Reprinted from the *Journal of Soil and Water Conservation*, Volume 63, Number 4. © 2008 by the Soil and Water Conservation Society. All rights reserved.

Sediment and phosphorus removal from simulated storm runoff with compost filter socks and silt fence

L.B. Faucette, K.A. Sefton, A.M. Sadeghi, and R.A. Rowland

Abstract: In 2005, the US Environmental Protection Agency National Menu of Stormwater Best Management Practices, National Pollutant Discharge Elimination System Phase II for Construction Sites, listed compost filter socks as an approved best management practice for controlling storm runoff and sediment on construction sites. Like most new technologies used to control sediment on construction sites, little has been done to evaluate their performance relative to conventional sediment control barriers, such as silt fences. The objectives of this study were (1) to determine and compare the sediment removal efficiency of silt fence and compost filter socks, (2) to determine if the addition of polymers to compost filter socks could reduce sediment and phosphorus loads, (3) to determine relationships between compost filter media particle size distribution and pollutant removal efficiency and hydraulic flow rate. Simulated rainfall was applied to soil chambers packed with Hatboro silt loam on a 10% slope. All runoff was collected and analyzed for hydraulic flow rate, volume, total suspended solids (TSS) concentration and load, turbidity, and total and soluble P concentration and load. Based on 7.45 cm h^{-1} (2.9 in hr^{-1}) of simulated rainfall-runoff for 30 minutes duration, bare soil (control) runoff TSS concentrations were between 48,820 and 70,400 mg L^{-1} (6.5 oz gal^{-1} and 9.4 oz gal^{-1}), and turbidity was between 19343 and 36688 Nephelometric Turbidity Units. Compost filter sock and silt fence removal efficiencies for TSS concentration (62% to 87% and 71% to 87%), TSS load (68% to 90% and 72% to 89%), and turbidity (53% to 78% and 54% to 76%) were nearly identical; however with the addition of polymers to the compost filter socks sediment removal efficiencies ranged from 91% to 99%. Single event support practice factors (P factor) for silt fence were between 0.11 and 0.29, for compost filter socks between 0.10 and 0.32, and for compost filter socks + polymer between 0.02 and 0.06. Total and soluble P concentration and load removal efficiencies were similar for compost filter socks (59% to 65% and 14% to 27%) and silt fence (63% and 23%). Although when polymers were added to the filter socks and installed on phosphorus fertilized soils, removal efficiencies increased to 92% to 99%. Compost filter socks restricted hydraulic flow rate between 2% and 22%, while the silt fence restricted between 5% and 29%. Significant correlations ($p < 0.05$) were found between middle range particle sizes of compost filter media used in the filter socks and reduction of turbidity in runoff; however, hydraulic flow rate was a better indicator (stronger correlation) of total pollutant removal efficiency performance for compost filter socks and should be considered as a new parameter for federal and state standard specifications for this pollution prevention technology.

Key words: best management practice—compost filter socks—phosphorus—sediment

Due to Phase II enforcement of the National Pollutant Discharge Elimination System for storm water discharge from construction activities in 2003, evaluating the effectiveness and performance of sediment control devices has become increasingly important. As states begin to revise their erosion and sediment control manuals to reflect new information on best management practices (BMPs), many are requiring that erosion and sediment control practices meet a minimum performance standard (South Carolina Department of Health and Environmental Control 2005).

Silt fence is the current industry standard used for sediment control in construction activities; therefore, its performance has been widely evaluated (Wyant 1981; Fisher and Jarret 1984; US Environmental Protection Agency [USEPA] 1993; Barrett et al. 1998; Britton et al. 2000). In a study evaluating the sediment trapping efficiency of silt fence, Wishowski et al. (1998) observed that as sediment particle sizes decrease, trapping efficiency declines. Barrett et al. (1998) adds that most studies reporting sediment removal efficiencies for silt fence are somewhat overstated since many have used a disproportionately large fraction of sand particles with relatively low sediment-laden concentrations of storm water runoff. They observed that 92% of the total suspended solids (TSS) were clay and silt, grain sizes an order of magnitude smaller than the openings in the silt fence fabric, and due to very low settling velocities were normally not removed by sedimentation (Barrett et al. 1998). Barrett et al. (1995) reported that silt fence sediment removal efficiency is a result of increased ponding behind the silt fence. A similar study by Kouwen (1990) concluded that excessive ponding of runoff is due to eroded sediment clogging the silt fence filter fabric. Barrett et al. (1998) later discovered that sediment removal efficiency by silt fence was correlated to runoff detention behind the silt fence, not the filtration of the fabric. Because there is no standard test method to evaluate sediment control barriers, the investigators have chosen to compare experimental treatments to silt fence since it is widely accepted as a sediment control BMP.

In 2005, the USEPA National Menu of BMPs for National Pollutant Discharge Elimination System Phase II listed compost filter socks as an approved BMP for controlling storm runoff on construction sites (USEPA 2006). In a study conducted at the University of Georgia using three simulated storm events, on a 10% slope, filter berms reduced total solids loads by 35% and exhibited 21% greater runoff flow rates

L. Britt Faucette is an ecologist and director of research, Filtrexx International LLC, Decatur, Georgia. **Kerry A. Sefton** is a biologist and **Ali M. Sadeghi** is a soil physicist at the Hydrology and Remote Sensing Laboratory, USDA Agricultural Research Service, Beltsville, Maryland. **Randy A. Rowland** is a plant physiologist at the Environmental Microbial Safety Laboratory, USDA Agricultural Research Service, Beltsville, Maryland.

compared to silt fence on a disturbed sandy clay loam subsoil (Faucette et al. 2005). The compost filter socks used for this study may be considered contained filter berms. Under bench scale conditions on a 3:1 slope, using simulated runoff with a total sediment concentration of 3,000 mg L^{-1} (3,000 ppm), Faucette and Tyler (2006) reported an average sediment removal efficiency of 98% for 10 compost filter socks. Suspended solids concentration and turbidity (Nephelometric Turbidity Units [NTUs]) reduction averaged 70% and 55%, respectively, over three runoff events. Table 1 summarizes selected studies on sediment removal performance of silt fence and compost filter socks.

Table 1

Sediment removal efficiencies for silt fence and compost filter socks.

