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Vegetative Covers to Control Sediment and Phosphorus (P) in Runoff from Dairy Waste Application Fields

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Abstract. *Excessive Phosphorus (P) in runoff contributes to eutrophication of fresh water bodies. Studies have shown that manure and effluent from animal feeding operations (AFOs) applied to waste application fields (WAFs) have contributed to excess P in segments of the North Bosque River in east central Texas. There is a growing need for environmentally sound, economically viable, and easy to establish best management practices (BMPs) to control such pollution. Vegetative buffer strips offer a potential solution for reducing runoff P from WAF by extracting it from soil and by reducing sediment P delivery to streams by decreasing runoff and soil erosion. In a field study, eight plots (5m $\times$ 5m), were assigned to four replicated treatments namely control (bare, plant cover) cool season grass, warm season forb, warm season grass, and warm season legume to assess their efficacy of runoff sediment control and P sequestration potential from soil. These plots were established on a coastal Bermuda grass WAF that received dairy lagoon effluent. A runoff collection system; a 1m $\times$ 1m sub-plot with a runoff conveyance and collection apparatus, was established on the upstream and downstream margins of each plot. Natural rainfall runoff samples were collected and analyzed for total P, soluble P, and total suspended solids (TSS). Additionally, the total mass of runoff collected from each sub-plot was estimated. Results show that the warm season forb (perennial sunflower), and warm season grass (switchgrass) were the most effective treatments for reduction of runoff P, followed by coastal Bermuda, and cool season grass.*

Keywords. Phosphorus, BMPs, Eutrophication, Vegetative filter strip, Non-point source

Introduction

Impairment of fresh water bodies due to pollutant loading from point and non-point (NPS) sources is harmful to the human and aquatic life. Controlling pollution from NPS is more difficult than point source due to the lack of a single identifiable pollution source. In 1996, Texas Commission on Environmental Quality (TCEQ) declared some segments of North Bosque River (NBR) polluted due to nutrient loading from NPS (TNRCC, 1999). Monitoring of instream water quality data in the NBR watershed (fig. 1) suggested that application of dairy manure to crop and pastureland contributed to NPS pollution (McFarland and Hauck, 1999). Phosphorus (P) was identified as the pollutant impairing water quality in NBR (Kiesling et al., 2001). In 2002 nearly 40,000 milking cows were housed in 82 dairies in the NBR watershed (McFarland and Hauck, 2004). A dairy cow excretes nearly 27 kg P per year as manure (Mukhtar, 2007). When P rich dairy manure is applied to agricultural fields in excess of plant requirements, the excess P in eroded soil becomes a source of P to the runoff. Eutrophication of water bodies occurs due to increase in P level through runoff which leads to a reduction of the aesthetic value of water by decreasing dissolved oxygen content and by creating odor and taste problems.

To protect the quality of NBR water, a total maximum daily load (TMDL) for P was implemented by TCEQ in December 2001 with the goal of reducing soluble reactive P by 50% (TNRCC, 2001). In order to meet the objective of TMDL, there is a growing need for best management practices (BMPs) to protect water quality from P pollution. Harvesting of soil P through plant uptake is an attractive method as it is feasible, easy to establish, environmentally friendly, and economically preferable. A vegetative filter strip (VFS) is one such potential BMP. The VFS is also known as a buffer strip, buffer zone, filter strip, grass filter strip, and grass buffer strip. It is a band of vegetation established perpendicular to the slope and runoff with potential to reduce the amount of runoff, decrease erosion, increase filtration time, and provide time for sediment and nutrient settling.

