

VEGETATIVE COVERS FOR SEDIMENT CONTROL AND PHOSPHORUS
SEQUESTRATION FROM DAIRY WASTE APPLICATION FIELDS

A Thesis

by

SUBHASIS GIRI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2008

Major Subject: Biological and Agricultural Engineering

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Approved by:

Chair of Committee,	Saqib Mukhtar
Committee Members,	Ann Kenimer
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ABSTRACT

Vegetative Covers for Sediment Control and Phosphorus Sequestration from Dairy
Waste Application Fields. (August 2008)

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Chair of Advisory Committee: Dr Saqib Mukhtar

Excessive phosphorus (P) in runoff contributes to eutrophication of fresh water bodies. Studies have shown that manure and effluent applied from animal feeding operations 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 to control such pollution. Vegetative buffer strips offer a potential solution for reducing runoff P from WAFs by extracting it from soil and by reducing sediment P delivery (due to reduced runoff and soil erosion) to streams. In a field study, ten plots ($5\text{m} \times 5\text{m}$) were assigned to five replicated treatments, namely control (bare, without having any 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 $1\text{m} \times 1\text{m}$ sub-plot with a runoff conveyance and collection apparatus, was installed on the upstream and downstream margins of each

plot. Natural rainfall runoff samples were collected and analyzed subsequently for total P, soluble P, and total suspended solids in the laboratory. Additionally, the total mass of runoff collected from each sub-plot was calculated. Results suggested that the warm season forb and warm season grass were the most effective vegetative covers for the reduction of runoff P, followed by coastal Bermuda and cool season grass, respectively. The lesser amount of runoff total P in these two treatments was due to lesser runoff mass and lesser sediments in the runoff due to initial interception of rain and less raindrop impact on soil because of denser vegetative cover in both treatments compared to all other treatments.

DEDICATION

This thesis is dedicated to my parents without whom I have no existence in this world. With their love and support throughout my journey, I was able to come to Texas A&M University for my Master of Science program.

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First of all I would like to thank my parents, Raghunath Giri and Shantilata Giri. Your love and support throughout my 24 years are incredible. Special thanks to my Mom for always believing in me and supporting me during my tough times.

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INTRODUCTION

Nearly 97% of the total water on the earth is in oceans while 3% of water is fresh water (Black, 1996). Out of 3% of the total fresh water, only 0.03% is available for terrestrial and aquatic life. The water present in rivers, streams, creeks, lakes, and reservoirs is the important renewable resource needed for all terrestrial organisms and mainly used for drinking, recreation, and as a habitat for aquatic plants and animals. Degradation of water quality becomes harmful for both human and aquatic life. Impairment of this fresh water occurs due to loading of pollutants from both point and nonpoint sources (NPS). Controlling pollution from NPS is more difficult than point source due to lack of a single identifiable pollution source. That is why researchers are studying ways to reduce the NPS pollution in order to prevent the degradation of water quality. The contributors to NPS pollution include agricultural fields, construction sites, forests, highways, and septic tanks. Agricultural field is one of the main sources of NPS pollution due to excessive application of livestock manures, fertilizers, pesticides, and herbicides.

The U.S. is one of the leading milk producing countries in the world. In 2007, total milk production was expected to be 84 billion liters that would generate \$27 billion in revenue. (IBISWorld, 2007). The leading milk producing states in U.S. are California, Wisconsin, Texas, New York, Pennsylvania, and Idaho. In 2006, Texas had 335,000 milk cows that produced an average of 3,263 million liters of milk

This thesis follows the style of *Transactions of the ASABE*.

(National Agriculture Statistics Service, 2006). Apart from milking cows, Texas is first among all states in livestock and livestock products and ninth in dairy products (Stuff about States, 2004). Most of the dairy farms are located in east central Texas. Erath County is the home to the largest number of dairy operations in Texas. This County is located in the North Bosque River (NBR) watershed (figure on p.8). It is estimated that a dairy cow produces 27 kg phosphorus (P) per year (Mukhtar, 2007). Apart from manure, feed, bedding material, and process generated waste water also are sources of nutrients such as nitrogen (N) and phosphorus (P). Improper storage and disposal of animal waste is a serious threat to water quality as it may be rich in P. Though P is essential for plant growth, but over application of dairy manure and waste water to agricultural fields results in excessive accumulation of P in soil. Runoff with excess P levels from heavily manured waste application fields (WAFs) to the water bodies can cause rapid growth of algae and other aquatic plants resulting in a decrease of dissolve oxygen level. Degradation of water quality occurs due to lack of oxygen and the water cannot be used for drinking purpose due to taste and odor problem.

Due to the excessive P concentrations in the water, two segments (1225, 1255) of NBR were declared as impaired under section 303 (d) of the Clean Water Act in 1998 (TNRCC, 2001). A total maximum daily load (TMDL) was established in order to control the impairment of the water bodies. The ultimate goal of the TMDL was to reduce soluble reactive P by 50% in the entire NBR (TNRCC, 2001). To meet the objective of the TMDL, there is a growing need of best management practices (BMPs)

which can optimize the problem of excess P movement from WAFs to the nearby water bodies. The BMPs should allow dairy producers to manage the excess P without decreasing herd size. Harvest of P through plant up-take is an attractive method as it is feasible, easy to establish, environmental friendly, and economically preferable. That is why the vegetative filter strips (VFS) are one of potential BMPs in the present day that has attracted the attention of the researchers to solve the present water quality problem due to NPS pollution. Construction of VFS below manure storage facilities, composting sites or crop fields receiving dairy manure, and waste water could potentially harvest P from runoff. The P in runoff is present in two forms; water soluble form and sediment bound form. Reduction of P in runoff can be achieved by either reducing the sediment content or by reducing the total amount of runoff. The VFS does both; reduces sediment content by its filtering mechanism and impedes runoff (Mankin et al., 2007; Abu-Zreig et al., 2003). Hence, VFS could offer a potential solution for addressing both manure management and degradation of water quality. Utilization of manure for production of forages and recycling P through forage harvest is an effective approach to handle the excessive P issue.

The VFS is also known as a buffer strip, buffer zone, filter strip, grass filter strip, and grass buffer strip. It is the band of vegetation established perpendicular to runoff from WAFs or effluent storage area which reduces the amount of runoff, decreases erosion, increases filtration time, and provides more time for settling of nutrients. Nutrient removal occurs in VFS through a series of processes such as adsorption, sedimentation, and decomposition. The efficiency of VFS varies according to the types

of flow (concentrated and uniform flow). Apart from the flow pattern, the efficiency of VFS also depends on the type of vegetation, soil type, slope, density of vegetation, source area, and the width of vegetation. Infiltration, deposition, and nutrient up-take are three mechanisms by which VFS reduces nutrients from runoff.

Infiltration is one of the important mechanisms that increases the nutrient removal capacity of VFS. The VFS helps in infiltration by slowing down the runoff rate which provides more time for infiltration. Hence greater VFS width has higher infiltration compared to shorter VFS length. Apart from VFS width, the infiltration rate depends on soil type, soil cover, and amount of soil moisture. Infiltration reduces a considerable amount of P in runoff when the runoff contains more soluble P than runoff having less soluble P. Soluble P along with water and other nutrients enters into the soil through soil pore which reduces the amount of P and nutrients in runoff.

Deposition is another important mechanism that increases the efficiency of VFS in reducing nutrients when the nutrients in runoff are sediment bound rather than in soluble form. Most of the P present is in sediment bound form rather than in soluble form, so this mechanism could be an efficient method in removing P from runoff. The vegetative cover (VC) of VFS acts as filter which traps sediments from runoff. The VC reduces the runoff rate allowing more traveling time inside the VFS. The heavier sediment bound pollutants settle down on the bottom while others attach to leaves and other parts of the VFS. Apart from the forms of P, deposition of sediment particle depends on VC, runoff rate, and soil slope.

Nutrient uptake is the third mechanism which increases the efficiency of VFS by reducing P from soil. Plant requires nutrients for growth and P is one of the essential nutrients for plants which plays a crucial role for growth and helps in the formation of energy. That is why P is one of the important nutrients applied by the producers for plant growth. During active growth period, plants absorb soluble P and other essential nutrients from soil which ultimately decreases P and nutrients content in runoff.

This study was based on a simple theory where the extraction capacity of treatment plants is correlated with their active growth periods. Figure 1 (a) and (b) represent the soil P extraction by warm season plants (WSP) and by cool season plants (CSP) throughout the year, respectively.

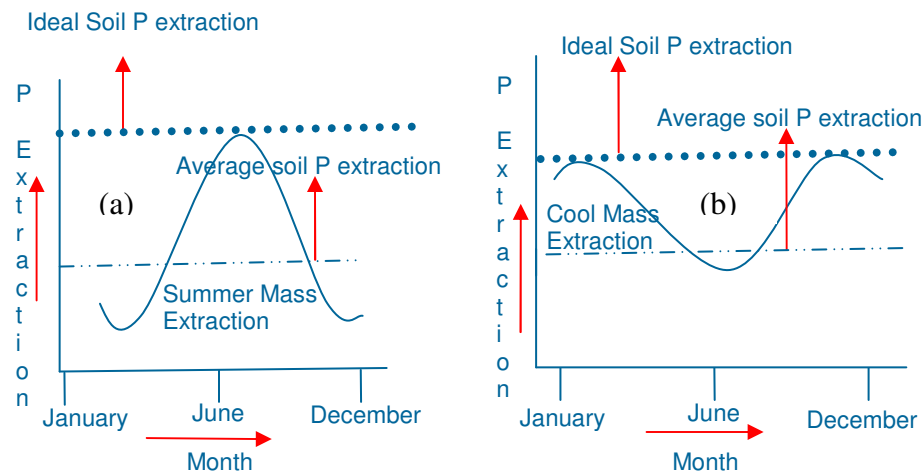


Figure 1. Soil P extraction by WSP (a) and CSP (b)

The thin dotted line (fig. 1 a and b) represents the average soil P extraction throughout the year by either warm or cool season plants which is less than the ideal soil P

extraction. Plants extract more soil P during their active periods (WSP extracts more during summer season whereas CSP extracts more during winter season) and extract little or no soil P during inactive growth period. Figure 2 represents the combined effect for soil P extraction by both warm and cool season plants, leading to a higher P extraction level designated as ideal soil P extraction through out the year. Here both WSG and CSG extract more soil P during their active period which will increase the average soil P extraction capacity throughout the year.