Sediment control barriers	Sediment removal efficiency	Reference
Silt fence	3% turbidity	Horner et al. 1990
Silt fence	0% turbidity	Barrett et al. 1998
Silt fence	0% to 20% clay	USEPA 1993
Silt fence	50% silt	USEPA 1993
Silt fence	80% + sand	USEPA 1993
Compost filter sock	98% total solids	Faucette and Tyler 2006
Compost filter sock	70% suspended solids	Faucette and Tyler 2006
Compost filter sock	55% turbidity	Faucette and Tyler 2006

All federal and state agency standard specifications for compost filter socks (and filter berms) include a parameter for filter media particle size distribution. It has been assumed that this particle size distribution represents the optimum characteristic that predicts affective removal of pollutants from storm runoff and allows for sufficient hydraulic flow though and permittivity of the filter sock. It is the particle size distribution within these sediment control barriers that create macro- and micro-pores that likely influence flow through and sediment trapping mechanisms.

In a study that surveyed 45 different compost filter media used in filter socks, Faucette et al. (2006) reported that under bench scale conditions there was a linear relationship in hydraulic flow though rate and percent of pollutants passing through the filter media. Investigators reported the lower the flow through rate of the filter media, the higher the resultant suspended solids removal and turbidity reduction efficiency. This may be due to sediment deposition generated by runoff flow restriction or perhaps fewer pores and smaller pore spaces led to an increased ability to physically trap small sediments in runoff.

Faucette et al. (2006) reported a correlation in percent of compost filter media particle sizes over 9.5 mm (0.375 in) and under 6.3 mm (0.25 in) and hydraulic flow through rate, under bench scale conditions using synthetic runoff. The greater the percent of particle sizes over 9.5 mm (0.375 in), the higher the flow through rate; conversely the greater the percent of particle sizes below 6.3 mm (0.25 in) the lower the flow though rate. This was likely because the greater the amount of small particle sizes in the filter media matrix, the lower the porosity (or number of pores) and the smaller the pore spaces. Additionally, more small particles generally means more surface area, which may increase friction on the runoff water passing through the filter media, thereby slowing aqueous movement through the media.

In a similar study evaluating hydraulic flow through rate and sediment removal efficiency of silt fence and filter socks, Keener et al. (2006) reported that average hydraulic flow-through rates for filter socks were 50% higher, although suspended solids removal efficiency was not significantly different. This implies that filter socks do not rely on flow restriction and sediment deposition to remove suspended solids from storm runoff to the extent that silt fence does. Due to the heterogeneous porous matrix and greater surface area within the filter sock, this device functions more like a water filter relative to silt fence, which functions more like a small sediment detention pond due to its reliance on blinding, flow restriction, and sediment deposition.

In 1998, the USEPA national water quality assessment reported 35% of streams were found to be severely impaired, and nutrient loading was identified as the principle cause for 30% listed (USEPA 2000). Mineral fertilizers are commonly applied to establish specified erosion control grasses on construction sites and can lead to significant nutrient loading of storm runoff (Glanville et al. 2004; Faucette et al. 2005). Additionally, on disturbed construction site soils, where soil becomes detached, sediment bound P can become desorbed transforming into soluble P (Westermann et al. 2001). Where sedimentation is minimal due to effective erosion control practices, sediment bound P is typically much lower, and soluble P can be more than 80% of total P (Berg and Carter 1980). Soluble P is more reactive, or bioavailable to aquatic plants, than sediment-bound P and is thereby more likely to cause algae blooms and eutrophic conditions in receiving waters.

While compost filter socks have been used primarily for controlling sediment, there is evidence in the literature that compost filter socks have the ability to filter soluble nutrients through chemical adsorption (Faucette and Tyler 2006; Faucette et al. 2006). The humus fraction of compost has the ability to chemically adsorb free ions such as soluble phosphorus (P) and ammonium nitrogen (N) (Brady and Weil 1996). Minor reduction for nitrate-N and total P from runoff water between 1 and 7 mg L^{-1} were reported (Faucette and Tyler 2006; Faucette et al. 2006).

Sediment barriers are typically poor at targeting turbidity and suspended solids in runoff and often do little to reduce soluble nutrient concentrations (Leytem and Bjorneberg 2005). In recent years, polymers have been used on construction sites to improve water quality by targeting turbidity, suspended solids, and nutrients. Anionic polymer coagulants and flocculants may be added to compost filter socks to target these pollutants in storm water runoff. Hayes et al (2005) found that polymers can reduce average turbidity on disturbed soils characteristic to construction sites. Leytem and Bjorneberg (2005) reported a 98% reduction in soluble P concentration in sediment ponds using polymer flocculants, while Moore (1999) and Harper et al. (1999) found total phosphorus in storm runoff could be reduced by as much as 75% to 90%. These new applications may be of critical importance on highly disturbed silt and clay soils, soils recently fertilized for vegetation establishment, or near total maximum daily load (TMDL) listed receiving waters and watersheds. Additionally, sediment control barriers that can remove soluble pollutants from storm runoff, in addition to sediment, should be considered by environmental regulators and design engineers specifying structural sediment control practices.

The objectives of this study were (1) to compare the sediment removal efficiency of silt fence and compost filter socks, (2) to determine if the addition of polymers to

Figure 1
Experimental setup with rainfall simulator and soil chambers.

compost filter socks can reduce sediment and phosphorus loads, and (3) to determine relationships between compost filter media particle size distribution, hydraulic flow-through rate and pollutant removal efficiency.

Materials and Methods

Experimental Setup. Four (1 to 4) experiments were conducted in 2005 at the Environmental Quality Laboratory, USDA Agricultural Research Service, Beltsville, Maryland. The objective of experiment 1 and 2 was to determine and compare silt fence and compost filter sock performance on sediment removal efficiency and hydraulic flow rate; the objective of experiment 3 was to evaluate the effect of adding sediment-targeted polymers to the compost filter sock on these performance parameters; and the objective of experiment 4 was to evaluate the effect of adding phosphorus-targeted polymers to the compost filter socks on these parameters in addition to phosphorus removal efficiency. A 10:27:5 (N:P:K) commercial fertilizer was added to the soil boxes in experiment 4 by broadcasting on the soil surface at 28 kg ha^{-1} (150 lb ac^{-1}) of ortho-P (5.88 g chamber^{-1} [0.2 oz]).