The sediment removal mechanism in VFS consists of filtration, deposition, adsorption, absorption, and infiltration (Dillaha et al., 1989). Phosphorus in runoff exists in particulate and water soluble forms (Abu-Zreig et al., 2003). Reduction of P in runoff can be achieved by reducing the sediment content or by reducing the amount of runoff. The VFS does both; it reduces sediment content by its filtering mechanism and impedes runoff. Several studies have evaluated the performance of VFS in reducing sediments (Gharabaghi et al., 2006; Abu-Zreig et al., 2003; Lim et al., 1998; Patty et al., 1997; Robinson et al., 1996; Chaubey et al., 1994; Dillaha et al., 1989). Researchers (Blanco-Canqui et al., 2004; Abu-Zreig et al., 2003; Sanderson et al., 2001; Lee et al., 1999; Patty et al., 1997) also have looked at P removal by VFS in different soil types under different climatic conditions. In a field experiment, Abu-Zreig et al. (2003) found that under simulated rainfall conditions, native grass species (no description of species provided) were more effective in extraction of P than ryegrass and red fescue. With 94% of the P in particulate form, the trapping efficiency of P was 61%, whereas trapping efficiency of sediment was 84%. Another study by Lee et al. (1999) using simulated rainfall concluded that switchgrass was more effective in reduction of both P and sediment in a fine loamy soil than cool season grass, and the reduction of P was mainly due to deposition of sediment in filter strips. Switchgrass reduced 55% of incoming total P; whereas, cool season grass (Brome, timothy, and fescue) decreased 44% of incoming total P in the runoff. Switchgrass and cool season grass filter strips removed 78 % and 75% of incoming sediment, respectively. Lim et al. (1998) reported that tall fescue was efficient in reducing P from incoming runoff on a silt loam soil under simulated rainfall and infiltration was the primary mechanism of P removal, as most of the runoff P was in soluble form. Patty et al. (1997) reported that the grass buffer strips (ryegrass) were effective in reducing soluble P by 22 to 89% of the incoming P in runoff in a silt loam soil. McFarland and Hauck (2004) found that coastal Bermuda grass was more effective in reducing runoff P than sorghum / wheat. Coastal Bermuda decreased total P by 67% and soluble P by 53%, while sorghum / wheat reduced total P and soluble P by 44% and 48%, respectively, when compared to control plots.

Several studies have evaluated the performance of VFS in reducing sediments and nutrients from runoff in different parts of the U.S. using different types of vegetation. These field experiments were conducted in different types of soil and under various climatic conditions. Most studies concluded that VFS is an effective BMP to control the excess nutrients in runoff from different types of sources (livestock manure storage, crop fields, forest area). In Texas, few studies have evaluated the performance of VFS for controlling nutrients from runoff using different varieties of plant covers. Hence additional research is needed to identify the varieties of vegetative covers suitable as VFS.

The objectives of this project were (1) to assess the influence of various vegetative cover types (warm season grass, cool season grass, warm season forbs, and coastal Bermuda) on sediment removal and P transport in the runoff from natural rainfall events, and (2) to recommend best vegetative covers as VFS for effective reduction of P mobility in the runoff throughout the year.

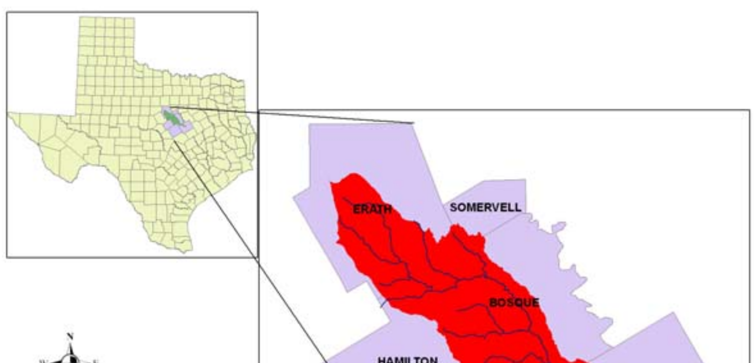


Figure 1. Location of North Bosque River watershed in Texas.