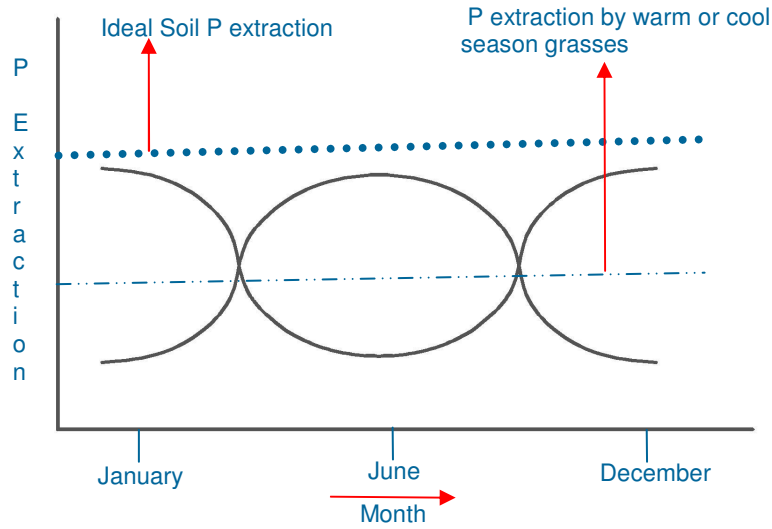


Figure 2. Combined effect of soil P extraction by WSP and CSP

LITERATURE REVIEW

Phosphorus in NBR

The NBR is located in east central Texas (fig. 3). It begins in Earth County and flows through the cities of Stephenville, Hico, Meridian, Valley Mills and drains into lake Waco. Impairment of the two segments of NBR is due to both point and NPS sources, but it is largely associated with animal feeding operations (Texas Commission on Environmental Quality (TCEQ), April 2003). Erath County is home to a large number of dairy operations. About 40,000 milking cows were housed in 82 dairies in NBR watershed during October 2002 (McFarland and Hauck, 2004). A dairy cow excretes an estimated 27 kg P per year as manure (Mukhtar, 2007). Improper management of this huge amount ($27 \times 40,000$ kg) of dairy manure is a serious threat to NBR water quality. This is a growing concern as water of NBR is the primary source of drinking water for the City of Waco and other surrounding cities. In 1996, TCEQ declared that NPS loading of nutrients was the most serious threat to meeting designated uses along the NBR (TNRCC, 1996). In 1998, two segments of NBR were declared as impaired under section 303 (d) of the Clean Water Act (TNRCC, 2001). The impairment of water was related to aquatic plant growth due to excessive nutrients. The P was identified as the limiting nutrient (Kiesling et al., 2001). The TCEQ developed a TMDL for NBR to reduce the nutrient loading in order to maintain the water quality and approved this plan in December 2002 whereas Texas State and Water Conservation Board (TSSWCB)

passed it in January 2003. A TMDL determines how much maximum amount of pollutants a water body can assimilate while still meeting the standard for its safe use.

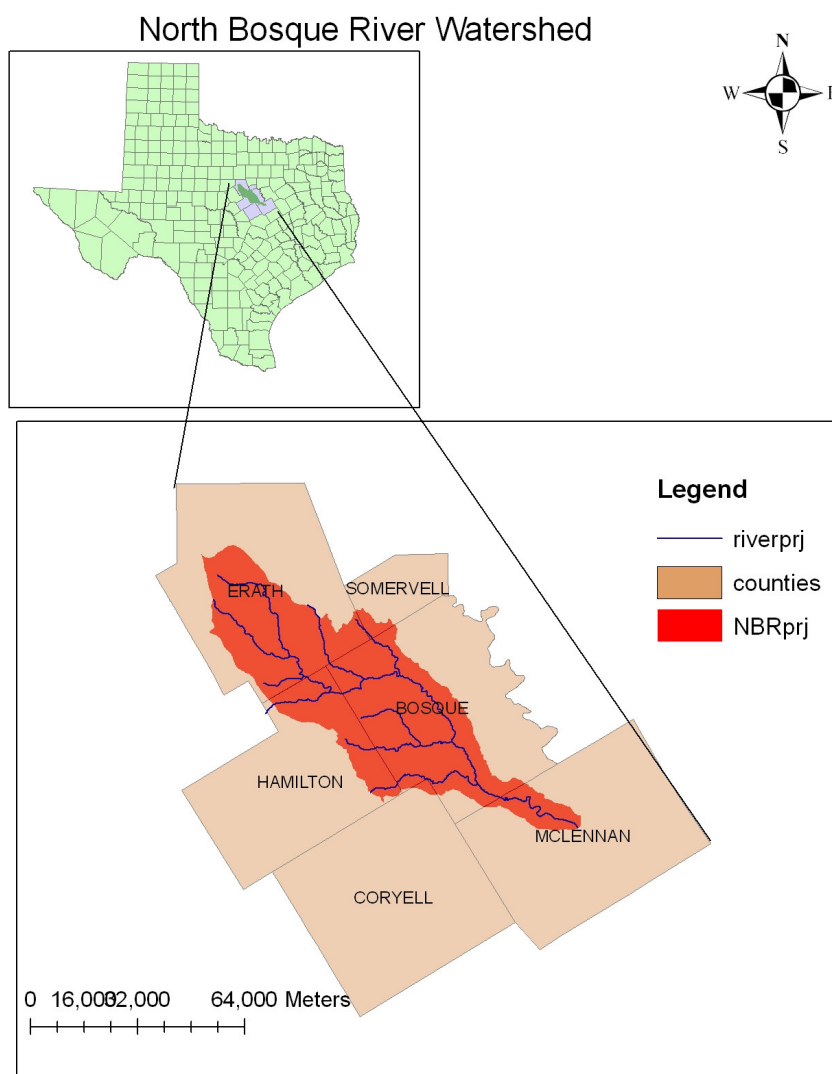


Figure 3. North Bosque River Watershed

The objective of the TMDL was to reduce annual pollutants and soluble P loading in NBR. Reduction in soluble P loading would reduce the algal bloom and other aquatic plants in NBR.

Sediment and nutrient removal

Dillaha et al. (1989) evaluated the performance of orchardgrass (*Dactylis glomerata*) as a VFS on eroded Groseclose silt loam soil. In their experiment, the plots were closer to cropland and commercial fertilizer was the source of nutrients to experimental plots. Simulated rainfall was applied to the plots for collection of runoff samples. They found that 4.6 m and 9.1 m wide VFS removed an average of 61 and 79% of the incoming P, and 70 and 84% of incoming suspended solids, respectively. The sediment removal capacity of VFS was nearly same as the P removal capacity, as most of the P entering the VFS was sediment bound.

Chaubey et al. (1994) used fescue (*Festuca arundinacea* Schreb) in VFS to evaluate the efficiency of VFS in controlling sediment and nutrients from land areas treated with swine manure. They applied swine manure at the top portion of their experimental plot and used simulated rainfall to generate runoff on a Captina silt loam soil. Their result suggested that fescue VFS was significant in reducing the mass of total P (TP), ortho-P ($\text{PO}_4\text{-P}$), total suspended solids (TSS), total Kjeldahl nitrogen (TKN) and ammonia nitrogen ($\text{NH}_3\text{-N}$). The incoming TP was reduced by 67 and 92%; whereas, incoming $\text{PO}_4\text{-P}$ was decreased by 65 and 94% by 3 m and 21 m wide fescue VFS, respectively.

Robinson et al. (1996) established VFS on a Fayette silt loam to determine its effectiveness on sediment concentration on cropland. Their VFS consisted of bromegrass (*Bromus inermis*), alfalfa (*Medicago sativa*), and orchardgrass (*Dactylis glomerata*). They found that under natural rainfall condition, 3 m and 9.1 m wide VFS reduced more than 70% and 85% of incoming sediment from runoff.

Hawkins et al. (1998) used Bermudagrass (*Cynodon dactylon*) and ryegrass (*Lolium perenne*) for their study to determine the feasibility of VFS in controlling nutrients from a swine lagoon. They established VFS in Pacolet sandy soil and Marvyn loamy sand and applied waste water to each plot. They found that the reduction of TP mass was more than 50% of the incoming P. They concluded that high mass reduction of P was due to greater reduction of runoff volume.

Patty et al. (1997) determined the efficacy of grassed buffer strips in reducing pesticide losses in runoff from a large cultivated plot in a hydromorphic silt loam soil. They used simulated rainfall to collect runoff samples from ryegrass buffer strip. They found that the incoming runoff volume was reduced by 43 to 99.9%; whereas, the incoming suspended solids by 87 to 100%. The incoming soluble P in runoff was reduced by 22 to 89% with the strip.

McFarland and Hauck (2004) demonstrated P reduction of a field high in extractable P by using coastal Bermudagrass (*Cynodon dactylon*) and sorghum (*Sorghum bicolor*) / winter wheat (*Triticum*) under natural rainfall condition. They established bermudagrass in Duffau soil; whereas, sorghum / wheat in Windthorst soil.

They found that bermudagrass reduced 51% of incoming $\text{PO}_4\text{-P}$ and 61% of incoming TP; whereas sorghum / wheat did not show a consistent decrease in either $\text{PO}_4\text{-P}$ or TP.

Blanco-Canqui et al. (2004) compared the effectiveness among fescue filter strip (FS), barrier fescue FS, and barrier native FS in reducing runoff, sediment, nitrogen, and P loss in a Mexico silt loam soil. They used switchgrass (*Panicum virgatum*) as barrier in fescue (*Festuca arundinacea*) FS and native FS. Native FS consisted of gamagrass (*Tripsasum dactyloides*), Indiangrass (*Sorghastrum scorparium*), big bluestem (*Andropogon gerardi*), gray-head coneflower (*Ratibida pinnata*), and purple coneflower (*Echinacea purpurea*). Under simulated rainfall, they found that barrier fescue FS was more effective in reducing runoff, sediment, and nutrients than fescue FS. Fescue FS and barrier native grass FS were equally effective in reducing runoff, sediment, and nutrient loss.