All soil chambers were elevated at a 10% slope and exposed to a mean 7.45 cm h^{-1} (2.93 in hr^{-1}) simulated rainfall event for 30 minutes, to simulate a worst case scenario under bench scale conditions. All runs within experiments were completed within 48 hours. Each experiment tested five treatments, including one control (bare soil), all replicated in triplicate. Each treatment was installed into a soil chamber, with four soil chambers installed on a rainfall turntable per experimental run (figure 1). A total of 15 treatment replicates were randomly assigned and tested during four runs per experiment (the last run only contained three soil treatments). Currently, no standard test methodology exists for evaluating sediment control barriers.

Rainfall Simulation and Soil Chamber System. The experimental design was set up to simulate rainfall-runoff and collect and analyze storm runoff from soil chambers installed with various sediment control barrier treatments. The rainfall-runoff simulation system used in this study has been previously described in detail by Isensee and Sadeghi (1999). The rainfall-runoff simulation system consists of an adjustable rainfall simulator (two oscillating linear dripping units that provide simulated rain at 0° and 180° over the raintable), a peristaltic pump to supply water to the dripper units, a 2.4-m (7.9-ft) diameter, 1-rpm turntable (that supports and rotates four soil chambers under oscillating dripping units), four chamber elevation platforms (to support the soil chambers at the desired slope of 0% to 20%), and 15 soil chambers. The soil chambers used in this experiment are constructed of 15-mm (0.6-in) thick marine plywood, with inside dimensions of 100 cm length by 35 cm width by 25 cm depth (39 in length by 14 in width by 10 in depth), and are described in detail in Sadeghi and Isensee (2001).

Soil chambers were prepared by packing a Hatboro silt loam (Ap horizon) into each of the 15 chambers. The soil was added in small increments to the chambers and packed with a pressure of approximately 0.15 kg cm^{-2} (2.1 lb in^{-2}) before the next incremental addition (Sadeghi and Isensee 2001). Soil was packed until the chambers contained 7.62-cm (3-in) depth of soil. Twenty-four to 48 hours before the runoff simulation, the chamber drains were plugged, and chambers were placed on the raintable and exposed to fifteen minutes of simulated rainfall at a rate of 5.4 cm h^{-1} (2.1 in hr^{-1}), to pre-wet the soil. The adjustable runoff drain was then unplugged and the gate was positioned so the runoff drain was level with the soil surface. Silicone was used to seal the gate to prevent leaks during the simulation.

Treatment Description and Installation. All treatments for the four experiments (19 total treatments) are described in table 2. Compost filter media, derived from composted yard debris, used within the filter sock was supplied by erosion control contractors currently using the compost filter sock technology for sediment control on construction activities. No processing of compost filter media was conducted once received at the experimental laboratory from the erosion control contractors. Compost filter sock treatments with same numbers came from the same erosion control contractor. For treatments requiring polymer addition, pre-weighed polymers were added and thoroughly mixed with 5 kg (11 lb) of compost filter media by combining materials in a 18.9 L (5 gal) bucket and vigorously shaking and rolling the sealed bucket for 2 minutes. Polymer inclusion rate to compost filter media was 20 g kg^{-1} (0.3 oz lb^{-1}). After mixing, the mixed materials were filled and compacted into a 20.3-cm (8-in) diameter high density polyethylene photodegradable mesh (9.5-mm [0.4-in] openings) containment sock system ('filter sock'). Filter socks were then placed at the down slope end of the soil chamber and were slightly compacted. Compost filter media was used to backfill the filter sock and soil interface on the upslope side of the filter sock, according to federal standard specifications (American Association of State Highway and Transportation Officials 2006).

Particle size distribution of all compost filter media treatments was determined. Particle size distribution of the filter media may affect pollutant removal efficiency and hydraulic flow-through rate of the filter sock (Faucette et al. 2006). A composite sub-sample of the filter media was taken prior to runoff analysis and analyzed for particle size distribution (Test Methods for the

Table 2
Experimental treatments.

Treatment	Experiment 1	Experiment 2	Experiment 3	Experiment 4
1	Silt fence	Silt fence	Silt fence	Silt fence
2	Compost filter sock 1	Compost filter sock 4	Compost filter sock 5 + BioFloxx	Compost filter sock 5 + PhosLoxx1
3	Compost filter sock 2	Compost filter sock 2	Compost filter sock 5 + PAM	Compost filter sock 5 + PhosLoxx2
4	Compost filter sock 3	Compost filter sock 5	Compost filter sock 5 + Silt Stop	Bare soil
5	Bare soil	Bare soil	Bare soil	

Examination of Composting and Compost 02.02 B) using test methods described by the Test Methods for the Examination of Composting and Compost (US Composting Council 1997). Particle size distribution standard specifications for compost filter socks used for runoff-sediment control applications are 99% passing 50 mm (2 in), 30% to 50% passing 10 mm (3/8 in) (American Association of State Highway Transportation Officials 2006; USEPA 2006). Particle size distributions for each filter media treatment are presented in table 3.

Various polymers were added to the filter sock for experiment 3 and 4. Experiment 3 added coagulant and flocculent polymers designed to reduce TSS and turbidity in surface runoff flowing through the filter sock. The BioFloxx polymer is a water soluble anionic chitosan acetate powder (≤1 mm [≤0.04 in]) derived from shellfish. The PAM is a water soluble anionic polyacrylamide powder with a paper fiber (5 mm [0.2 in]) carrier used for field application purposes. The Silt-Stop is a water soluble anionic polyacrylamide co-polymer blended powder (≤1 mm). All three anionic polymers are flocculants and coagulants commonly used to floc and settle suspended solids in sediment and storm water detention ponds and stabilize disturbed soils through coagulation on construction sites.

Experiment 4 added polymers designed to reduce phosphorus in detained water systems to the filter sock system in order to target soluble phosphorus in runoff. Both polymers (PhosLoxx1 and PhosLoxx2) were a proprietary blend that partially utilizes alum (aluminum sulfate) and/or gypsum (calcium sulfate) materials in granular forms (≤2 mm [≤0.08 in]).

