

Storm Water Pollutant Removal Performance of Compost Filter Socks

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In 2005, the U.S. Environmental Protection Agency (USEPA) National Menu of Best Management Practices (BMPs) listed compost filter socks (FS) as an approved BMP for controlling sediment in storm runoff on construction sites. The objectives of this study were to determine if FS with or without the addition of a flocculation agent to the FS system can significantly remove (i) suspended clay and silt particulates, (ii) ammonium nitrogen ($\text{NH}_4\text{-N}$) and nitrate-nitrite nitrogen ($\text{NO}_3\text{-N}$), (iii) fecal bacteria, (iv) heavy metals, and (v) petroleum hydrocarbons from storm water runoff. Five separate (I–V) 30-min simulated rainfall-runoff events were applied to soil chambers packed with Hartboro silt loam (fine-loamy, mixed, active, nonacid, mesic fluvaquent Endoaquepts) or a 6-mm concrete veneer on a 10% slope, and all runoff was collected and analyzed for hydraulic flow rate, volume, pollutant concentrations, pollutant loads, and removal efficiencies. In corresponding experiments, runoff was analyzed for (i) size of sediment particles, (ii) $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$, (iii) total coliforms (TC) and *Escherichia coli*, (iv) Cd, Cr, Cu, Ni, Pb and Zn, and (v) gasoline, diesel, and motor oil, respectively. Results showed that: (i) FS removed 65% and 66% of clay (<0.002 mm) and silt (0.002–0.05 mm), respectively; (ii) FS removed 17%, and 11% of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$, respectively and when NitroLoxx was added to the FS, removal of $\text{NH}_4\text{-N}$ load increased to 27%; (iii) total coliform and *E. coli* removal efficiencies were 74 and 75%, respectively, however, when BactoLoxx was added, removal efficiency increased to 87 and 99% for TC and 89 and 99% for *E. coli*, respectively; (iv) FS removal efficiency for Cd, Cr, Cu, Ni, Pb, and Zn ranged from 37 to 72%, and, when MetalLoxx was added, removal efficiency ranged from 47 to 74%; and (v) FS removal efficiency for the three petroleum hydrocarbons ranged from 43 to 99% and the addition of PetroLoxx increased motor oil and gasoline removal efficiency in the FS system.

IN 1998, the USEPA national water quality assessment stated that 35% of American streams were found to be severely impaired and nearly 75% of the U.S. population lives within 16 km (10 mi) of an impaired water body (USEPA, 2007). In response, as part of the 1972 Clean Water Act, the USEPA has frequently designated streams for total maximum daily load (TMDL) development for specific pollutants. Since 1995, pathogens (5081 listed), metals (5054 listed), and nutrients (3511 listed) have been the three most frequently listed causes of impairments for TMDL designations. These pollutants are the number one (8913 cases), fourth (6473 cases), and fifth (5625 cases) leading causes of impaired water quality in the United States (USEPA, 2007). Concentrations in urban stormwater runoff and urban stormwater runoff studies for TSS range from 19 to 10,000 mg L^{-1} , total N and nitrate N range from 0.14 to 29.0 mg L^{-1} , metals 0.01 to 5.0 mg L^{-1} (Flint and Davis, 2007).

These pollutants can be generated by urban nonpoint sources, such as storm runoff from impervious surfaces including parking lots, roadways, and rooftops; and vegetated areas such as lawns, golf courses, and pet parks. On disturbed soils, such as on construction sites, that are prone to detachment and transport, these pollutants are often attached to sediment; however, sediment-bound pollutants can quickly become desorbed, thereby transforming into soluble pollutant forms (Westermann et al., 2001). Where sedimentation is minimal due to effective erosion control management practices or where permanent stabilization is complete, soluble pollutants have shown the potential to exceed 80% of the total pollutant load (Berg and Carter, 1980). Soluble pollutants are typically more reactive and bioavailable to aquatic organisms, relative to sediment-bound pollutants. To protect and improve receiving water quality, BMPs should be developed to substantially reduce soluble pollutant loading. Quantifiable benchmarks and standards for BMP performance should be developed to allow designers to make responsible decisions and site plans based on design and water quality goals using best available technologies.