Lee et al. (1999) conducted a study to evaluate the short term effectiveness of native switchgrass (*Panicum virgatum*) and cool season grass FS in removing sediment and nutrients on a Coland soil under simulated rainfall condition. Their cool season grass FS consisted of brome grass (*Bromus inermis*), timothy (*Phleum pratense*), and fescue (*Festuca* spp.). They found that, 3 m and 6 m wide switchgrass filter strip removed 69% and 78% of incoming sediment while the respective widths of cool season grass reduced 62% and 75% of incoming sediment. The incoming TP was reduced by 39% and 55% for 3 m and 6 m switchgrass filter strip; whereas, 35% and 49% for respective width of cool season grass filter strips. They suggested that, for the short term (exact period not

mentioned) effectiveness, both switchgrass and cool season grass filter strip removed same quantity of sediment from cropland runoff.

Chaubey et al. (1995) used simulated rainfall to determine the effectiveness of VFS in controlling constituents in runoff from poultry litters on Captina silt loam soil. Runoff samples were collected after it flowed through a fescue (*Festuca arundinacea*) cover. It was reported that fescue cover reduced significant amounts of incoming PO₄-P and TP.

Schellinger and Clausen (1992) conducted a study to measure the effectiveness of VFS in reducing solids from dairy barnyard runoff. Their VFS consisted of a mixture of red and Kentucky tall fescue (*Festuca* spp.), annual and perennial rye grass (*Lolium* spp.), and Kentucky bluegrass (*Poa* spp.) on Massena silt loam and Kingsbury silty clay loam. The barnyard runoff was introduced into the VFS through a plastic pipe after passing through a detention pond. They determined that VFS was not effective in the reduction of waste water concentration from a barnyard but it reduced significant amounts of suspended solids and TP. They observed that VFS retained greater amount of sediment mass during the growing period.

Abu-Zreig et al. (2003) conducted a field experiment using simulated rainfall to examine the efficiency of VFS for removal of P from the cropland runoff. They used perennial ryegrass (*Lolium perenne* L.), legume, creeping red fescue (*Festuca rubra*) mix, and native grass species (name not given) as vegetative covers on a silt loam soil. The P trapping efficiency was highest for the native grass species followed by perennial rye grass and a combination of legume and red fescue. They found that the highest

percentage of P was trapped by the native grass species due to their greater vegetative cover among all of the treatment plants. The removal of P was correlated with the removal of sediment for all vegetative covers in their experiment.

Borin et al. (2005) demonstrated the effectiveness of buffer strip (BS) in reducing runoff, suspended solids, and nutrients from a crop field under natural rainfall condition. Their BS consisted of trees (*Platanus hybrida* Brot), shrubs (*Virburnum opulus* L.) and grass (*Festuca aurundinacea* L.) in a fulvi-calcaric Cambisol of sandy loam texture. They found significant change in concentrations of incoming runoff, sediment, and TP but no change in concentration of incoming $\text{PO}_4\text{-P}$ and nitrogen. The reduction of TP was due to the removal of sediment bound P.

Sanderson et al. (2001) conducted a field experiment to demonstrate the effectiveness of switchgrass (*Panicum virgatum*) filter strip in reducing nutrients on Windthorst fine sandy loam soil under natural rainfall condition. They determined that switchgrass was effective in reducing total reactive P, but the recovery of P as biomass was low compared to P present in applied manure. They suggested that the low P recovery might be due to the same VFS area to manure treated area.

Mankin and Cairo (2003) established fescue filter strip on Newtonia silt loam soil to evaluate the efficiency of VFS by using the runoff from a feedlot. They found that the fescue VFS reduced 85% of runoff, 84% of incoming P, and 85% of incoming sediments. Removal of sediment was due to sedimentation inside the VFS in their experiment.

Kim et al. (2006) demonstrated the efficiency of VFS for removing P from milk house waste on two different soils (Coarse-loamy over sandy and Coarse-loamy, mixed, mesic typic). Their VFS consisted of tall fescue (*Festuca arundinacea*), orchardgrass (*Dactylis glomerata*), and timothy (*Phlem pratense*). Waste water from milk house was discharged into VFS through pipes. They found that VFS reduced lesser amount of soluble reactive P from the milk house waste water on both soil types as compared to applied milk house waste water into VFS.

Mankin et al. (2006) quantified nutrients concentration of runoff from an unstocked feedlot after passing through brome (*Bromos inermis*) VFS. They established the VFS on four different types of soils namely Shellabarger fine sandy loam, Crete silt loam, Newtonian silt loam, and Wells loam. Runoff from the feedlot was stored in a settling basin before flowing into VFS through a pipe. They found that VFS reduced 66% of incoming TP, 66.5% of incoming TN and no discharge of runoff was found for 90% of the feedlot runoff events. They suggested the removal of constituents from runoff was positively correlated with VFS to drainage area and negatively to rainfall depth.

Mankin et al. (2007) conducted a field experiment on grass-shrub riparian buffer system (RBS) to measure the impact of vegetation type on the reduction of runoff water, sediment, P, and nitrogen. The study included three types of RBS; namely natural succession grass (NSG), natural grass with American plum (*Prunus american*) (NG/P), and NSG with American plum (NSG/P) on Hobbs silt loam soil. The NSG consisted of cool season grasses with downy brome (*Bromus japonicus*) while natural grass consisted

of warm season perennial grasses such as Indian grass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*). Simulated rainfall was used in the RBS to quantify effectiveness. They determined that RBS was efficient in reducing mass of runoff (>77%), sediment (>99%), and TP (>85%) when compared to respective incoming masses of these parameters to RBS. Infiltration played a key role in reducing sediments and vegetation type was important in removal of TP in their experiment.

Hay et al. (2006) conducted a study to investigate the efficiency of VFS in reduction of nutrients, sediment, and pathogens from a flood irrigated pastureland on a Luvisol soil. Their VFS composed of perennial ryegrass (*Lolium perenne*), orchardgrass (*Dactylis glomerata*), white clover (*Trifolium repens*), and strawberry (*Trifolium fragiferum*). Their results suggested significant decrease in TSS, TKN, Poly-P, and NH_3 , compared to control plots; however they did not find a constant effect of VFS on reduction of these constituents. Their data suggested a positive correlation between runoff rate and pollutant loads in runoff.

Lim et al. (1998) determined the effect of VFS length (6.1 m, 12.2 m, and 18.3 m) in quantifying nutrient reductions, from a plot treated with cattle manure. Their experimental plot was established on a Maury silty loam soil. They applied cattle manure on the upper portion of their plot while the lower portion was covered with Kentucky 31 tall fescue (*Festuca arundinacea* Schreb). Simulated rainfall was used to generate runoff from the plot. Their results showed that fescue VFS reduced significant amount of $\text{PO}_4\text{-P}$, TSS, TS, and TP from the incoming runoff. They suggested that most of the P in the runoff was present in soluble form rather than particulate form, so

infiltration played a vital role in reduction of phosphorus from runoff. Out of three VFS lengths, 6.1 m was the most effective length in controlling the mass transport of all the constituents ($\text{PO}_4\text{-P}$, TSS, TS, and TP) from runoff.

Dosskey et al. (2007) conducted a study to evaluate the changes in effectiveness of VFS in removal of nutrients since its establishment on a Sharpsburg silty clay loam soil. They used simulated runoff along with agricultural chemicals and sediments (sand, clay, organic matter) to compare the efficiency of new grass and new forest with a reference plot. The reference plot consisted of old grass along with sorghum and soybeans. The “newgrass” plot was composed of switchgrass (*Panicum virgatum* L. var. Blackwell), tall fescue (*Festuca arundinacea*), smooth brome (*Bromus inermis*), wild buckwheat (*Polygonum convolvulus*), common lambquarters (*Chenopodium album*), field pennycress (*Thlaspi arvense*), and foxtail (*Setaria* spp.). The new forest consisted of same grasses in “newgrass” plot, along with bush honeysuckle (*Lonicera maackii*), goldren current (*Ribes aureum*) and fast growing trees, eastern cottonwood (*Populus deltoids* Bartr) and silver maple (*Acer saccharinum* L.). They found that initially new grass and new forest plots were worse than the reference plot for reduction of nutrients and runoff. But by the third growing season (3-yr of establishment), both newly established VFS performed similar to the reference plot.

Srivastava et al. (1996) determined the relationship between pollutant source area length (6.1m, 12.2m, and 18.3 m) to VFS area length (18.3 m, 12.2 m, and 6.1 m) in a field study. They established experimental plot on Captina silt loam soil and applied poultry manure on the top portion of the plot while the bottom portion was covered with

fescue (*Festuca arundinacea* Schreb.) grass. A rainfall simulator was used in their field plots just after the application of manure to generate runoff. Their data suggested that effectiveness of VFS in reduction of incoming $\text{PO}_4\text{-P}$ and TP ranged from 22-82% and 21-66%, respectively. They found that concentration of pollutants ($\text{NH}_3\text{-N}$, TKN, $\text{PO}_4\text{-P}$, and TP) decreased with an increase in the VFS length but mass of pollutants in the runoff remained unchanged.

Goel et al. (2004) evaluated the effectiveness of different types of vegetative covers in reduction of nutrients and sediments in the runoff from a cropland treated with cattle manure. Experimental plots were constructed on a Guelph loam soil having four different types of vegetation namely perennial rye grass, sod (Kentucky blue grass), a mixed grass species, and no vegetation. They applied slurry with water at the upper part of VFS to quantify VFS effect to improve water quality. They observed that more than 90% of incoming TSS and TP were reduced by all types of VFS both in concentration and on mass basis. Sod grass filter strip was most efficient in reduction of both sediment and soluble P as compared to other types of vegetation. They also determined that switchgrass was efficient in reduction of coarse sediment while switch grass-woody plant treatment was more effective in trapping clay and soluble nutrients.

Komor and Hansen (2003) measured the efficiency of grass covered FS on Adolph silt loam and Normania loam soil. In their experiment, runoff from feedlots was stored in a settling basin before going into grass VFS. They found that the grass FS reduced 14- 75% of incoming P, and 24-82% of incoming dissolve P in the runoff.

Dillaha et al. (1985) measured the efficiency of orchardgrass VFS in reducing sediment and P in runoff from a field applied with dairy manure. They used simulated rainfall on eroded Groseclose silt loam soil. They found that VFS was more efficient in reduction of sediment than P in runoff from a feedlot. They suggested that VFS was more effective in reduction of both sediment and nutrients from uniform flows than from concentrated flows and VFS was not effective in reduction of soluble P from runoff.

The effectiveness of various VFS cover types for different pollution sources under different climatic conditions was summarized in table 1.