All experiments used 900-mm (36-in) tall geosynthetic silt fence adhering to a minimum tensile strength of 118 kg (260 lb) (ASTM-D4632), #30 apparent opening size (maximum sieve size) (ASTM-D4751), and a maximum elongation of 40% (ASTM-D4751). Silt fence was installed in a V-formation (so ends were positioned upslope), at the down-slope end of the soil chamber. Six inches of the silt fence were trenched into the soil, 6.4 cm (2.5 in) deep and 8.9 cm (3.5 in) upslope. The soil displaced by trenching was replaced and thoroughly compacted around the silt fence prior to rainfall-runoff simulation. The top 30.5 cm (12 in) of the silt fence was cut off after installation (sediment accumulation and flow rates did not require the extra material). Polymers were not added to the silt fence as the researchers assumed it would readily leach through the fabric.

Runoff Sampling and Analysis. All runoff was collected in 500 mL (16.9 oz) pre-weighed glass jars. A runoff sample was collected once the sample jar reached volumetric capacity. After sample collection, all jars were weighed to calculate total runoff volume. This data was combined with the elapsed time data to develop runoff hydrographs for each treatment.

All runoff samples were processed for soluble P, total P, TSS, and turbidity. Using a 20-mL (0.7-oz) syringe (BD Luer-Lok #305617), sampled aliquots were passed through a 0.45-µm (0.000018-in) syringe filter (Pall IC Acrodisc #AP-4585). Filtered samples were processed for ortho-P by flow injection analysis (Lachat QuikChem #10-115-01-1-A). For total P quantification persulfate digestion was used to oxidize organic and particulate matter using 50-mL (1.7-oz) sample aliquots (Pierzynski 2000). Once oxidized, these samples were processed using flow injection analysis for orthophosphate (Lachat QuikChem #10-115-01-1-A). A LaMotte 2020 Turbidimeter was used to

Table 3
Particle size distribution for compost filter media for all compost filter sock treatments.

	Particle size distribution of compost filter media						
Treatment	>25 mm	16 to 25 mm	9.5 to 16.0 mm	6.3 to 9.5 mm	4 to 6.3 mm	2 to 4 mm	<2 mm
Filter sock 1	2.7%	12.3%	13.7%	14.9%	11.2%	11.2%	34%
Filter sock 2*	0%	16.1%	39.6%	13%	6.3%	7.2%	17.8%
Filter sock 3*	12.4%	14.1%	28.2%	21.8%	9.8%	4.7%	9%
Filter sock 4	0%	0%	22.1%	28.2%	22.3%	12.4%	15%
Filter sock 2*	0%	16.1%	39.6%	13%	6.3%	7.2%	17.8%
Filter sock 5*	0%	14.9%	44.8%	13.4%	7%	6.9%	13.1%
Filter sock 5*+ BioFloxx	0%	14.9%	44.8%	13.4%	7%	6.9%	13.1%
Filter sock 5*+ PAM	0%	14.9%	44.8%	13.4%	7%	6.9%	13.1%
Filter sock 5*+ Silt-Stop	0%	14.9%	44.8%	13.4%	7%	6.9%	13.1%
Filter sock 5* + PhosLoxx1	0%	14.9%	44.8%	13.4%	7%	6.9%	13.1%
Filter sock 5* + PhosLoxx2	0%	14.9%	44.8%	13.4%	7%	6.9%	13.1%

* Compost filter media meets particle size distribution standard specification (American Association of State Highway and Transportation Officials 2006). Note: Compost filter media that did not meet particle size distribution specification was too fine.

Table 4

Mean pollutant concentration values, flow rate, and percent removal or reduction for all experimental treatments.

		TSS		Turbidity		Total P		Soluble P		Total P w/ fertilizer added		Soluble P w/ fertilizer added		Flow rate	
Treatment	Experiment	g L^{-1}	Removal (%)	NTU	Reduction (%)	mg L^{-1}	Removal (%)	mg L^{-1}	Removal (%)	mg L^{-1}	Removal (%)	mg L^{-1}	Removal (%)	gal min^{-1} (linear $ft)^{-1}$	Difference (%)
Bare soil (control)	1	70.40b	ND	36,688b	ND	31.18b	ND	0.438b	ND	ND	ND	ND	ND	0.0727a	ND
Silt fence	1	9.34a	87	8,805a	76	11.46a	63	0.337a	23	ND	ND	ND	ND	0.0515b	29
Filter sock 1	1	9.21a	87	8,165a	78	10.94a	65	0.317a	28	ND	ND	ND	ND	0.0633ab	13
Filter sock 2	1	13.9a	80	10,884a	70	12.93a	59	0.377ab	14	ND	ND	ND	ND	0.0715a	2
Filter sock 3	1	13.38a	81	10,234a	72	12.86a	59	0.359ab	18	ND	ND	ND	ND	0.0710a	2
Bare soil (control)	2	49.34b	ND	31,504b	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.0977a	ND
Silt fence	2	14.30a	71	14,508a	54	ND	ND	ND	ND	ND	ND	ND	ND	0.0924a	5
Filter sock 2	2	18.60a	62	14,954a	53	ND	ND	ND	ND	ND	ND	ND	ND	0.0856ab	13
Filter sock 4	2	16.30a	67	14,128a	55	ND	ND	ND	ND	ND	ND	ND	ND	0.0785b	20
Filter sock 5	2	11.05a	78	12,205a	61	ND	ND	ND	ND	ND	ND	ND	ND	0.0763b	22
Bare soil (control)	3	61.56c	ND	32,793c	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1126a	ND
Silt fence	3	20.85b	66	16,371b	50	ND	ND	ND	ND	ND	ND	ND	ND	0.1074a	5
Filter sock 5 + BioFloxx	3	1.87	97	2,003a	94	ND	ND	ND	ND	ND	ND	ND	ND	0.0747b	34
Filter sock 5 + PAM	3	5.41a	91	6,835a	79	ND	ND	ND	ND	ND	ND	ND	ND	0.0782b	31
Filter sock 5 + Silt-Stop	3	1.88	97	659a	98	ND	ND	ND	ND	ND	ND	ND	ND	0.0598c	47
Bare soil (control)	4	48.82c	ND	19,343c	ND	ND	ND	ND	ND	81.56b	ND	36.58b	ND	0.1098a	ND
Silt fence	4	18.25b	63	10,687b	45	ND	ND	ND	ND	37.02a	55	16.10a	56	0.0859b	22
Filter sock 5 + PhosLoxx1	4	6.61a	87	5,588a	71	ND	ND	ND	ND	34.99a	57	0.17a	99	0.0882b	20
Filter sock 5 + PhosLoxx2	4	5.47a	89	4,428a	77	ND	ND	ND	ND	30.07a	63	2.61a	93	0.0923b	16