Materials and Methods

Site Description and Field Plots

The study was conducted on improved pastureland located in east central Texas that previously received dairy lagoon effluent. Eight plots (5 m × 5 m) were established on a Windthorst fine sandy loam soil. The entire plot area, plus an additional 5 m margin above and below the plots, were treated with post-emergent herbicides to control existing and competing vegetation. As shown in figure 2, cool season grass (CSG), warm season grass (WSG), warm season forb (WSF), and control treatments, each having two replications, were established randomly on eight plots. Due to severe drought conditions during the first year of the study, the cool season legume (CSL) treatment was abandoned and those plots were reassigned as control plots (bare) for the remainder of the study. The two sets of plots (R1 and R2) were separated by a 5 m buffer zone and each plot within the set was separated by a 1 m margin in order to avoid treatment edge effect. A 1 m × 1 m sub-plot with a runoff conveyance and collection system was established on the upstream and downstream margin of each treatment replication. All the upstream sub-plots were installed in existing coastal Bermuda grass except two sub-plots were kept bare (control). All the down-stream sub-plots were installed inside each treatment. Each sub-plot was isolated from the overland flow by 10 cm high metal borders. After a natural rainfall runoff producing event, water from each sub-plot was conveyed to its respective collector through plastic tubing. The collection system consisted of a 45.7 cm dia. x 1.2 m deep culvert inserted in a 60.9 cm dia. x by 1.2 m deep hole augured down slope from each sub-plot. A 113.5 L capacity barrel was placed inside the culvert and covered with a plastic lid. A hole was drilled into the lid for a 5 cm diameter plastic tube to convey runoff from the sub-plot to the barrel. Culverts were covered with a metal lid to prevent entry of insects and water into the barrel from external sources. A weather station was installed to record rainfall intensity and amount (fig. 2) at the experimental site. After a runoff producing event, the barrel from each collection system was removed and the entire mass of water and sediment collected in each barrel was weighed. After collecting a thoroughly mixed, 1 L sample of the barrel contents, barrels were emptied, cleaned, and then replaced into the culvert. Runoff samples were kept on ice and transported to the Texas Institute for Applied Environmental Research (TIAER) laboratory for total suspended solid (TSS), total phosphorus (TP), and soluble ortho-phosphorus (SOP) analyses.