Table 1. Performance of VFS in sediment and nutrient removal

Reference	Source of Pollution	Cover Type	Soil Type	Source of Runoff	%Reduction of TSS	%Reduction of TP	%Reduction of Soluble P
Dillaha et al. (1985)	Dairy manure	orchard grass	Groseclose silt loam	simulated	Effective*	less effective*	not effective*
Hussein et al. (2007)	-	vetiver grass	Vertisol	simulated	Effective*	–	–
Komor and Hansen (2003)	Feedlots	grass	Adolph silt loam and Normania loam	feedlot runoff	14 to 75	–	24 to 82
Goel et al. (2004)	Cropland	perennial rye grass, Kentucky blue grass	Guelph loam	Simulated	> 90	> 90	–
Srivastava et al. (1996)	Poultry manure	fescue	Captina silt loam	Simulated	effective*	21to 66	22 to 82
Dosskey et al. (2007)	Crop land	switch grass tall fescue smooth brome, others	Sharpsburg silty clay loam	Simulated	effective*	effective*	effective*
Lim et al. (1998)	Cattle manure	Kentucky-31 tall fescue	Maury silty loam	Simulated	75	75	75
Hay et al. (2006)	Pasture land	Strawberry white clover Ryegrass	Luvisol	Flood irrigation	effective*	–	effective*
Mankin et al. (2007)	Artificial Source	american plum downy brome	Hobbs silt loam	Simulated	99	85	–
Mankin et al. (2006)	Feed lot	brome	sandy loam silt loam well loam	Feed lot runoff	effective*	65.9	–

Table 1. (Continued)

Reference	Source of Pollution	Cover Type	Soil Type	Source of Runoff	%Reduction of TSS	%Reduction of TP	%Reduction of Soluble P
Kim et al. (2006)	Milk house	tall fescue timothy	Barbour and series Lackawanna	Milk house runoff	–	–	Less effective*
Mankin and Cairo 2003)	Feed lot	fescue	Newtonian silt loam		85	84	–
Abu-Zreig et al. (2003)	Crop land	perennial rye grass red fescue	silt loam	Simulated	84	61	–
Dillaha et al. (1989)	Crop land	orchard grass	Groseclose silt loam	Simulated	84	79	–
Chaubey et al. (1994)	Swine manure	fescue	Captina silt loam	Simulated		67	65
Schellinger and Clausen (1992)	Dairy barnyard	kentucky tall fescue rye grass kentucky bluegrass	Massena silt loam Kingsbury silty clay loam	Dairy barnyard runoff	33	12	
Lee et al. (1999)	Cropland	switch grass brome grass, timothy fescue	Coland soil	Simulated	66	37	34
Blanco-Canqui et al. (2004)	Fertilizer	switch, gama indian grass big bluestem gray-head cornflower	Mexico silt loam	Simulated	78	–	37
McFarland and Hauck (2004)	manure	coastal bermudagrass sorghum, winter wheat	Duffau soil Windthorst	natural	–	61	51
Patty et al. (1997)	Cultivated plot	rye grass	hydromorphic silt loam	Simulated	87 to 100	–	22 to 89
Schellinger and Clausen (1992)	Dairy barnyard	kentucky tall fescue ryegrass kentucky bluegrass	Massena silt loam Kingsbury silty clay loam	Dairy barnyard runoff	33	12	

*Qualitative assessment is provided

OBJECTIVES

Researchers 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 soil types and under various climatic conditions, most of them concluded that VFS is an effective BMP to control the excess nutrient issues, in runoff from different source types (livestock manure, crop field, forest area). In Texas, few studies have looked at performance of VFS in controlling nutrients from runoff using different varieties of plant covers. Most studies have evaluated the performance of VFS by using simulated rainfall; hence, additional research is required to identify the varieties of vegetative covers suitable for VFS under natural rainfall condition. Therefore, the objectives of this study were as follows:

- 1) To assess the influence of various vegetative cover types (warm season grass, cool season grass, warm season forb, and coastal Bermuda) on sedimentation and on P transport in the runoff from waste application fields under natural rainfall events.
2. To recommend vegetative covers suitable as VFS for effective reduction of P mobility in the runoff throughout the year.

To achieve these objectives, runoff from different treatment plots under natural rainfall events was collected and soil and plant tissue were analyzed for P content. The distinguish feature of this study was examining the influence of six varieties of plant covers simultaneously in this study area, in reducing runoff P and sediment under natural rainfall condition. The other distinguished features of this study were no application of

dairy effluent after establishment of treatment plots and establishment of smaller treatment sub-plots in order to minimize temporal variation.

METHODOLOGY

Experimental site



Figure 4. Location of experimental plot in Erath County, Texas

The experimental site for this study was located at a dairy landscape in Erath County near Stephenville, in east central Texas (fig. 4). The study was conducted on an improved pastureland that previously received dairy lagoon effluent runoff through a center pivot irrigation system. The experimental plots (5 m × 5 m) were established on a Windthorst fine sandy loam soil (fine, mixed, thermic, Udic Paleustalf).

Field plot set-up

At the experimental site, 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.

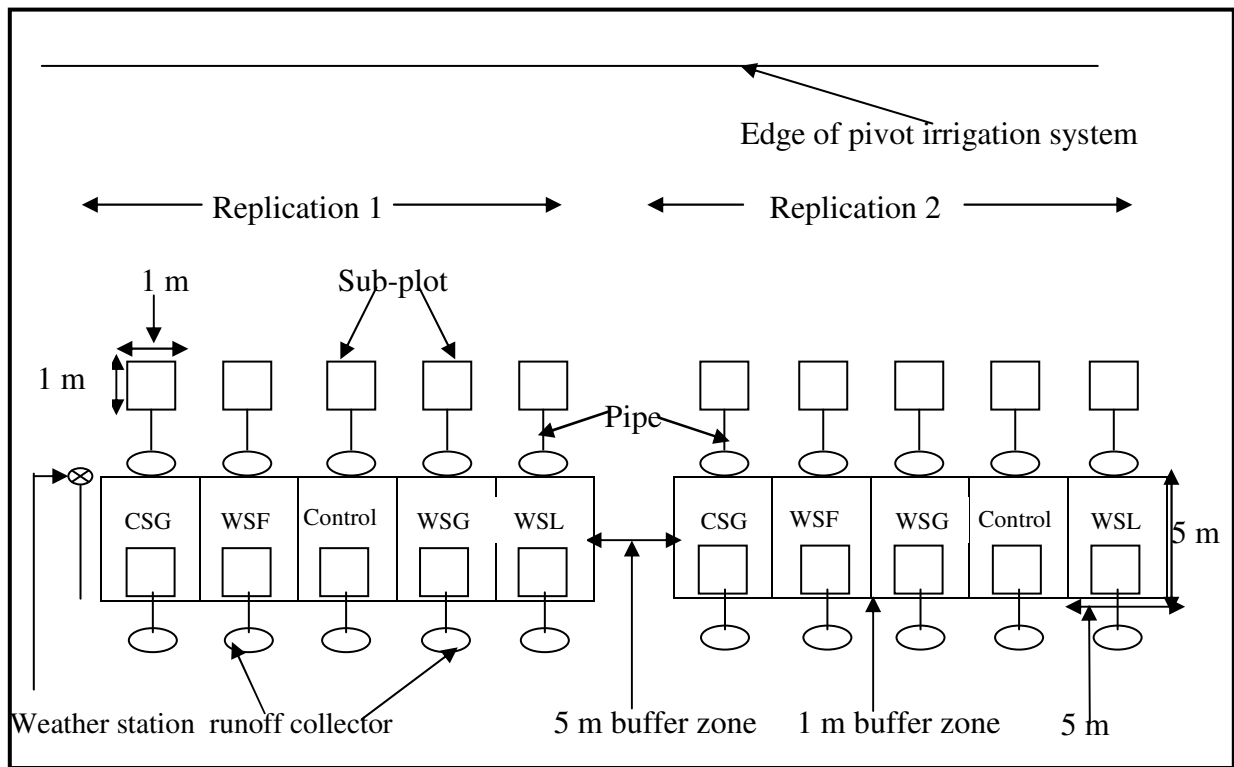


Figure 5. Schematic of field plots in the study area, 2005- 2008

After the removal of existing vegetation, ten plots (5m x 5m) were marked and the positions of 1m x 1m sub-plots were identified. As shown in figure 5, cool season grass (CSG), warm season grass (WSG), warm season forb (WSF), warm season legume (WSL), and control treatments, each having two replications, were established randomly on ten plots. The two replications (R1 and R2) were separated by a 5 m buffer zone (fig. 5) and each plot within the replications was separated by a 1 m margin in order to avoid treatment edge effect. A 1 m \times 1 m sub-plot with a runoff conveyance and collection system was established on the upstream and downstream margins of each treatment replication (figure 5).

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 collection system through plastic tubing.

Runoff conveyance and collection system

The runoff collection system was installed inside the ground and the distance was kept within 1 m from each sub-plot. At 0.5 m from the downstream edge of each sub-plot, a 61 cm diameter hole (fig.6 a) was augured for a runoff conveyance and collection system. The bottom of the hole was compacted and leveled with a hand tamper for proper positioning of a 113 L barrel to collect runoff from the sub-plot. A 1.2 m and 46 cm diameter culvert (fig. 6 b) was installed into the hole to prevent the hole from collapsing.