Notes: TSS = total suspended solids. ND = data were not collected for this parameter and/or treatment. Means with same letter were not significantly different at $p < 0.05$.

quantify turbidity for each sample. Total suspended soilds were processed by filtering 100 mL (3.4 oz) of raw sample through a glass microfiber filter (Whatman #934-AH), using a Buchner funnel and light vacuum. Pre-weighed filters were dried at 104°C (219°F) for one hour and weighed to determine TSS (g L^{-1}).

Analysis of Results. Total mass loads were determined for TSS, total P, and soluble P. Loads were determined by multiplying sample concentration means by the runoff volume. Flow rates were converted from mL s^{-1} to L min^{-1} linear cm^{-1} and gal min^{-1} linear ft^{-1} by correcting for box width (35 cm [14 in]) to a standard linear length of sediment control barrier (cm or ft). Single event support practice (P factor) is defined as the soil loss ratio from a given treatment relative to a bare soil (control) under the same set of environmental conditions (Demars et al. 2000; Clopper et al. 2001; Erosion Control Technology Council 2004). Single event P factors were determined for each treatment using TSS loads.

Statistical analysis for means separation was performed using Proc Mixed, SAS Institute version 9.1, on the effect of filter sock, filter sock + polymer, and silt fence treatments on TSS, turbidity, total P, soluble P, and hydraulic flow rate. Separation of means was determined to be significantly different at the $p < 0.05$ level. A regression analysis was performed to determine the strength of correlation relationships between compost filter media particle size, hydraulic flow rates, and removal efficiency of the pollutants described above. Regression analysis was determined significant if the relationship had an r value > 0.70 at the $p < 0.05$ level.

Results and Discussion

Suspended Solids and Turbidity. During experiment 1 and 2, all treatments were significantly different from the control, as compost filter socks reduced TSS concentration between 80% and 87%, and the silt fence reduced TSS by 87% (table 4). During experiment 2, the filter socks reduced runoff TSS concentration between 62% and 78%, and the silt fence reduced TSS by 71%. This supports Faucette and Tyler's (2006) and Faucette et al. (2006) findings that filter socks can reduce runoff TSS between 59% and 82%, and between 58% and 70%, respectively. Experiment 3 utilized sediment-reducing polymers within the filter sock to target suspended solids and turbidity in runoff. Total suspended solids removal efficiency for these filter socks was between 91% and 97%, and 66% for the silt fence. Faucette et al. (2006) similarly reported polymers added to filter socks reduced TSS between 88% and 90%. Total suspended solid removal efficiency for the chitosan- and polyacrylamide-based polymers used within the filter socks were nearly identical. Although experiment 4 was designed to reduce runoff phosphorus, all filter socks with polymer significantly reduced TSS relative to silt fence and the control. Total suspended soild removal efficiencies were between 84% and 89% for the filter sock treatments with alum and gypsum, and were 63% for the silt fence. These results show that polymers typically used to remove P when added to the filter socks do not contribute TSS to runoff and may be used to reduce TSS in runoff.

Total suspended solid loads from bare soil (control) for experiment 1 through 3 ranged from 17,300 to 23,517 kg ha^{-1} (7.6 tn ac^{-1}

Table 5

Total pollutant load and percent reduction or removal for all experimental treatments.

		Total suspended solids		P factor	Total P w/ fertilizer added		Soluble P w/ fertilizer added	
Treatment	Experiment	kg ha^{-1}	Removal (%)	reduction (%)	mg	Removal (%)	mg	Removal (%)
Bare soil (control)	1	21,514b	ND	ND	ND	ND	ND	ND
Silt fence	1	2,340a	89%	0.11	ND	ND	ND	ND
Filter sock 1	1	2,209a	90	0.10	ND	ND	ND	ND
Filter sock 2	1	3,706a	83	0.17	ND	ND	ND	ND
Filter sock 3	1	3,857a	82	0.18	ND	ND	ND	ND
Bare soil (control)	2	17,300b	ND	ND	ND	ND	ND	ND
Silt fence	2	4,440a	74	0.26	ND	ND	ND	ND
Filter sock 2	2	5,491a	68	0.32	ND	ND	ND	ND
Filter sock 4	2	4,634a	73	0.27	ND	ND	ND	ND
Filter sock 5	2	2,960a	83	0.17	ND	ND	ND	ND
Bare soil (control)	3	23,517b	ND	ND	ND	ND	ND	ND
Silt fence	3	6,703a	72	0.29	ND	ND	ND	ND
Filter sock 5 + BioFloxx	3	509a	98	0.02	ND	ND	ND	ND
Filter sock 5 + PAM	3	1,423a	94.	0.06	ND	ND	ND	ND
Filter sock 5 + Silt-Stop	3	417a	98	0.02	ND	ND	ND	ND
Bare soil (control)	4	ND	ND	ND	676.1b	ND	229.9b	ND
Silt fence	4	ND	ND	ND	323.8a	52	120.9a	47
Filter sock 5 + PhosLoxx1	4	ND	ND	ND	261.7a	61	1.5 a	99
Filter sock 5 + PhoxLoxx2	4	ND	ND	ND	233.1a	66	18.6 a	92

Notes: ND = data were not collected for this parameter and/or treatment. Means with same letter were not significantly different at $p < 0.05$.

and 10.4 tn ac^{-1}). During experiment 1, the filter socks reduced TSS loads between 82% and 90%, and the silt fence reduced TSS loads by 89% (table 5). During experiment 2, all of the treatments significantly reduced TSS loads relative to the control; the compost filter socks reduced TSS loads between 68% and 83%, and the silt fence reduced TSS loads by 74%. During experiment 3, filter socks with polymers reduced TSS loads between 94% and 98%, and the silt fence reduced TSS loads by 72%. There was no quantifiable difference between the PAM and chitosan polymers.