In 2005, the USEPA National Menu of BMPs for the National Pollutant Discharge Elimination System (NPDES) Phase II for Construction Activity Stormwater Management listed compost FS as an approved BMP for controlling storm runoff on construction sites (USEPA, 2006). Filtrexx International manufactures and distributes Filter Soxx (FS), which adhere to these USEPA speci-

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Published in J. Environ. Qual. 38:1233–1239 (2009).
doi:10.2134/jeq2008.0306
Received 2 July 2008.

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Abbreviations: BMP, best management practice; FS, filter socks; ICP–OES, inductively coupled plasma optical emission spectrometry; PHC, petroleum hydrocarbons; TMDL, total maximum daily load.

fications. Nearly 45 state and local agencies have approved the use of FS for control of sediment originating from construction activities (Filtrexx International, 2008). Studies conducted at The University of Georgia (Faucette et al., 2008), The Ohio State University (Keener et al., 2007), and by the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) (Faucette et al., 2008) have shown that this technology is an effective sediment control barrier for disturbed soils.

While FS have been used primarily for controlling sediment, there is evidence to suggest FS have the ability to filter soluble pollutants typically found in storm water flows originating from urban and suburban postconstruction surfaces (Faucette and Tyler, 2006; Faucette et al., 2006). The organic fraction of compost has the ability to chemically adsorb free ions, such as soluble P and ammonium N (Brady and Weil, 1996). The USDA-ARS (Faucette et al., 2008) reported removal efficiencies for compost FS between 14 and 28% for soluble P, and between 1 and 17% for $\text{NO}_3\text{-N}$. Faucette and Tyler (2006) also reported removal concentrations between 1 and 7 mg L^{-1} (1 and 7 ppm) for nitrate N and total P, and motor oil removal efficiencies between 85 and 99% when initial runoff concentrations of motor oil ranged between 1000 and 10,000 mg L^{-1} . Given the large land area required for proper design and function, and the high cost to install and maintain most stormwater management BMPs, compost FS may offer a low cost, low land area footprint solution to improving stormwater quality in a variety of urban and rural applications, particularly where land use is at a premium.

Historically, flocculation agents have been used to target specific pollutants in water and storm water treatment systems to improve water quality. Hayes et al. (2005) found that flocculation polymers can reduce average runoff turbidity on disturbed soils. Leytem and Bjorneberg (2005) reported a 98% reduction in soluble P concentrations in sediment ponds using flocculation agents, while Moore (1999) and Harper et al. (1999) found total P in storm runoff could be reduced by as much as 75 to 90%. Logsdon (1983) reported that flocculation agents can be an effective means to remove asbestos fibers in municipal drinking water treatment around Lake Superior. The USDA-ARS reported that by adding flocculation agents to compost FS runoff soluble P from fertilized soils can be reduced by 93 to 99%, and turbidity can be reduced by 79 to 98% (Faucette et al., 2008).

By adding flocculation agents to FS, target pollutants may be treated in sheet and/or concentrated storm water flows before entering receiving waters through physical removal of sediment-bound pollutants and through chemical adsorption of oppositely charged ions present on the surfaces of flocculation agents and the target pollutant. These applications may be of critical importance on soils recently fertilized for vegetation establishment, near 303(d) listed receiving waters, and around rooftops, parking lots, road ways, and pet parks.

Research Objectives

The objectives of this study were to determine if FS with or without the addition of a flocculation agent to the FS can significantly remove (i) clay and silt particulates, (ii) ammonium

N and $\text{NO}_3\text{-N}$, (iii) fecal bacteria, (iv) heavy metals, and (v) petroleum hydrocarbons (PHC) from storm water runoff.

Materials and Methods

Experimental Design, Rainfall Simulation, and Soil Chamber System

The laboratory study was set up to simulate rainfall and to collect and examine runoff from soil chambers with and without FS installed (Fig. 1). Five separate experiments (I–V) were conducted to test the removal efficiency of FS, with and without flocculation agent treatment additions, of various pollutants from runoff generated by a rainfall simulator (Table 1). A bare soil or bare concrete surface was used as the control for each experiment. All treatments and controls were randomly assigned to box chambers and repeated in triplicate for statistical analysis. Each experiment was designed to evaluate treatment performance on a specific group of pollutants typically found in urban runoff. Experiment I evaluated removal of fine sediment particulates, clay (<0.002 mm) and silt (0.002–0.05 mm); Exp. II evaluated removal of inorganic N, $\text{NH}_4\text{-N}$, and $\text{NO}_3\text{-N}$; Exp. III evaluated removal of coliform bacteria and *Escherichia coli*; Exp. IV evaluated removal of typical urban stormwater metals, Cd, Cr, Cu, Ni, Pb, and Zn; and Exp. V evaluated removal of petroleum hydrocarbons (polycyclic aromatic hydrocarbons), motor oil, diesel fuel, and gasoline.