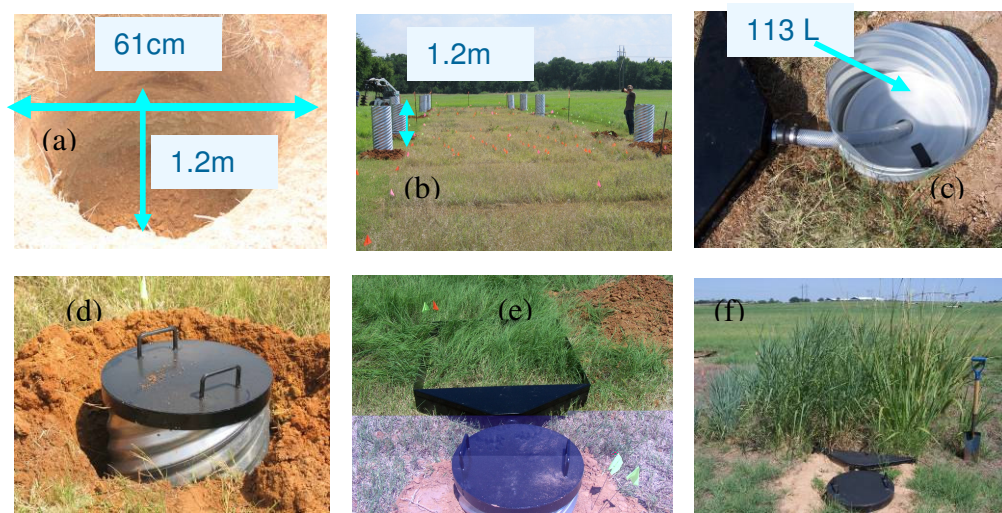


Figure 6. Experimental field plot set-up and runoff collection system

The capacity of the barrel placed inside the culvert was sufficient to hold up to 7.5 cm of runoff from a 25-yr, 24-hr rainfall from the sub-plot. This estimated was based on the hydrologic soil conditions and land use management using SCS curve number (USDA-NRCS, 1972). The container was covered by a plastic lid (fig. 6 c) and a hole was drilled in the center of the lid to insert a 5 cm reinforced flexible tube into the barrel. The other end of the pipe was connected to a custom-built v-shaped metal gutter installed at the down stream end of the sub-plot. The gutter and the culvert were covered with metal lids to prevent the entry of rainfall and external water into the barrel (fig. 6 d and e). To convey runoff from the sub-plot to the barrel, all the runoff collection and conveyance systems were positioned and installed perpendicular to the direction of the flow of water from their respective sub-plots. Additionally, a weather station was

installed next to the field plots (fig. 5) to record rainfall intensity and amount at the experimental site.

Treatment description

The plant materials for this study consisted of different types of grasses, legumes, and a forb. Grasses consisted of cool season grass (CSG) and warm season grass (WSG), whereas legume consisted of cool season legume (CSL) and warm season legume (WSL). Warm season forb (WSF) was the only forb used in this study.

The CSG consisted of Virginia wildrye (*Elymus virginicus*), western wheatgrass (*Elytrigia smithii*), tall fescue (*Festuca arundinacea*), and Jose tall wheatgrass (*Agropyron elongatum*). The CSG treatment plants were established in May 2005 by both transplantation and broadcasting methods and the plant density was 11 plants/m². After planting, only Virginia wildrye survived, but severe drought from May 2006 to May 2007 inhibited its growth. Spring season is the active growth period for Virginia wildrye.

The WSG consisted of switchgrass (*Panicum virgatum*), Indiangrass (*Sorghastrum nutans*), and gamagrass (*Tripsasum dactyloides*). These treatment plants were established in May 2005 by transplantation and the plant density was 2 plants/m². All plants survived and maintained a healthy appearance throughout the study period. Summer season is the active growth period for WSG.

The CSL consisted of hairy vetch (*Vicia villosa*), rose clover (*Trifolium hirtum*), and arrowleaf clover (*Trifolium vesiculosum*). Transplantation was the planting method for this treatment established in May 2005 whereas the planting density was 4 plants/m².

Plants in this treatment did not survive due to the drought that resulted in less available soil moisture for plant growth. Hence these plots were reassigned as control plots throughout the course of the study and used as reference plots with no vegetation for runoff control and P extraction.

The WSL consisted of Illinois bundleflower (*Desmanthus illinoensis*) and Prairie Acacia (*Acacia angustissima*). These treatment plants were established in August 2005 through transplantation and the planting density was 4 plants/m². Due to the poor stand density of WSL, the CSL treatment plants were planted to WSL treatment plots in order to provide better coverage in the plots, however these treatment plots did not establish well and were covered with CB and other weedy species common to the area.

The WSF treatment planted in May 2005 consisted of only perennial sunflower (*Helianthus maximilliana*) and survived throughout the study period with good plant coverage. Transplantation was the only planting method and the planting density was 2 plants/ m². Summer and fall are active growth periods for this treatment plant.

Coastal Bermuda grass (*Cynodon dactylon*) was the only preexisting cover type which was used in this study. This treatment is active during summer season.

Sample collection and laboratory analysis

Runoff samples

After a runoff producing rainfall event, the barrel from each runoff 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. If the collected runoff samples from the treatment plots were less than 1 L, then those samples were sent for analysis of TP to the soil, water, and forage testing laboratory (SWFTL) in the Soil and Crop Department at Texas A&M University, College Station.

The EPA method no. 160.2 (Budde, 1995) was used for analysis of TSS. In this method a well mixed runoff sample was filtered through a 0.45 micron glass fiber filter and the unfiltered residue was heated at 103-105° C until a constant weight achieved. The calculation for TSS was done using the equation 1.

$$\text{TSS (mg/l)} = [\text{weight of unfiltered residue (mg)} / \text{volume of sample (ml)}] \times 1000 \quad (1)$$

For laboratory analysis of TP, the EPA method 365.4 was used. First the runoff sample was heated in a block digester at 380° C and digested with sulfuric acid (H₂SO₄), potassium sulfate (K₂SO₄), and mercuric sulfate (HgSO₄) for two and half hours, then the sample was cooled and diluted with distilled water to 25 ml, finally calorimetric analysis was done by comparing sample peak heights with the standard curve to determine the amount of phosphorus.

Orthophosphate (SOP) was determined by EPA method 365.2, in this method a dilute solution of phosphorus was reacted with ammonium molybdate [(NH₄)₆MO₇O₂₄ *4 H₂O] and antimony potassium tartrate (C₈H₄K₂O₁₂Sb₂ *3H₂O) in presence of sulfuric acid (H₂SO₄) medium to form an antimony-phospho-molybdate complex.

Orthophosphorus in the solution formed blue color which was measured through color absorbance at 650 nm with a spectrometer.

Soil samples

Soil samples were taken from each treatment plot during the establishment of treatment plants. Four samples were taken from the surface to 8 cm depth from each treatment plot. Samples from within a treatment replication were mixed and one composite sample per replication for treatment was sent to the laboratory for analysis of TP and SOP.

Soil TP

Soil samples were air dried at 25 to 30° C and crushed to pass 2 mm sieve. After that, 2 gm of soil was placed into an extraction bottle and 25 ml of Mehlich-3 extracting solution was added. Then the solution was shaken for 5 minutes at 200 rpm at room temperature between 24 to 27° C. The solution was filtered through a Whatman no. 42 filter paper and analysis of phosphorus was done using Spectro Ciros ICP-AES at 178 nm wave length.

Soil SOP

The 20 ml of deionized water was added with 2 gram of soil sample in a bottle and it was shaken for 1-hr. Then the solution was centrifuged for 10 minutes at 6000 rpm. After that, the solution was filtered through a Whatman no. 42 filter paper for analysis of SOP at 178 nm wave length using Spectro Ciros ICP-AES. Two drops of hydrochloric acid (HCL) were added to the filtered solution before analysis of SOP through Spectro Ciros ICP-AES in order to avoid precipitation of P.

Forage samples

Forage samples were collected in 2007 from three different location of each buffer zone of a replicated treatment plot (fig. 5) using a 0.4 m² wooden sampling frame and a uniform cutting height was maintained through the harvesting. The fresh weight of forage samples was measured in order to obtain forage yield on a dry matter basis. Then each sample was placed in an oven at 55°C until no change in the dry weight of a sample was observed. The percentage of moisture content was obtained by dividing dry weight of each sample by fresh weight. After that, a composite sample was prepared from three sub-samples collected from each buffer zone (two composite samples per treatment) and analyzed for TP (Texas Agricultural Extension Service, 1980) in the laboratory. First 1 ml of sample was added to 12 ml of color developing solution which is a combination of 0.5 g of ammonium molybdate $[(\text{NH}_4)_6\text{MO}_7\text{O}_{24} \cdot 4 \text{H}_2\text{O}]$, 5.5 ml of concentrated sulfuric acid (H_2SO_4), 5 ml of antimony potassium tartrate solution ($\text{C}_8\text{H}_4\text{K}_2\text{O}_{12}\text{Sb}_2 \cdot 3\text{H}_2\text{O}$), 1 g ascorbic acid ($\text{C}_6\text{H}_8\text{O}_6$), and distilled water. Then the solution was digested in Kjeldahl nitric acid digester for 45 minutes at room temperature. The TP was determined using standard curve through a UV/ VIS spectrometer at 880 nm wavelength.

Statistical analysis

Statistical analysis to compare treatment effects for different parameters from both runoff and plant tissue data was conducted using analysis of variance procedure (ANOVA) in SPSS (Statistical Package for Social Sciences). First, significant differences for parameters among treatment were checked with an F-test, then Tukey's Honestly significant difference (HSD) method was used to compare treatment means for

runoff mass, TSS, TP, and SOP. Means were considered significantly different from one another at $P < 0.05$ level of significance. During the data analysis, a zero (0) value was assigned to all parameters (runoff mass, TP, SOP, and TSS) of treatments having no runoff samples for a given rainfall event.

RESULTS AND DISCUSSION

Precipitation in the study area

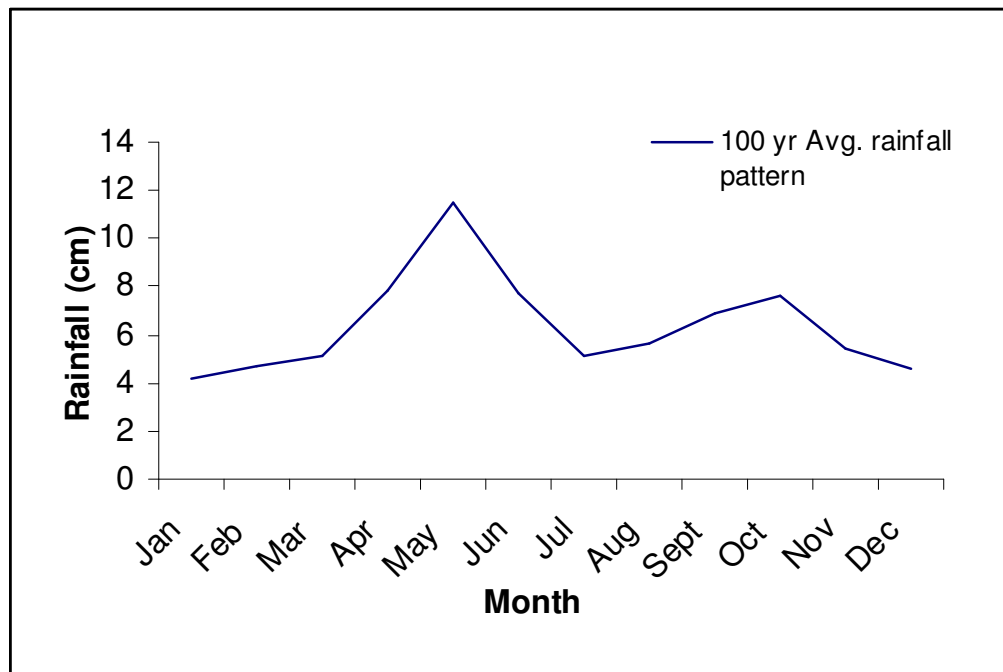


Figure 7. Historical rainfall pattern in the study area

The bi-modal curve in figure 7 represents the 100-yr average historical rainfall pattern in the study area (Texas AgriLife Research, 2008). The precipitation is generally low during early spring (January-March) peaking by late May, followed by a similar pattern of low rainfall during late summer (July-September) and peaking again in late October. However, during the course of this study; from June 2006 to April 2007 and September 2007 to February 2008, below normal precipitation was observed (fig 8).