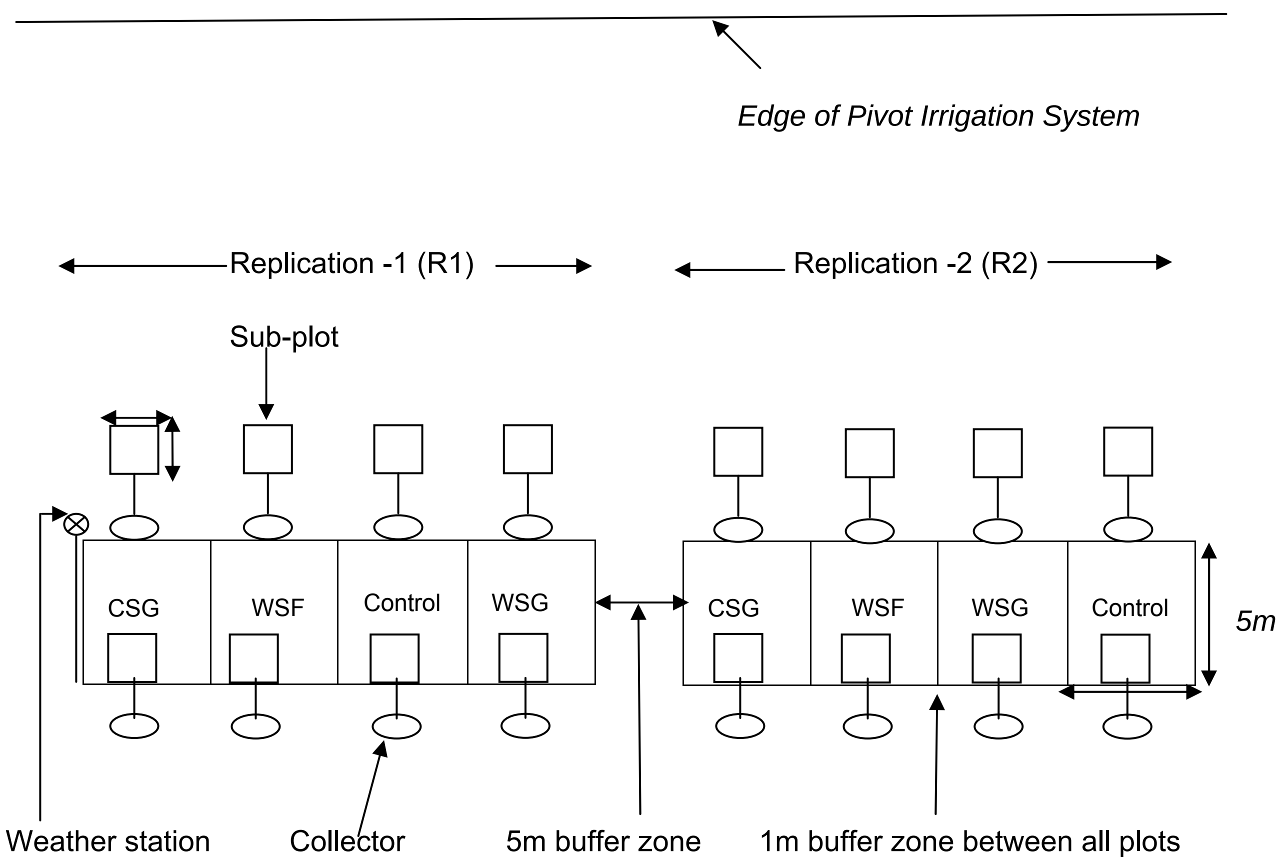


Figure 2. Schematic of field plots in the study area, 2005- 2008

Forage samples were collected randomly from three different locations within each plot and each sample was heated at 55ºC until no change in weight was observed. Then, a composite sample was prepared from three sub-samples from each treatment and the sample was analyzed in the laboratory for TP extraction by a vegetative cover.

During treatment establishment, four soil samples were taken from each plot from the surface to 8 cm depth. A composite of the four samples per plot was sent to the laboratory for analysis of TP and SOP. In this way, two composite samples per treatment were analyzed.

Treatment Description

The warm season grass (WSG) treatment consisted of a mixture of Indiangrass (*Sorghastrum nutans*), Eastern gamagrass (*Tripsacum dactyloides*) and switchgrass (*Panicum virgatum*), whereas the cool season grass (CSG) treatment consisted wildrye (*Elymus virginicus*) only. Perennial sunflower (*Helianthus maximiliana*) was the only warm season forb (WSF), whereas remnant coastal Bermuda grass (CB) (*Cynodon dactylon*) was used as the preexisting treatment on the plots. After one year of establishment (2005), WSG, WSF,and CB continued to grow but severe drought inhibited the growth of CSG after October, 2006.

Table 1 indicates the dates and amounts of rainfall at the experimental site.

Table 1. Rainfall data of the experimental site

Date	Rainfall(cm)
3/20/2006	11.4
4/20/2006	4
4/29/2006	5.4
5/3/2006	4
5/4/2006	2
5/4/2007	3
5/11/2007	4
5/30/2007	3.4
6/7/2007	5.6
6/15/2007	2
7/30/2007	2.5
8/20/2007	4.5
8/31/2007	0.66
9/4/2007	1.6
9/11/2007	3.4

The greatest amount of rain fell on March 20, 2006; whereas the least amount of rainfall occurred on August 31, 2007. Due to a severe drought in the area from May, 2006 to May, 2007, little measurable runoff was collected from any sub-plots during that period.

Result and Discussion

Soil TP and SOP

As shown in table 2, soil TP and SOP at the experimental site varied among treatments. The TP was greatest in the WSG treatment plots followed by CB, control, WSF, and CSG treatment plots. The SOP in the control treatment was greatest followed by CSG, WSF, CB, and WSG. The SOP as a percent of TP for these treatments varied from 24.4% for CSG to 11% for WSG treatment.

