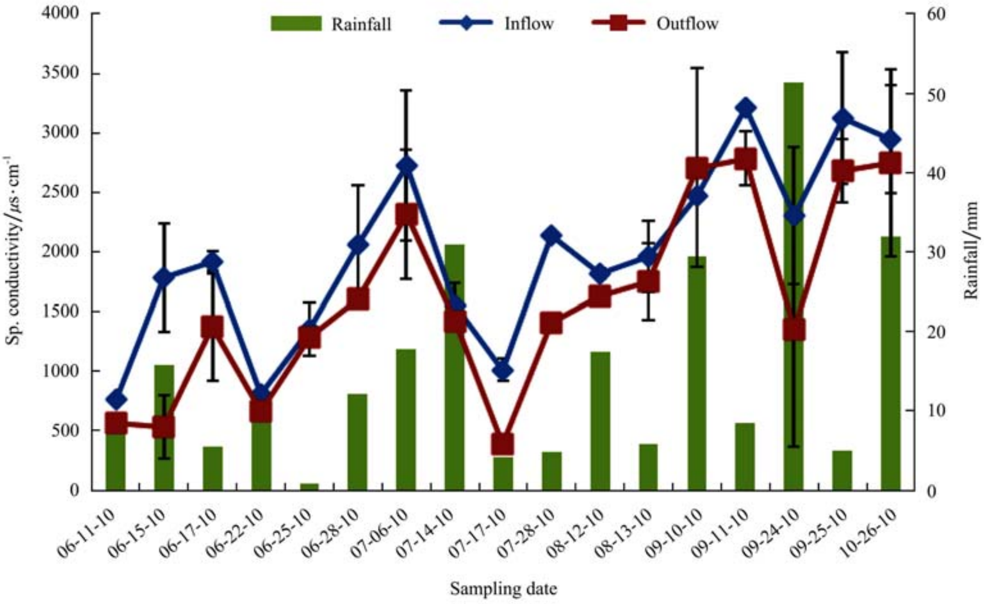

Figure 14 Specific electrical conductivity in runoff samples during different sampling events
(Error bars represent standard deviation of means)

4 Conclusions

Based on the results and discussion above the following conclusions can be made:

1) A vegetative filter strip without settling basin was effective in reducing solids and nutrients concentrations from feedlot runoff water, except for soluble nutrients.

2) On an average, the VFS was able to reduce TS concentration by 33.7%, TSS by 68.0%.

3) Total phosphorus and OP concentration reductions were by 29.9% and 19.8%, respectively, whereas potassium concentration reduction was 19.8%.

4) Similarly, NH_4-N and TKN concentration reduction was by 31.8% and 35.6%, respectively.

5) The buffer was not effective in reducing NO_2-N + NO_3-N although the level of these two constituents was

very low.

6) A wider VFS might be beneficial to enhance infiltration and soluble pollutants removal efficiency.

Acknowledgements

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References

Andersen, D., R. Berns, L. Moody, I. Khanijo, M. Helmers, C. Pederson, and J. Lawrence. 2009. Performance of six vegetative treatment systems for controlling runoff from open beef feedlots in Iowa. ASABE Paper Number: 097054. ASABE, St. Joseph, Mich.: ASABE.

APHA. 2005. Standard Methods for Examination of Water Wastewater. 2nd ed. Washington, D.C.: American Public Health Association.

Barrett, M. E. 1999. Complying with the Edwards Aquifer Rules: technical guidance on best management practices. Austin: Texas Natural Resource Conservation Commission.

Chaubey, I., D. R. Edwards, T. C. Daniel, P. A. Moore Jr., and D. J. Nicols. 1994. Effectiveness of vegetative filter strips in retaining surface-applied swine manure constituents. *Transactions of ASAE,* 37(3): 845-850.

Chaubey, I., D. R. Edwards, T. C. Daniel, P. A. Moore, and D. J. Nichols. 1995. Effectiveness of vegetative filter strips in controlling losses of surface-applied poultry litter constituents. *Transactions of ASAE,* 38(6): 1687-1692.