The rainfall simulation system has been previously described in detail by Guber et al. (2007) and consisted of a rain simulator equipped with a TeeJet ¼ HH SS 14 WSQ nozzle (Spraying Systems Co., Wheaton, IL) mounted on a frame at approximately 2.6 m (8.5 ft) above the chamber surfaces. The chambers used in this experiment were constructed of 15 mm (0.6 in) thick plywood, with inside dimensions of 100 cm (39.4 in) length by 35.56 cm (14 in) width by 25 cm (9.8 in) depth, and were described in detail in Sadeghi and Isensee (2001) (Fig. 1).

Chambers were prepared by packing a Hartboro silt loam (Ap horizon) soil. The soil was added in small increments to the 15 chambers and packed with a pressure of approximately 0.15 kg cm^{-2} (2.14 psi) before each addition (Sadeghi and Isensee, 2001). Soil was packed until the chambers contained 7.62 cm (3 in) of soil. A week before the runoff simulation, the chamber drains were plugged and 3.8 L (1 gal) of water was uniformly applied to each chamber to prewet the soils. If necessary, the adjustable runoff drain was unplugged and the gate was positioned so the runoff drain was level with the soil surface. Silicone was used to seal the gate and prevent any leaks during the simulation. For Exp. V, involving PHC, the soil surfaces were covered with a 6.4 mm (0.25 in) concrete veneer to simulate surface conditions from road ways and parking lots. The concrete veneer was separated from the soil surface by a thin black plastic sheet.

Experimental Setup and Rainfall-Runoff Collection

The area under the rainfall simulator allowed four chambers to be tested at one time (Fig. 1). Chambers were tilted to a 10% slope and exposed to 30 min of rainfall. Twelve cups (8.9

cm [3.5 in] in diameter and 11.4 cm [4.5 in] high) were placed adjacent to the soil chambers during simulation to quantify average rainfall intensity. Table 1 shows the average rainfall intensity for each experiment. Runoff from each chamber was collected in a series of 1 L preweighed Nalgene bottles, with the exception of Exp. V, in which all runoff was collected in a 19-L (5-gal) bucket. For Exp. I through IV, after the simulations, the bottles were weighed to calculate total runoff volume. Mean runoff volume and time elapsed data (30–40 min) were used to develop runoff hydrographs for each treatment. For Exp. V, the total runoff volume was determined by measuring water height and area in each collection bucket.

Treatment Description and Installation

The FS, filled with specified composted filter media (USEPA, 2006), were manufactured and supplied by Filtrexx International (Fig. 1) (Filtrexx International 2008). No processing was conducted once FS were received at the experimental laboratory. The compost filter media was enclosed in a tubular mesh netting material. The manufacturer uses a mechanical auger to fill an empty mesh netting sock with composted filter media and seals the ends with metal clips. The mesh netting was a 5 mm (0.20 in) photodegradable polypropylene with 3.2 mm (0.13 in) diamond mesh apertures. The containment of the compost filter media in the open mesh netting allows surface runoff to flow freely through the FS, while containing the filter media and potential sediment and soluble pollutants present in runoff. Twenty centimeter (8 in) diameter FS were cut to fit tightly to the chamber width dimension (35.56 cm [14 in]). The FS were placed at the down slope end of the chamber and slightly compacted manually to ensure ground surface contact. Compost filter media was used to backfill chamber corners and the FS and surface contact interface. Preweighed flocculation agents were added to treatments by manually broadcasting on the backfill filter media along the entire width of the FS and chamber, at the point where surface runoff meets the FS. This application procedure follows manufacturer's field installation guidelines. Application rates for flocculation agents and the experiment in which they were used are listed in Table 1. Application rates followed manufacturer's (Filtrexx International) application specifications (based on per linear meter of FS). Flocculation agents were added to evaluate their potential impact on pollutant removal efficiency. Additives included NitroLoxx (for nitrogen), BactoLoxx (for bacteria), MetalLoxx (for heavy metals), and PetroLoxx (for petroleum hydrocarbons). These flocculation agents are similar to those commonly used to flocculate and chemically adsorb opposite charged ionic pollutants commonly treated in water and storm



Fig. 1. Experimental set up.

water treatment facilities. All flocculation agents are derived from natural aggregate materials and were applied in granular form ($\leq 2\text{mm}$ [0.08 in]). All flocculation agents were supplied by Filtrexx International.