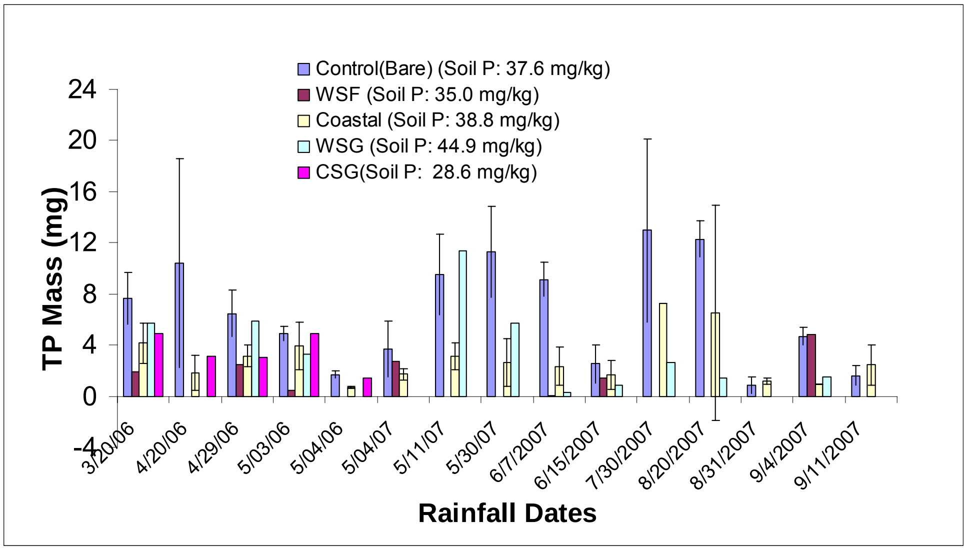
Table 2. Soil TP and SOP for different treatment plots

Plot	TP(mg/kg) *	STDEV TP	SOP(mg/kg) *	STDEV SOP	SOP as %TP
Control	37.6	11.8	9	0.9	24
CSG	28.6	4.8	7	3.5	24.4
CB	38.8	13.8	5.4	2.3	14
WSG	44.9	17.6	5	0.07	11
WSF	35	7.6	6.5	0.6	18.5

*Mean value, n = 2

Treatment effectiveness for runoff TP

As expected within a given rainfall event, the control treatment produced a greater mass of TP as compared to other treatments. Runoff samples from each rainfall event showed that WSF treatment had lower TP than all other treatments (fig. 3) due to the least amount of sediment in the runoff (fig. 5). Despite the highest soil P among all the treatments, WSG treatment had the second lowest amount of TP due to the mass of runoff and sediment only higher than that from WSF treatment (fig. 5). Coastal Bermuda was the third most effective treatment to reduce TP in the runoff. Soil TP of CB treatment was greater than control treatment (table 2) but the TP mass in the runoff from the CB treatment was lower than the control treatment. This was due to greater reduction of sediment in the runoff (fig. 5) from CB treatment as compared to the control treatment.



Data without error bar is from one plot of the treatment

Figure 3. Comparison of mass of runoff TP among treatments

The CSG treatment produced less TP in the runoff than the control and WSG treatments. This result was due to a combination of the lower initial soil TP (among all treatments) and sediment mass from CSG treatment compared to the control treatment (table 2).

Treatment effectiveness for runoff SOP

Figure 4 illustrates soil and runoff SOP from each treatment. The runoff from WSG treatment had the greatest SOP, followed by control, WSF, CB and CSG treatments. The WSG soil TP was the greatest of all treatments (table 2) and it had the second lowest sediment (TSS) in the runoff resulting in this trend. On the other hand, the CSG treatment had the lowest runoff SOP. This resulted from CSG treatment having the lowest soil TP. The CB treatment had the second least amount of SOP in the runoff due to less amount of soil SOP (table 2, only greater than CSG) and the third least sediment in the runoff (fig. 5).

In contrast, WSF and WSG treatments had the cleanest runoff. They ranked lowest in TSS mass in runoff among all treatments. Therefore, more P was present in the soluble than the sediment form in runoff compared to other treatments (fig. 4).