Hence, insufficient or no water was collected in the barrel to sample various parameters from the runoff from any of the sub-plots from June, 2006 to April, 2007.

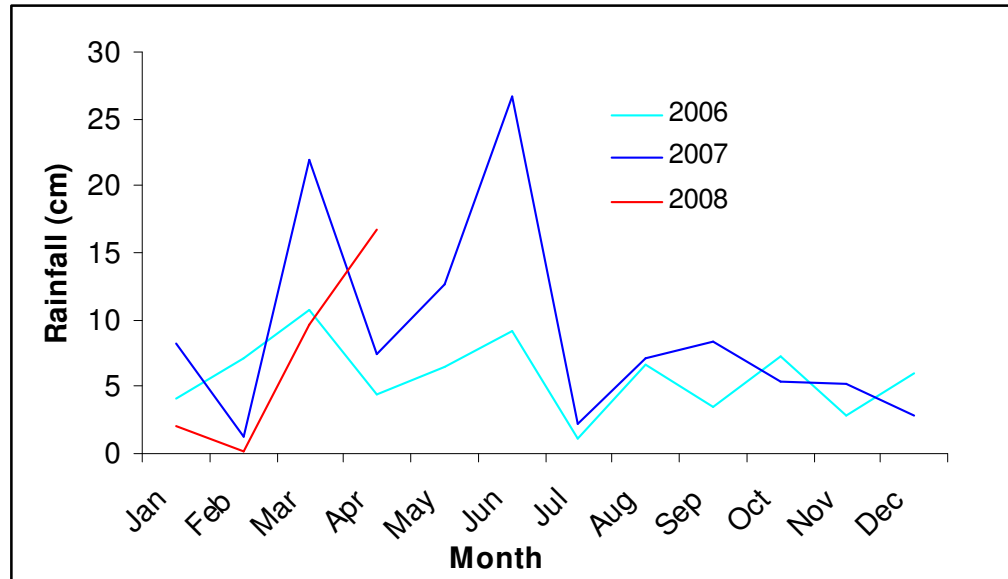


Figure 8. Rainfall pattern in the study area during the study period

Table 2 shows the dates and amounts of 22 runoff generating rainfall events during the course of this study at the experimental site. The greatest amount of rain (11.4 cm) fell on March 20, 2006; whereas the least amount of rainfall (0.66 cm) occurred on August 31, 2007.

Table 2. Rainfall data of the experimental site

Date	Rainfall (cm)
3/20/2006	11.4
4/20/2006	4
4/29/2006	5.4
5/03/2006	4
5/04/2006	2
5/04/2007	3
5/11/2007	4
5/30/2007	3.4
6/07/2007	5.6
6/15/2007	2
7/30/2007	2.5
8/20/2007	4.5
8/31/2007	0.66
9/04/2007	1.6
9/11/2007	3.4
2/13/2008	1.5
2/18/2008	4.3
3/04/2008	1.8
3/07/2008	2
3/11/2008	1.2
3/19/2008	8
4/11/2008	2.7

Soil TP and SOP

At the beginning of the study, soil samples were taken from all treatment plots to determine TP and SOP in the top 8 cm layer. As shown in table 3, soil TP concentrations varied from 28.6 to 44.9 mg/kg; whereas SOP concentrations varied from 5 to 9 mg/kg among treatments at the experimental site. The TP was the greatest in the WSG treatment plots followed by CB, control, WSF, and CSG treatment plots. The SOP in the control treatment plots was the 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 3. Soil TP and SOP for different treatment plots

Plot	No. of samples	Mean TP (mg/kg) [a]	Mean SOP (mg/kg) [a]	SOP as % TP
Control	2	37.6 ^a ± 11.8	9 ^a ± 0.9	24
CSG	2	28.6 ^a ± 4.8	7 ^a ± 3.5	24.4
CB	4	38.8 ^a ± 13.8	5.4 ^a ± 2.3	14
WSG	2	44.9 ^a ± 17.6	5 ^a ± 0.07	11
WSF	2	35 ^a ± 7.6	6.5 ^a ± 0.6	18.5

[a] Means within the column followed by same letter are not significantly different at $P \leq 0.05$ according to analysis of variance

Analysis of variance found no significance difference among the mean concentration of TP and SOP among the treatment plots.

Plant tissue analysis

Forage samples were taken in 2007 from each treatment plot and analyzed in the laboratory to obtain the TP content extracted (up-take) by plants. The number of samples within a treatment varied depending on the number of plant species included in a treatment. As shown in table 4, the mean P up-take varied from 11.5 kg to 3.3 kg per hectare (ha) among different treatment plants. While soil TP content of WSF treatment ranked fourth (table 3) behind WSG, CB, and Control treatment plots, plant P extracted by the WSF treatment was the greatest followed by WSG, CB, and CSG treatments (table 4).

Table 4. Plant P capture from different treatments during 2007

Treatment name	No. of samples	TP(kg/ha) ^[a]
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 $P \leq 0.05$ 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. 8). In contrast, P up-take (3.3 kg/ha) for the CSG treatment was significantly lower than all other treatments. This was due to the combination of lowest soil TP and poor vegetative stand in this treatment plot compared to other treatments (table 3). The P up-take by the CB treatment was second lowest (9.3 kg/ha, table 4), but it was statistically similar to that for the WSG and WSF treatments.

Plant dry matter analysis

The dry matter (biomass) among the treatments ranged from 4794 kg/ha for WSF to 6275 kg/ha for WSG (table 5). While WSG treatment had the greatest biomass of all treatments no significant differences were found in the biomass among treatments (table 5). After treatment establishment, it was observed that WSG and WSF had denser vegetative canopies (figure on page 38) as compared to CB and CSG treatments. Except for the WSF, the biomass for all other treatments increased with an increase in the observed density of the vegetative canopies in a sub-plot (figure on page 38).

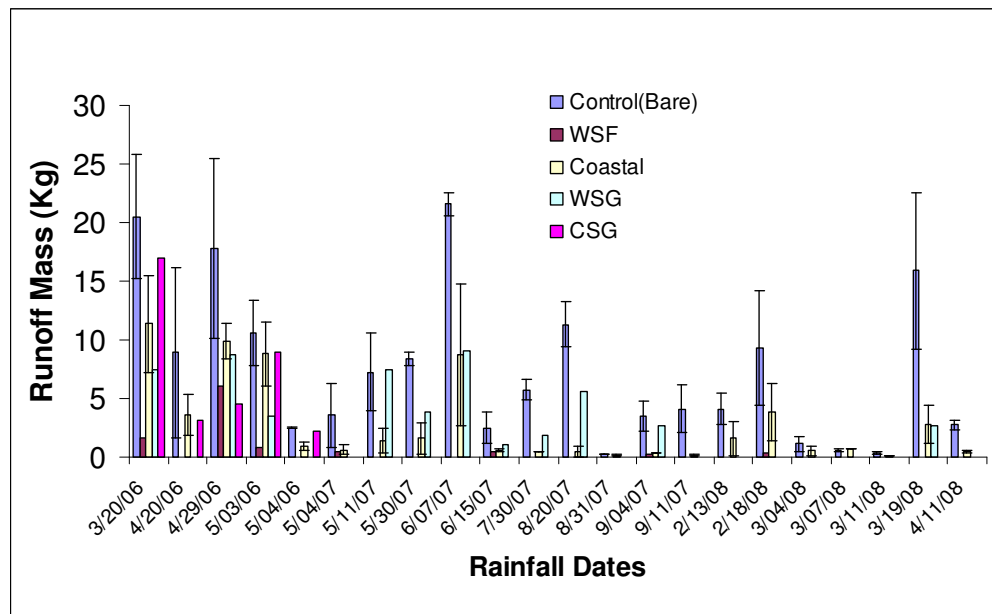
Table 5. Comparison of biomass among the treatments

Treatment name	No. of samples	Biomass (kg/ha) ^[a]
WSF	4	4794 ^a ± 1122
CSG	4	4836 ^a ± 1660
Coastal Bermuda	8	5861 ^a ± 1720
WSG	12	6275 ^a ± 954

[a] Means within the column followed by same letter are not significantly different at $P \leq 0.05$ according to analysis of variance

Treatment effectiveness for runoff control

As expected, runoff produced from a natural rainfall event was less from vegetative than the bare (control) treatment plots.



Data without error bar is from one plot of the treatment

Figure 9. Comparison of runoff mass among the treatments

Warm season forb was the most effective of all treatments in reducing runoff mass followed by WSG, CB, and CSG treatments (fig. 9). In fact, out of twenty-two rainfall events, WSF and WSG treatments produced no measurable runoff during twelve and eleven events, respectively. This was due to denser vegetative canopies of these two treatments as compared to CB and CSG treatments (fig. 10) intercepting rainfall, stronger root system, and protected soil surface from compaction due to direct rain drop impact which increased infiltration. Blanco-Canqui et al. (2004) observed that switchgrass barrier in barrier Fescue filter strip (FS) reduced more runoff mass compared to Fescue FS due to more infiltration in barrier Fescue FS than Fescue FS from a simulated rainfall because of more surface debris and deep rooting system of switchgrass in barrier Fescue FS compared to Fescue FS.