Dickey, E. C., and D. H. Vanderholm. 1981. Vegetative treatment of livestock feedlot runoff. *Journal of Environmental Quality,* 10 (3): 279-284.

Dillaha, T. A., J. H. Sherard, D. Lee, S. Mostaghimi, and V. O. Shanholtz. 1988. Evaluation of vegetative filter strips as a best management practice for feed lots. *Journal of Water Pollution Control Federation,* 60(7): 1231-1238.

Dillaha, T. A., R. B. Reneau, S. Mostaghimi, and D. Lee. 1989. Vegetative filter strips for agricultural non point source pollution control. *Transactios of ASAE,* 32(2): 513-519.

Duchemin, M., and R. Hogue. 2009. Reduction in agricultural non-point source pollution in the first year following establishment of an integrated grass/tree filter system in southern Quebec (Canada). *Agriculture, Ecosystems and Enviroment,* 131(1-2): 85-97.

Edwards, W. M., L. B. Owens, and R. K. White. 1983. Managing runoff from a small, paved beef feedlot. *Journal of Environmental Quality,* 12(2): 281-286.

Fajardo, J. J., J. W. Bauder, and S. D. Cash. 2001. Managing nitrate and bacteria in runoff from livestock confinement areas with vegetative filter strips. *Journal of Soil and Water Conservation,* 56(3): 185-191.

Gilley, J. E., B. Eghball, and D. B. Marx. 2007. Nutrient concentrations of runoff during the year following manure application. *Transactions of ASABE,* 50(6): 1987-1999.

Hawkins, G. L., D. T. Hill, E. W. Rochester, and C. W. Wood. 1998. Evaluation of vegetative filter strips for swine lagoon waste water. *Transactions of ASAE,* 41(3): 639-643.

Hay, V., W. Pittroff, E. E. Tooman, and D. Meyer. 2006. Effectiveness of vegetative filter strips in attenuating nutrient and sediment runoff from irrigated pastures. *Journal of Agricultural Science,* 144 (4): 349-360.

Kizil, U. 2010. Comparison of alternative feedlot runoff management systems. *African Journal of Agricultural Research,* 5(3): 236-242.

Koelsch, R. K., J. C. Lorimerr, and K. R. Mankin. 2006. Vegetative treatment systems for management of open lot runoff: review of literature. *Applied Engineering in Agriculture,* 22(1):141-153.

Lim, T. T., D. R. Edwards, S. R. Workman, B. T. Larson, and L. Dunn. 1998. Vegetated filter strip removal of cattle manure constituents in runoff. *Transactions of ASAE,* 41(5): 1375-1381.

Lorimor, J. C., S. Shouse, and W. Miller. 2002. Vegetative filter strips for open feedlot runoff treatment. Iowa State University Press, Ames, Iowa.

Mankin, K. R., and C. G. Okoren. 2003. Field evaluation of bacteria removal in a VFS. ASAE Paper No. 032150. St. Joseph, Mich.: ASAE.

Mankin, K. R., P. L. Barnes, J. P. Harner, P. K. Kalita, and J. E. Boyer. 2006. Field evaluation of vegetative filter effectiveness and runoff quality from unstocked feedlots. *Journal of Soil and Water Conservation,* 61(4): 209-217.

Mendez, A., T. A.Dillaha, and S. Mostaghimi. 1999. Sediment and nitrogen transport in grass filter strips. *Journal of American Water Resources* Association, 35(4): 867-875.

Miller, J. J., B. J. Handerek, B. W. Beasley, E. C. S. Olsen, L. J. Yanke, F. J. Larney, T. A. McAllister, B. M. Olsen, L. B. Selinger, D. S. Chanasyk, and P. Hasselback. 2004. Quantity and quality of runoff from a beef cattle feedlot in southern Alberta. *Journal of Environmental Quality*, 33(3): 1088-1097.

NDDoH. 2005. North Dakota livestock program design manual.