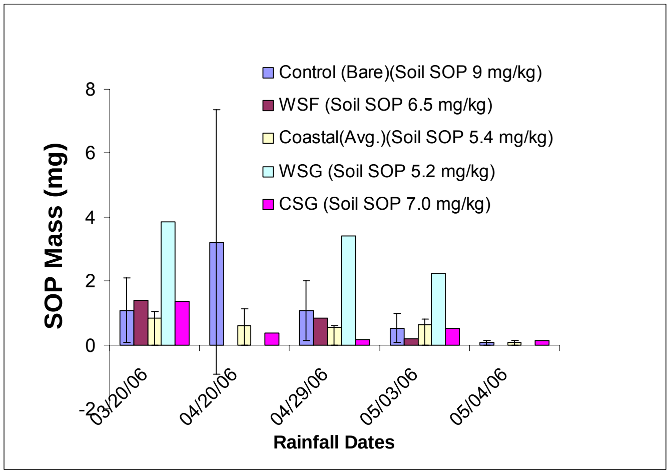


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Figure 4. Comparison of mass of runoff SOP among the treatments

The control treatment had the second highest SOP as %TP (almost equal to that of CSG, table 2) in soil but due to the greatest amount TSS in the runoff of this treatment, less runoff P was in the soluble form.

Treatment effectiveness for TSS

All treatments were deemed effective for reducing runoff TSS when compared to control treatment (fig. 5).

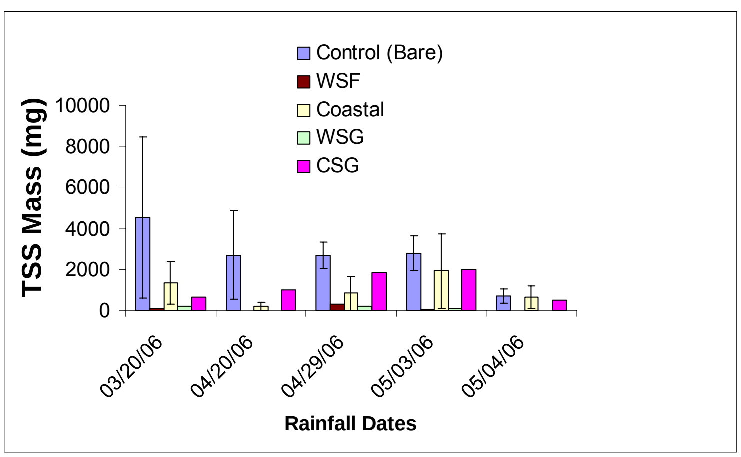

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Figure 5. Comparison of mass of runoff TSS among the treatments

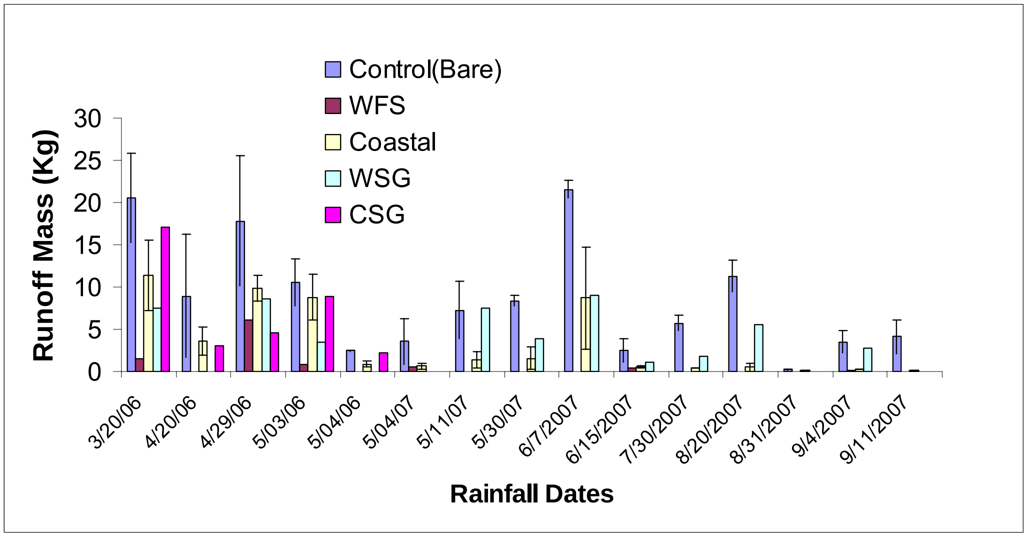
The reduction of sediment mass in runoff was greatest in the WSF followed by WSG, CB, and CSG treatments (fig. 5). The reduction of sediment was nearly the same for WSF and WSG due to the extensive amount of vegetative cover of these treatments (fig. 6). As a result, the extensive vegetative cover reduced the raindrop impact on soil that resulted in less sediment in the runoff. As expected, the greatest amount of runoff sediment was measured from the control treatment, which contributed the greatest amount of TP in runoff from those treatments (fig. 3).