Pollutants were added to the chamber system to generate concentrations under a worst-case scenario. Experiment I used bare soils to generate clay and silt runoff sediment loads. For Exp. II, 34:0:0 (N-P-K) N fertilizer was uniformly applied to the top 40 cm (15.7 in) of the slope at a rate of 202 Kg ha^{-1} (180 lbs ac^{-1}) ($17.8 \text{ g per chamber}$) 12 h before simulation. For Exp. III, fresh bovine manure slurry (10% solids) was obtained from a free-stall barn located at the Dairy Research Unit of the USDA-ARS-Beltsville Agricultural Research Center (BARC), Beltsville, MD, and applied immediately before simulation to the top 70 cm (27.6 in) of the slope at a rate of 10 Kg m^{-2} (44.6 ton ac^{-1}) (2 L per chamber). For Exp. IV, metals were applied in solution using 500 mL multi-component stock solution containing 15 mg L^{-1} (15 ppm) each of Cd, Cr, Cu, Ni, Pb, and Zn elements. The stock solution was prepared 24 h before simulations by mixing 150 mL of 1000-mg L^{-1} Cd, Cr, Cu, Ni, Pb, and Zn into 10 L deionized water. The 500 mL solution was uniformly applied immediately before simulation to the top 70 cm (27.6 in) of the slope. For Exp. V, 100 mL

Table 1. Experimental treatments, flocculation agent application rates, pollutant application rates, and rainfall intensity by experiment.

Experiment	Treatments	Application rate of flocculation agent g linear m ⁻¹	Application rate of pollutant	Rainfall intensity cm h ⁻¹
I	Bare soil, FS	None	None	11.03 ± 0.29
II	Bare soil, FS, FS+NitroLoxx	422	202 Kg N ha ⁻¹	11.19 ± 0.14
III	Bare soil, FS, FS+BactoLoxx	422	10 kg manure m ⁻²	9.57 ± 0.20
IV	Bare soil, FS, FS+MetalLoxx	422	15 mg L ⁻¹ Cd, Cr, Cu, Ni, Pb, Zn	10.12 ± 0.11
V	Bare concrete, FS, FS+PetroLoxx	498	100 mL motor oil, diesel, gasoline	11.17 ± 0.10

FS = FilterSocks.

each of gasoline, diesel fuel, and motor oil (5W30 weight) were each uniformly applied to the top of the slope immediately before simulation.

Runoff Analysis

Total suspended solids (TSS) concentration (g L^{-1}) was determined by oven-drying (at 60°C [140°F] for 48 h) after filtration. Turbidity was determined using the LaMotte 2020 Turbidimeter. Particle size analysis of runoff sediment was determined using a laser scattering particle diameter frequency distribution analyzer (Horiba LA-920, Horiba Jobin Yvon Inc., Edison, NJ). Particle sizes were grouped according to clay sediment (<0.002 mm), silt sediment (0.002 – 0.05 mm), class 1 (0.02 – 5.75 μm) sediments; and class 2 (5.75 – 19.95 μm) sediments. Concentrations of nitrate N and ammonium N (mg L^{-1}) were determined by automated continuous flow injection analysis (Lachat QuikChem methods no.12-107-04-1-B and no. 12-107-06-2-A, respectively). Concentrations of TC and *E. coli* (MPN 100 mL^{-1}) in runoff were determined using Colilert Defined Substrate Technology and Quanti-Tray/2000 analysis (IDEXX United States, Westbrook, ME). Soils were sampled (2.54 cm [1 in] depth) for determination of Cd, Cr, Cu, Ni, Pb, and Zn concentrations (mg Kg^{-1} [ppm]). Composite samples were taken from four random locations within the chambers. Metals concentrations in runoff were partitioned between its aqueous (mg L^{-1}) and solid (sediment) phases (mg Kg^{-1}). All samples were analyzed by inductively coupled plasma optical emission spectrometry (ICP-OES) (PerkinElmer, Waltham, MA). Elements below ICP detection limits were analyzed by atomic absorption spectroscopy. Total solids analysis was performed to determine loss of sediment-bound metals. Total solids concentration (g L^{-1}) was determined by oven-drying 100 mL of raw sample at 60°C (140°F) for 48 h. Petroleum hydrocarbon runoff samples were processed by TestAmerica Laboratory (Exton, PA) for determination of gasoline (Gasoline Range of Organics, GRO, USEPA Method 8015B), diesel fuel (Diesel Range of Organics, DRO, USEPA Method 8015B), and motor oil (Silica Gel Treated N-Hexane Extractable Material, SGT-HEM, USEPA Method 1664) concentrations (mg L^{-1}). Means for all pollutant concentrations were determined using three replications per treatment. Runoff loads for sediment particles, N species, bacteria, and PHC were determined by multiplying pollutant concentrations by water or sediment volume. Removal efficiencies for all treatments in all experiments were determined by the equation: $\text{RE} = 100 - [(\text{RLT}/\text{RL}) \times 100]$, where RE is removal efficiency (%), RLT is runoff load from treatment, and RL is runoff load from the control.