All treatments significantly reduced turbidity in runoff relative to the control during experiment 1 and 2 (table 4). Filter socks reduced turbidity between 53% and 78%, while silt fence reduced turbidity between 54% and 76%. Where flocculants were added to the filter socks in experiment 3, turbidity was reduced between 79% and 98%, and only 50% for the silt fence treatment. Faucette et al. (2006) similarly reported turbidity reduction by filter socks with flocculants between 77% and 90%. In experiment 4, all filter socks with polymers (intended to target phosphorus) significantly reduced turbidity relative to silt fence and the control. Turbidity reduction for the filter sock treatments were between 71% and 77%, and 45% for the silt fence. These results show that the polymers added to the filter socks do not contribute turbidity to runoff and may be used to target turbidity reduction in runoff.

Support Practice Factor. Single event support practice (P) factors used in the USLE soil prediction model are often used by erosion and sediment control planners to evaluate between sediment control practices and to estimate the potential erosion reduction a given practice may provide under a given set of field conditions for single event storm scenarios. P factors for silt fence for experiments 1 through 3 were between 0.11 and 0.29 (table 5). These P factors are considerably better than the silt fence P factor reported by Fifield (2001), 0.60, but worse than 0.048 silt fence P factors (reported as sediment loss ratio) reported by Faucette et al. (2005). The P factors for filter socks without polymers were between 0.10 and 0.32, and with sediment-reducing polymers between 0.02 and 0.06. Kelsey et al. (2006) reported P factor values for straw wattles between 0.66 and 0.81, and excelsior fiber logs between 0.29 and 0.45; while Faucette et al. (2005) reported a P factor (reported as sediment loss ratio) of 0.041 for compost filter berms. Variability for reported P factors between these studies is likely due to the experimental conditions to which each sediment control barrier was exposed.

Total and Soluble Phosphorus. During experiment 1, all treatments significantly reduced total P relative to bare soil. The filter socks reduced total P between 59% and 65%, and the silt fence reduced total P by 63% (table 4). Results were similar for soluble P, as one of the filter socks and the silt fence significantly reduced soluble P from runoff, while the remaining filter socks were not significantly different. Soluble P removal efficiency from runoff for the filter socks was between 14% and 27%, and 23% for the silt fence. These results are likely because most of the total P in runoff was sediment-bound (99%); therefore, effective control of sediment had the same affect on P. This provides further evidence that filter socks do not contribute P to runoff water, which is similar to results from Faucette and Tyler (2006), and may have the ability to reduce soluble P in runoff as reported by Faucette et al. (2006).

Experiment 4 included polymers within the matrices of the filter socks to target runoff P, particularly soluble P. Soils in this experiment were amended with 28 kg ha^{-1} (150 lb ac^{-1}) of ortho-P fertilizer (a typical application for establishing erosion control grasses). Due to the addition of fertilizer, 45% of total P in the runoff was in soluble P form (compared to 1% in the previous experiment). Soluble P concentration and load from the fertilized bare soil was 37 mg L^{-1} and 230 mg (0.008 oz), respectively. Soluble P reduction by the filter socks with polymers was between 93% and 99%, while the silt fence was 56%. Loading of soluble P was reduced by the filter socks with polymers between 92 and 99%, while the silt fence reduced soluble P loading by 47%. Faucette et al. (2006) similarly reported, with runoff soluble P concentrations of 100 mg L^{-1}, phosphorus-reducing polymers added to filter socks at 4.2 to 25.4 g kg^{-1}, reduced soluble P in runoff between 67% and 93%. The high soluble P removal efficiency by the compost sock with polymers is likely due to chemical ionic adsorption of soluble P to exchange sites on the polymer. Moderate soluble P removal efficiency of the silt fence is likely due to ionic adsorption of the soluble P to sediments held behind the silt fence. Filter socks with polymers also reduced total P loading, between 61% and 66%, while silt fence reduced total P loading by 52%.

Hydraulic Flow Rate. Hydraulic flow rates of sediment control barriers can provide needed information for erosion and sediment control planning and design. Flow-through rates can be used to determine spacing requirements, maximum allowable slope lengths and/or drainage areas contributing to sediment control barriers, and potential for overflow during rainfall-runoff events. In experiment 1, only the silt fence significantly restricted flow rate relative to the bare soil and was significantly different from two of the filter socks (table 4). The compost socks restricted flow rate between 2% and 13%, while the silt fence restricted flow by 29%. Keener et al. (2006) similarly reported that silt fence flow rates were approximately 50% slower relative filter socks. In experiment 2, relative hydraulic flow rates were lower in the compost sock treatments, as two of the filter socks were significantly slower than the control and the silt fence. During this experiment, filter socks restricted flow rates between 12% and 22%, while the silt fence reduced flow by 5%.

There are two plausible explanations for the reversal in hydraulic flow rate pattern between silt fence and filter socks relative to the control. Suspended solids and turbidity levels were greater during experiment 1 relative to experiment 2, and it is possible that higher runoff sediment concentrations act to restrict flow through the silt fence (through blinding) in greater relative proportion than to filter socks. Alternatively, the filter socks in experiment 1 had a higher percent of large particles, relative to the filter socks in experiment 2, increasing the porosity in the filter sock allowing water to move through at a faster rate. This supports results presented by Faucette et al. (2006) where compost filter media particle size distribution is the best predictor of flow through rate.

During experiment 3, polymers in the filter socks significantly restricted flow-through rates, relative to silt fence, whereas, compost socks with polymers reduced flow rates between 31% and 47%, silt fence reduced flow rate by only 5%. Because these polymers are coagulants once they react with water, flow friction and physical clogging of pores is typical within the filter sock. It is unclear whether flow restriction, flocculation, or coagulation was most responsible for sediment reduction in these treatments.

During experiment 4, all flow rates were significantly lower than the control. Silt fence reduced flow rate by 22%, while the filter socks reduced flow between 16% and 20%. Addition of phosphorus-targeting polymers to filter socks did not reduce flow through rate, as the polymers in experiment 3 did. This is likely because these polymers do not coagulate as the sediment-targeting polymers do.