Figure 6. WSF (L) and WSG (R) treatment plots

Treatment effectiveness for runoff control

As expected, runoff produced from a natural rainfall event was less from vegetative than the bare (control) plots. Warm season forb was the most effective of all treatment in reducing runoff mass followed by WSG, CB, and CSG treatments (fig. 7).

In fact, out of fifteen rainfall events, WSF and WSG treatments produced no measurable runoff during eight and five events, respectively. The denser vegetative canopies of these two treatments as compared to CB and CSG treatments, intercepted more rain and reduced the raindrop impact on soil causing less erosion and sediment transport in the runoff (fig. 6). The CB and CSG treatments had lesser vegetative cover than WSF and WSG treatments and that resulted into more runoff from these two treatments.



Data without error bar is from one plot of the treatment

Figure 7. Comparison of mass of runoff among the treatments

Plant Tissue Analysis

Forage samples were taken from each treatment and analyzed in the laboratory to obtain the TP content extracted (up-take) by plants. As shown in table 3, the mean P up-take varied from 11.5 kg to 3.3 kg per hectare (ha) among different treatment plants. While soil P content of WSF treatment ranked third (table 2), behind WSG and Control treatment plots, plant P extracted by the WSF treatment was the greatest followed by WSG, CB, and CSG treatments (table 3).

Table 3. Plant P up-take from different treatments during 2007.

Treatment name	N	Mean [a] (kg/ha)
CSG	2	3.3^{a} ±0.31
Coastal Bermuda	8	9.3^{b} ± 3.2
WSG	12	10.7^{b} ± 2
WSF	4	11.5^{b} ± 0.8

[a] Means within the column followed by different letter are significantly different at P ≤ 0.05 according to Tukey's Honestly Significance Difference

The greater up-take of P in both WSF and WSG treatments was evident from greater vegetative mass compared to other treatments (fig. 6). In contrast, P up-take (3.3 kg/ha, table 3) for the CSG was significantly lower than all other treatments. This may be due to the low soil TP in these treatments compared to other treatments (table 2). The P up-take by the CB treatment was second lowest (9.3 kg/ha, table 3), but it was statistically similar to that for the WSG and WSF treatments.

Conclusions

The vegetative covers studied provided good evidence of controlling sediment and P in the runoff from dairy effluent application fields. Among all the treatments, WSF and WSG were most effective in reducing mass of runoff P followed by CB, and CSG on a Windthorst fine sandy loam soil. Denser vegetative cover in these two treatments played an important role in lessening runoff P by reducing runoff and by decreasing sediment in the runoff due to less raindrop impact on soil. These two treatment cover types (sunflower and mixed warm season grass, respectively) also extracted more P from soil compared to all other treatments. Hence lesser runoff, lesser sediment, and greater plant P up-take from WSF and WSG plots suggests that a VFS of either WSF or WSG could potentially reduce the runoff P and could provide a better solution to NPS pollution of P from animal waste application fields. Additionally, these cover types may be used to enhance habitat or could be used as biomass to produce energy or fodder for livestock.

Acknowledgement

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