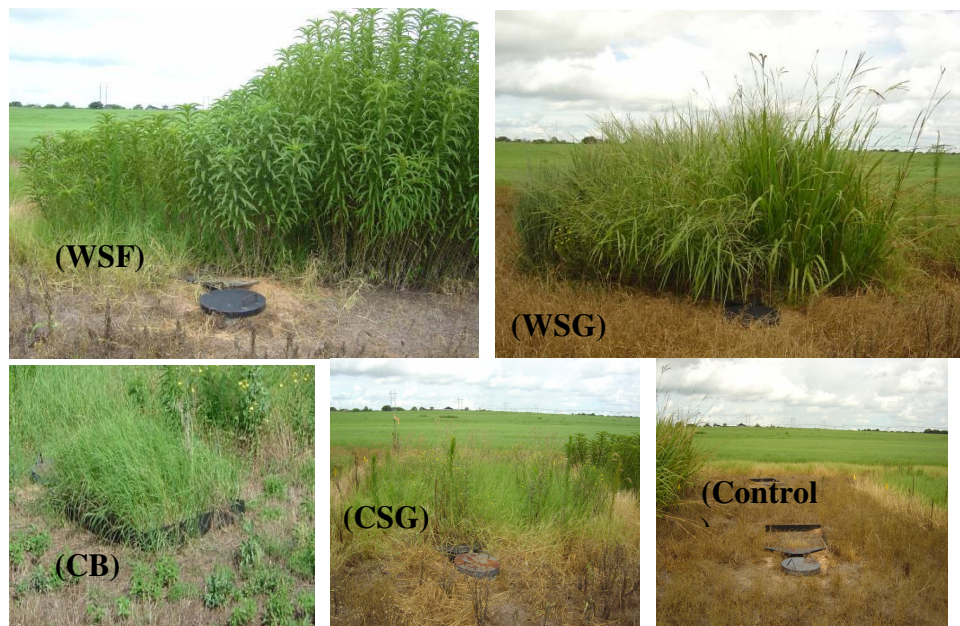


Figure 10. Comparison of vegetative covers among the treatments

The CB and CSG treatments had lesser vegetative cover than WSF and WSG treatments and that resulted into more runoff from these two treatments.

Table 6. Comparison of runoff among the treatments

Treatment name	No. of samples	Runoff mass (kg) ^[a]
Control	22	7.4 ^a ±6.5
CSG	5 ^[b]	7.2 ^a ±6
Coastal Bermuda	22	2.7 ^b ±3.5
WSG	22	2.5 ^b ±3.2
WSF	22	0.5 ^b ±1.3

[a] Means within the column followed by different letter are significantly different at $P \leq 0.05$ according to Tukey's Honestly Significant Differences

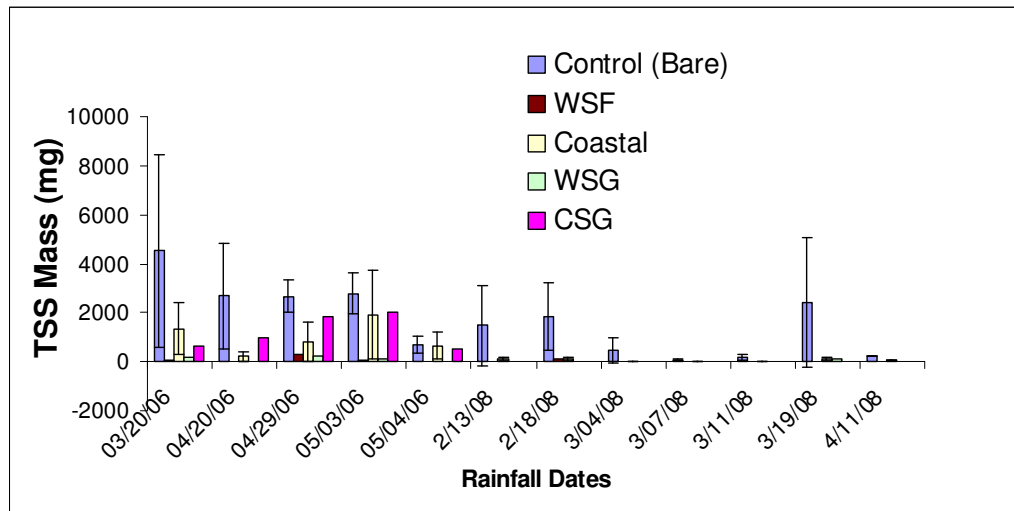
[b] The CSG treatment plot turned into weed plot after collecting 5 runoff samples

As shown in table 6, the mean runoff mass among the treatments varied from 0.5 kg for WSF to 7.4 kg for control. The WSF, WSG, and CB treatments produced significantly lesser amount of runoff compared to control and CSG treatments due to denser vegetative cover when compared to CSG or control treatments.

Treatment effectiveness for TSS

A lesser number of analyses were done for TSS compared to TP among the treatments due to less than needed (1 L) runoff mass collected from the sub-plots of each treatment after a rainfall event. All treatments were deemed effective for reducing runoff TSS when compared to control treatment (fig. 11). The reduction of sediment mass in runoff was greatest in the WSF followed by WSG, CB, and CSG treatments (fig. 11).

The reduction of sediment was nearly the same for WSF and WSG due to the extensive amount of vegetative cover of these treatments (fig. 10).



Data without error bar is from one plot of the treatment

Figure 11. Comparison of runoff TSS mass among the treatments

The denser vegetative canopies of these two treatments as compared to CB and CSG treatments intercepted more rain and reduced the runoff raindrop impact on soil causing less erosion and sediment transport in the runoff. Lee et al. (1999) also observed that a VFS of switchgrass reduced more sediment than a CSG VFS from a simulated rainfall due to differences in growth pattern between CSG and switchgrass.

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. 11).

The mean runoff TSS mass from sub-plots varied from 45 mg to 1675 mg among the treatments (table 7). The control and CSG treatments showed significantly greater

sediment in the runoff compared to other treatments due to no vegetation in control treatment and poor vegetative cover in CSG treatment compared to other treatments. In contrast, WSF and WSG treatments produced least amount of runoff TSS (45 mg and 55 mg, table 7) due to their extensive vegetative cover (fig. 10) compared to other treatments.

The mean runoff TSS in case of CB treatment was greater than WSF and WSG treatments (table 7), but it was statistically comparable to both treatments (WSF and WSG). The greater amount of runoff TSS in case of CB than WSF and WSG treatments was due to lesser vegetative cover in case of CB treatment compared to other two treatments.

Table 7. Comparison of runoff TSS mass among the treatments

Treatment name	No. of samples	Runoff TSS (mg) ^[a]
Control	12	1675 ^a ±1394
CSG	5 ^[b]	1211 ^a ±586
Coastal Bermuda	12	454 ^b ±623
WSG	12	55 ^b ±85
WSF	12	45 ^b ±83

[a] Means within the column followed by different letter are significantly different at $P \leq 0.05$ according to Tukey's Honestly Significant Differences

[b] The CSG treatment plot turned into weed plot after collecting 5 runoff samples

Table 8 presents the TSS data for all treatments on concentration (mg/l) basis. The mean TSS concentration among the treatments varied from 9 mg/l for WSG to 266

mg/l for control. The data shows that while WSF and WSG treatments significantly reduced sediment concentration (table 8) and mass (table 7) in the runoff compared to CSG, and Control treatments, the CB treatment did not significantly reduce the TSS concentration compared to the two treatments.

Table 8. Comparison of runoff TSS concentration among the treatments

Treatment name	No. of samples	Runoff TSS (mg/l) ^[a]
Control	12	266 ^a ± 138
CSG	5 ^[b]	246 ^a ± 137
Coastal Bermuda	12	203 ^a ± 364
WSF	12	28 ^b ± 48
WSG	12	9 ^b ± 13

[a] Means within the column followed by different letter are significantly different at $P \leq 0.05$ according to Tukey's Honestly Significant Differences

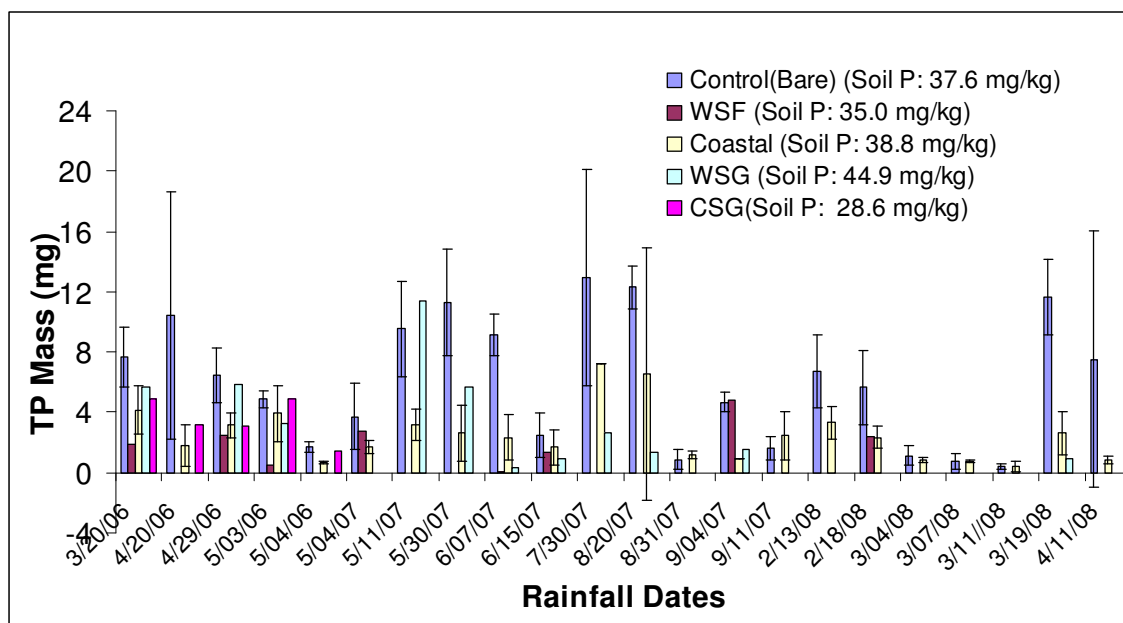
[b] The CSG treatment plot turned into weed plot after collecting 5 runoff samples

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. 12) due to the least amount of sediment in the runoff (fig. 11).

Despite the highest soil P concentration than all other treatments, WSG treatment had the second least amount of TP mass in the runoff due to the mass of runoff and sediment only higher than that from WSF treatment (fig. 12). In case of WSF and WSG

treatment, the lesser amount of runoff TP mass was due to lesser amount of runoff mass and sediment from both treatments because of denser vegetation compared to other treatments.