Particle Size Distribution, Hydraulic Flow Rate, and Pollutant Removal Efficiency. Results from experiment 1 showed that the filter sock with the highest percentage of small particles had the greatest reduction in runoff TSS concentration, turbidity, and total and soluble P concentration. Still, results from regression analysis ($\alpha < 0.05$) did not show a strong relationship with only a moderate relationship between particle sizes distributed between 6.3 mm (0.25 in) and 16 mm (0.63 in) and reduction in turbidity (α = 0.0395; r^2 = 0.477). Regression analysis did not show a significant correlation between particle size distribution and hydraulic flow rate.

Results from experiment 1, 2, and 3 showed that filter socks that exhibited the greatest hydraulic flow rate restriction had the greatest reduction of runoff TSS concentration and load, turbidity, total P, and soluble P. Experiment 3 supports manufacturers' claims that coagulating polymers, such as those used in this experiment, reduce sediment transport by slowing or restricting the flow of runoff. Results from regression analysis ($\alpha < 0.05$) showed a significant relationship between hydraulic flow rate restriction and reduction in turbidity (α = 0.01; r^2 = 0.765), TSS (α = 0.0177; r^2 = 0.642), total P (α = 0.0005; r^2 = 0.624), and soluble P (α = 0.0483; r^2 = 0.473) in runoff; although the strength of these relationships were only moderate.

This data demonstrates that hydraulic flow-through rate may be a better predictor for pollutant removal efficiency of compost filter media, rather than particle size distribution, and although specifications for particle size distribution are still a useful tool to predict performance, inclusion of hydraulic flow-through rate specifications for compost filter socks (and filter berms) should be seriously considered by specifiers and regulators.

Summary and Conclusions

Under bench scale conditions, 7.45 cm h^{-1} (2.9 in hr^{-1}) of simulated rainfall-runoff for 30 minute durations on bare soil conditions generated runoff TSS loads between 17,300 kg ha^{-1} and 23,517 kg ha^{-1} (7.6 tn ac^{-1} and 10.4 tn ac^{-1}), TSS concentrations between 48.8 and 70.4 g L^{-1} (6.5 oz gal^{-1} and 9.4 oz gal^{-1}), and turbidity between 19343 and 36688 NTUs. Compost filter socks, compost filter socks with polymers, and silt fence treatments significantly reduced TSS concentrations, TSS loads, and turbidity NTUs, relative to bare soil. Compost filter socks reduced TSS concentration in runoff between 62% and 87% (68% to 90% for TSS load), when polymers were added to the filter socks TSS removal efficiency increased to between 91% and 98% (94% and 98% for TSS load), while silt fence reduced TSS concentration between 63% and 87% (68% to 89% for TSS load). Similarly, silt fence reduced turbidity in runoff between 45% and 76%, filter socks reduced turbidity between 53% and 78%, and filter sock + polymers increased turbidity reduction to between 79% to 98%. Similarly, single-event support practice (P factor) for silt fence were between 0.11 and 0.27 and for filter socks between 0.10 and 0.32.

Filter socks and silt fence significantly reduced total P and soluble P in runoff. Polymers added to filter socks significantly reduced soluble P loads relative to silt fence. Filter socks reduced total P concentrations between 55% and 65% (59% to 66% for total P loads), and silt fence reduced total P concentrations between 55% and 63% (52% for loads). Filter socks reduced soluble P loading between 14% and 27%, while silt fence reduced soluble P loading by 23%. When 28 kg ha^{-1} (150 lb ac^{-1}) of ortho-P fertilizer was applied to bare soil polymers added to the filter socks reduced soluble P concentrations between 93% and 99% (92% to 99% for soluble P loads). Soluble P runoff concentration and load from the fertilized bare soil was 37 mg L^{-1} and 230 mg (0.008 oz), respectively, 45% of total P.

Compost filter socks and silt fence significantly restricted hydraulic flow rate relative to bare soil. The filter socks reduced flow rate between 2% and 22%, while silt fence reduced flow rate between 5% and 29%. Sediment polymers added to the filter socks reduced flow rate between 31% and 47%, likely due to their coagulation characteristics. A moderate correlation was observed for compost filter media particle sizes distributed between 6.3 mm (0.25 in) and 16 mm (0.63 in) and reduction in turbidity; however, regression analysis did not show a significant correlation between particle size distribution and hydraulic flow rate. A significant correlation was observed between hydraulic flow rate restriction and reduction in runoff turbidity, TSS, total P, and soluble P.

These results show that compost filter socks are effective at reducing turbidity and TSS from runoff and are similar to silt fence in sediment removal efficiency; however, if polymers are added to the filter socks removal efficiencies may be increased to 98%. Silt fence and filter socks have similar total P and soluble P removal efficiencies; however, if flocculants are added to filter socks, soluble P may be reduced up to 99%. Filter socks and silt fence had similar affects on hydraulic flow rates. However, if polymers used for targeting sediment are added to filter socks, hydraulic flow rate may be restricted. Particle size distribution specifications for compost filter media are a valuable tool for predicting performance of filter socks (and filter berms). However, hydraulic flow through rate is a better predictor of pollutant removal efficiency performance for this technology. In conclusion, filter socks are highly effective as sediment control barriers and can be customized to target specific storm water runoff pollutants such as turbidity, TSS, and soluble P. Targeting these pollutants in storm runoff will likely reduce their transport to, and pollution of sensitive receiving waters and TMDL listed water bodies. Additionally, federal and state standard specifications should consider inclusion of hydraulic flow rate parameters to increase prediction of compost filter sock (and filter berm) performance.

Acknowledgements

The authors wish to gratefully acknowledge Kate Jacobs, Molly Monahan, Sarah Waterworth, Katherine Wilson, Trevor Olexy, Jennifer Fetcho, and Leticia Drakeford for their assistance collecting samples during the experiments. Kate Jacobs, thank you also for your invaluable laboratory assistance and technical support. The authors would also like to thank Jared Taylor, Tom Truelsen, Mike Mirowski, Alex Marks, Rod Tyler, George Hilde, Steve Iwinski, and Cody Jackson for supplying materials.