North Dakota Department of Health, Bismarck, North Dakota.

Parker, D. B., D. E. Eisenhauer, D. D. Schulte, and D. L. Martin. 1999. Seepage characteristics and hydraulic properties of feedlot runoff storage pond. *Transactions of ASAE,* 42(2): 369-380.

Paterson, J. J., J. H. Jones, F. J. Olsen, and G. C. McCoy. 1980. Dairy liquid waste distribution in an overland flow vegetative-soil filter system. *Transactions of ASAE*, 23(4): 483-488.

Robinson, C. A., M. Ghaffarzadeh, and R. M. Cruse. 1996. Vegetative filter effects on sediment concentration in cropland runoff. *Journal of Soil and WaterConservation,* 51(3): 227-230.

Schellinger, G. R., and J. C. Clausen. 1992. Vegetative filter treatment of dairy barnyard runoff in cold regions. *Journal of Environmental Quality,* 21(1): 40-45.

Schwer, S. B., and J. C. Clausen. 1989. Vegetative filter treatment of dairy milkhouse wastewater. *Journal of Environmental Quality,* 18 (4): 446-451.

Scotford, I. M., T. R. Cumby, R. P. White, O. T. Carotn, F. Lorenz, U. Hatterman, and G. Provolo. 1998. *Journal of Agricultural Engineering Research*, 71(3): 291-305

Spellman, F. R., and N. E. Whiting. 2007. Environmental management of concentrated animal feeding operations (CAFOs), Boca Raton, Florida, USA: CRC Press.

Stevens, R. J., C. J. O'Bric, and O. T. Carton. 1995. Estimating nutrient content of animal slurries using electrical conductivity. *Journal of Agricultural Science,* 125(2): 233-238.

Stout, W. L., Y. A. Pachepsky, D. R. Shelton, A. M. Sadeghi, L. S. Saporito, and A. N. Sharpley. 2005. Runoff transport of faecal coliforms and phosphorus released from manure in grass buffer conditions. *Letters in Applied Microbiology,* 41: 230- 234.

Swanson, N. P., N. L. Mielke, J. C. Lorimor, T. M. McCalla, and J. R. Allis. 1971. Transport of pollutants from sloping cattle feedlots as affected by rainfall, intensity, duration, and reoccurrences. In: *Livestock Waste Management and Pollution Abatement*. Pp 51-55. ASAE, St. Joseph, MI 49085: ASABE.

USEPA (US Environmental Protection Agency). 2001. Funding Agricultural Best Management Practices with the Clean Water State Revolving Fund (EPA 832-F-01-006).

Webber, D. F., S. K. Mickelson, S. I. Ahmed, J. R. Russell, W. J. Powers, R. C. Schultz, and J. L. Kovar. 2010. Livestock grazing and vegetative filter strip buffer effects on runoff sediment, nitrate, and phosphorus losses. *Journal of Soil and Water Conservation,* 65(1): 34-41.

Woodbury, B. L., J. A. Nienaber, and R. A. Eigenberg. 2002. Operational evaluation of a passive beef cattle feedlot runoff control and treatment system. *Applied Engineering in Agriculture,* 18(5): 541-545.

Woodbury, B. L., J. A. Nienaber, and R. A. Eigenberg. 2005. Effectiveness of a passive feedlot runoff control system using a vegetative treatment area for nitrogen control. *Applied Engineering in Agrriculture,* 21(4): 581-588.

Yayintas, O. T., S. Yilmaz, M. Turkoglu, and Y. Dilgin. 2007. Determination of heavy metal pollution with environmental physicochemical parameters in waste water of Kocabas Stream (Biga, Canakkale, Turkey) by ICP-AES. *Environ. Monitoring Assessment,* 127(1-3): 389-397

Young, R. A., T. Huntrods, and W. Anderson. 1980. Effectiveness of vegetative buffer strips in controlling pollution from feedlot runoff. *Journal of Environmental Quality,* 9(3): 483-487.