Data without error bar is from one plot of the treatment

Figure 12. Comparison of runoff TP mass among the treatments

Abu-Zreig et al. (2003) also observed that higher percentage of vegetation cover in case of native grass species (name not mentioned) resulted in higher phosphorus trapping efficiency (PTE) compared to other types of vegetation on a silt loam soil through sedimentation and infiltration.

Coastal Bermuda was the third most effective treatment to reduce TP in the runoff. The Soil TP concentration of CB treatment was greater than control treatment (table 3) 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.11) from CB treatment as compared to the control treatment.

The CSG treatment produced lesser TP in the runoff than the control treatment. This result was due to a combination of the lower initial soil TP (among all treatments) and lesser sediment mass from CSG treatment compared to the control treatment (table 7).

Table 9. Comparison of means of runoff TP mass among the treatments

Treatment name	No of samples	Runoff TP (mg) ^[a]
Control	22	6 ^a ±4
CSG	5 ^[b]	3.5 ^a ±1.5
Coastal Bermuda	20 ^[c]	2.2 ^b ±1.5
WSG	22	1.8 ^b ±3
WSF	21 ^[c]	0.5 ^b ±1.0

[a] Means within the column followed by different letter are significantly different at $P \leq 0.05$ according to Tukey's Honestly Significant Differences

[b] The CSG treatment plot turned into weed plot after collecting 5 runoff samples

[c] Lesser number of samples in CB and WSF compared to WSG and control was due to removal of outliers

As shown in table 9, the mass of mean runoff TP varied from 6 mg to 0.5 mg for control to WSF treatment, respectively. The lesser runoff TP for WSF and WSG treatments was due to the lesser sediment mass in runoff (fig. 11) and greater up-take of P from soil (table 4) by these two treatments compared to other treatments. In contrast, runoff TP in case of control and CSG treatments was greater due to greater sediment mass in runoff (fig.11) from these treatments and lesser soil P up-take by the CSG treatment. The runoff TP of CB treatment was greater than WSF and WSG treatments (table 9) but it was statistically similar to those two treatments.

The mean TP concentration among the treatments varied from 0.6 mg/l for WSG to 2.7 mg/l for CB (table 10). The TP concentration from WSG, CSG, and WSF plots was significantly lower than that from control and CB treatment plots, where as, statistically similar TP concentration in the runoff from CB and control was observed (table 10). The CB plots had significantly greater TP concentration than that from CSG plots. In contrast, the mass TP of CB was significantly lower due to a combination of significantly lower mass of runoff and TSS as compared to the CSG treatment.

Table 10. Comparison of means of runoff TP concentration among the treatments

Treatment name	No of samples	Runoff TP (mg/l) ^[a]
Coastal Bermuda	20	2.7 ^a ±2.6
Control	22	1.2 ^a ±0.8
WSF	21	0.68 ^b ±1.3
CSG	5 ^[b]	0.63 ^b ±0.3
WSG	22	0.6 ^b ±0.7

[a] Means within the column followed by same letter are not significantly different at $P \leq 0.05$ according to analysis of variance

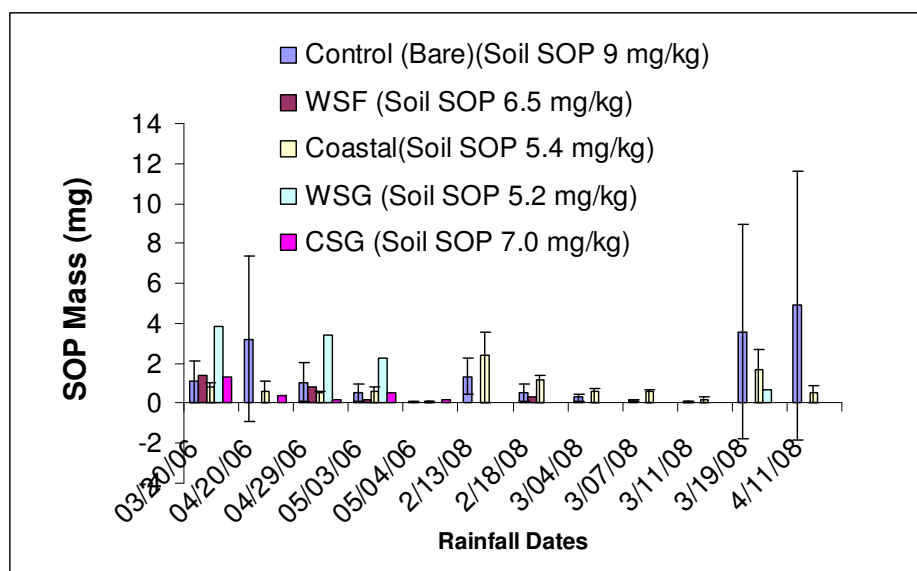
[b] The CSG treatment plot turned into weed plot after collecting 5 runoff samples

[c] Lesser number of samples in CB and WSF compared to WSG and control was due to removal of outliers

Treatment effectiveness for runoff SOP

Figure 13 illustrates soil and runoff SOP from each treatment. A lesser number of SOP analyses were done among the treatments compared to TP, due to less than needed (1 L) runoff mass collected from sub-plots of each treatment plot. The runoff from WSG treatment plots had the greatest SOP, followed by control, WSF, CB, and CSG

treatments. The WSG soil TP was the greatest of all treatments (table 3) and it had the second lowest sediment (TSS) in the runoff resulting in this trend.



Data without error bar is from one plot of the treatment

Figure 13. Comparison of runoff SOP mass among the treatments

On the other hand, the CSG treatment had the lowest runoff SOP. This resulted from lowest soil TP concentration for this treatment among all the treatments (table 3). The CB treatment had the second least amount of SOP in the runoff due to less amount of soil SOP (table 3, only greater than CSG) and the third least sediment in the runoff (fig. 11).

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 from these treatment plots compared to other treatments (fig. 13).

The control treatment had the second highest SOP mass in the runoff due to the highest soil SOP (table 3) and lack of extraction of P (table 4) from this plot compared to other treatment plots.

Table 11. Comparison of runoff SOP mass among the treatments

Treatment name	No. of runoff samples	Runoff SOP (mg) ^[a]
Control	12	1.4 ^b ±1.6
CSG	5 ^[b]	0.5 ^b ±0.5
Coastal Bermuda	12	0.82 ^b ±0.7
WSG	12	0.84 ^b ±1.5
WSF	12	0.23 ^b ±0.4

[a] Means within the column followed by same letter are not significantly different at $P \leq 0.05$ according to analysis of variance

[b] The CSG treatment plot turned into weed plot after collecting 5 runoff samples

As shown in table 11, the means of runoff SOP mass among the treatments varied from 0.23 mg to 1.4 mg. But statistically no significant difference was found for mean runoff SOP among the treatments. This trend may be due to no significant differences in soil SOP concentration among the treatments (table 3) during the establishment of treatment plots.

The SOP concentration varied from 0.07 mg/l for CSG to 1 mg/l for CB (table12). The CB treatment had significantly greater concentration of SOP in the runoff compared to other treatments (table 12).

Table 12. Comparison of runoff SOP concentration among the treatments

Treatment name	No. of runoff samples	Runoff SOP (mg/l) ^[a]
Coastal Bermuda	12	1.0 ^a ±1.0
Control	12	0.3 ^b ±0.4
WSF	12	0.2 ^b ±0.4
WSG	12	0.2 ^b ±0.3
CSG	5	0.07 ^b ±0.3

[a] Means within the column followed by different letter are significantly different at $P \leq 0.05$ according to Tukey's Honestly Significant Differences

[b] The CSG treatment plot turned into weed plot after collecting 5 runoff samples

CONCLUSIONS

To protect the water quality of the North Bosque River from sources including dairy WAFs, two TMDLs were established prompting a need for BMPs which could reduce the amount of P in the runoff from WAFs to water bodies.

In this vegetative covers study, runoff samples resulting from twenty-two natural rainfall events were collected from spring 2006 to spring 2008 from various treatment plots established on a pastureland that previously received dairy effluent. Apart from runoff samples, soil samples were collected during the establishment period of the treatment plants and forage samples were taken after 2-yr of establishing treatment plots in order to compare the efficacy of vegetative covers in reducing sediment and P in the runoff.

The results provided good evidence for controlling sediment and P in the runoff from dairy effluent application fields using well established vegetative covers. Among the treatments, WSF and WSG were most effective in reducing runoff P followed by CB, and CSG on a Windthorst fine sandy loam soil on mass basis whereas on concentration basis, the P reduction capacity was greatest in WSG followed by CSG, WSF, control , and CB, respectively.

Denser vegetative cover in these two treatments (WSG and WSF) played an important role in lessening runoff P by reducing runoff and by decreasing sediment in the runoff due to initial interception of rain and less raindrop impact on soil. Cleaner runoff was collected from these two treatment plots due to less sediment in the runoff

from both treatments. These two 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 vegetative filter strip 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 wild life habitat or could be used as biomass to produce energy or fodder for livestock.

FUTURE WORK

Results from this study suggested that WSF and WSG (sunflower and mixed warm season grass, respectively) were most effective treatments in reducing P and sediments in runoff resulting from natural rainfall events. Hence, the next step is to establish these two treatments separately as VFS below effluent ponds or WAFs in order to determine the efficiency of these two treatment vegetation types in reducing runoff P and sediment. Different combinations of widths and lengths of these VFS should be installed and studied for their effectiveness for a given ratio of effluent area to VFS area.

Due to the inherent spatial variability of experimental site, sometimes, especially during low rainfall events runoff data for only one of the two replications within a treatment was collected. In this study, only two replications were assigned to each treatment. Therefore, future studies should include three or four replications of vegetative covers to avoid similar situation.

During three years of this study, most of the runoff samples were collected in summer and spring season. A few samples were collected during winter season. The results obtained in this study reflect the effectiveness of treatment plants only during summer and spring seasons but not for winter season. Hence simulated rainfall should be considered during the drought period in order to observe the effect of treatment plants during all seasons.

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- Presented “Efficacy of different plant cover in reduction of phosphorous (P) from dairy waste application fields” in 2007 National Conference on Agriculture and the Environment, Monterey, California, November 7- 9, 2007
- Presented “Efficacy of vegetative filter strips in reducing phosphorous (P) in runoff from dairy waste application fields” in 15th National Non-Point Source (NPS) monitoring workshop, Driskill Hotel, Austin, August 27- 30, 2007