References

American Association of State Highway and Transportation Officials. 2006. Standard Specification for Transportation Materials and Methods of Sampling and Testing, Designation M10-03, Compost for Erosion/Sediment Control. Washington, DC: American Association of State Highway and Transportation Officials.

Barrett, M.E., J.E. Kearney, T.G. McCoy, and J.F. Malina. 1995. An Evaluation of the Use and Effectiveness of Temporary Sediment Controls. Center for Research in Water Resources, University of Texas at Austin. http://www.crwr.utexas.edu/reports/pdf/1995/rpt95-6.pdf.

Barrett, M.E., J.F. Malina, and R.J. Charbeneau. 1998. An evaluation of geotextiles for temporary sediment control. Water Environment Research 70(3):283-290.

Berg, R.D., and D.L. Carter. 1980. Furrow erosion and sediment losses on irrigated cropland. Journal of Soil and Water Conservation 35(6):267-270.

Britton, S.L., K.M. Robinson, B.J. Barfield, and K.C. Kadavy. 2000. Silt fence performance testing. Presented at the ASAE Annual International Meeting, July 2000. St. Joseph, MI: American Society of Agricultural Engineers.

Brady, N.C., and R.R. Weil. 1996. The Nature and Properties of Soils, 11th ed. NJ: Prentice Hall.

Clopper, P., M. Vielleux, and A. Johnson. 2001. Quantifying the performance of hillslope erosion control best management practices. Environmental Resources Congress Professional Paper.

Demars, K.R., R.P. Long, and J.R. Ives. 2000. New England Transportation Consortium use of wood waste materials for erosion control. NETCR 20, Project No. 97-3.

Erosion Control Technology Council. 2004. Erosion Control Technology Council Standard Specification for Rolled Erosion Control Products. Rev. 4904.

Faucette L.B., C.F. Jordan, L.M. Risse, M. Cabrera, D.C. Coleman, and L.T. West. 2005. Evaluation of storm water from compost and conventional erosion control practices in construction activities. Journal of Soil and Water Conservation. 60(6):288-297.

Faucette, L.B., and R. Tyler. 2006. Organic BMPs Used for Stormwater Management. International Erosion Control Association Conference Technical Session Proceedings, Long Beach, CA.

Faucette, B., F. Shields, and K. Kurtz. 2006. Removing storm water pollutants and determining relations between hydraulic flow-through rates, pollutant removal efficiency, and physical characteristics of compost filter media. Second Interagency Conference on Research in Watersheds, 2006 Proceedings. Coweeta Hydrologic Research Station, NC.

Fifield, J. 2001. Designing for Effective Sediment and Erosion Control on Construction Sites, Santa Barbara, CA: Forester Press.

Fisher, L.S., and A.R. Jarrett. 1984. Sediment retention efficiency of synthetic filter fabrics. Transactions of the ASAE 27(2):429-436.

Glanville, T., R. Persyn, T. Richard, J. Laflen, and P. Dixon. 2004. Environmental effects of applying composted organics to new highway embankments: Part 2: water quality. Transactions of the ASAE 47(2):471-478.

Harper, H.H., J.L. Herr, and E.H. Livingston. 1999. Alum treatment of stormwater runoff: An innovative BMP for urban runoff problems. *In* National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments. USEPA. USEPA/625/R-99/002.

Hayes, S.A., R.A. McLaughlin, and D.L. Osmond. 2005. Polyacrylamide use for erosion and turbidity control on construction sites. Journal of Soil and Water Conservation 60(4):193-199.

Horner, R.R., J. Guedry, and M.H. Kortenhof. 1990. Improving the Cost Effectiveness of Highway Construction Site Erosion and Pollution Control. Seattle, WA: Washington State Transportation Center, Washington State Transportation.

Isensee, A.R., and A.M. Sadeghi. 1999. Quantification of runoff in laboratory-scale chambers. Chemosphere 38(8):1733-1744.

Kelsey, K., T. Johnson, and R. Vavra. 2006. Needed information: Testing, analysis, and performance values for slope interruption perimeter control BMPs. International Erosion Control Association Conference Technical Session Proceedings, Long Beach, CA.

Keener, H., B. Faucette, and M. Klingman. 2007. Flow-through rates and evaluation of solids separation of compost filter socks vs. silt fence in sediment control applications. Journal of Environmental Quality 36(3):742-752.

Kouwen, N. 1990. Silt Fences to Control Sediment Movement on Construction Sites. Report MAT-90-03. Downsview, Ontario: Research and Development Branch Ontario Ministry of Transportation.

Leytem, A.B., and D.L. Bjorneberg, 2005. Removing soluble phosphorus in irrigation return flows with alum additions. Journal of Soil and Water Conservation 60(4):200-208.

Moore, P.A. 1999. Reducing phosphorus runoff and improving poultry production with alum. Poultry Science 78(5):692-698.

Pierzynski, G. 2000. Methods of Phosphorous Analysis for Soils, Sediments, Residuals, and Waters. Southern Cooperative Series Bulletin. Raleigh, NC: North Carolina State University.

Sadeghi, A.M., and A.R. Isensee. 2001. Impact of hairy vetch cover crop on herbicide transport under field and laboratory conditions. Chemosphere 44(2):109-118.

South Carolina Department of Health and Environmental Control. 2005. South Carolina DHEC Storm Water Management BMP Handbook. August 2005. http://www.scdhec.net/environment/ocrm/pubs/docs/SW/BMP_Handbook/Erosion_prevention.pdf.

US Composting Council. 1997. Test Methods for the Examination of Composting and Compost. Amherst, OH: The United States Composting Council.

USEPA (US Environmental Protection Agency). 2006. National Pollution Discharge Elimination System (NPDES) National Menu of Best Management Practices. Construction Site Stormwater Runoff Control: Compost Filter Socks. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/compostfiltersock.cfm.

USEPA. 1993. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. EPA 840-B-92-002. Washington DC: US Environmental Protection Agency.

Wishowski, J.M., M. Mano, and G.D. Bubenzer. 1998. Trap efficiencies of filter fabric fence. ASAE Paper No. 982158. St. Joseph, MI: American Society of Agricultural Engineers.

Wyant, D.C. 1981. Evaluation of filter fabrics for use in silt fences. Transportation Research Record 832(6):6-12.