Statistical Analysis

Statistical analysis for means separation was performed using Proc Mixed, SAS Institute Ver 9.1, on the effect of FS and FS plus flocculation agents on the runoff concentration and load of sediment, N, bacteria, metals, and petroleum hydrocarbons. Separation of means was determined to be significant at the $P < 0.05$ level.

Results and Discussion

Sediment Particle Size

Average total sediment load generated from the controls was 34 g (8.2 tons ac^{-1}), with 24% classified as clay sediment and 76% classified as silt sediment. The FS showed 65 and 66% removal efficiency for clay and silt particulates, respectively (Table 2), although difference in means was not significant. Mean FS removal efficiency for Class 1 (0.01 – 5.75 μm) and Class 2 (5.75 – 19.95 μm) sediment particulates was 60 and 80%, respectively. These sediment fractions typically represent the majority of suspended solids and turbidity found in surface waters. Additionally, water quality regulations often stipulate allowable limits for sediment particle size discharges.

Nitrogen

Mean runoff concentration from the control for ammonium N ($\text{NH}_4\text{-N}$) and nitrate N ($\text{NO}_3\text{-N}$) was 4.28 and 4.44 mg L^{-1} (4.28 and 4.44 ppm). Mean concentration from the FS treatment for $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ was 3.37 and 3.72 mg L^{-1} ; and from FS plus NitroLoxx was 3.31 and 4.53 mg L^{-1} , respectively. Means were not significantly different. Mean runoff N load from the controls was 54 and 55 mg of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ (Table 2). Removal efficiency for the FS was 17% for $\text{NH}_4\text{-N}$ and 11% for $\text{NO}_3\text{-N}$. The addition of NitroLoxx to the FS increased removal efficiency of $\text{NH}_4\text{-N}$ to 27% but did not increase $\text{NO}_3\text{-N}$ removal. Yu et al. (1993) and the Florida Department of Transportation (1994) reported $\text{NO}_3\text{-N}$ removal efficiencies between 10 and 20% for grass filter strips up to 46 m and Hsieh and Davis (2005) found removal efficiencies for bioretention systems between 1 and 43% and 2 and 49% for $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$. Removal of the $\text{NH}_4\text{-N}$ was likely due to ionic adsorption from the negatively-charged organic matter in the FS. The increased removal efficiency of $\text{NH}_4\text{-N}$ was likely due to the increased ionic adsorption capacity provided by the NitroLoxx flocculation agent. The surface of NitroLoxx particulates has a strong affinity for ammonium cations as it contains a high concentration of cationic exchange sites, which promote ion-exchange with and adsorption of ammonium N (Nguyen and Tanner, 1998; Englert and Rubio, 2005). Adsorption of $\text{NH}_4\text{-N}$ from runoff water may reduce transport and loading of receiving waters, thereby reducing the potential for eutrophication from N.

Bacteria

Mean runoff concentration ($\text{MPN}/100\text{mL}^{-1}$) from the controls was $2.02 \times 10^8/100 \text{ mL}^{-1}$ and $1.72 \times 10^8/100 \text{ mL}^{-1}$ for total coliforms and *Escherichia coli*. Mean concentration for the FS treatment was $0.58 \times 10^8/100 \text{ mL}^{-1}$ and $0.46 \times 10^8/100 \text{ mL}^{-1}$ for TC and *E. coli*, respectively. The FS plus BactoLoxx was $0.03 \times 10^8/100 \text{ mL}^{-1}$ and $0.02 \times 10^8/100 \text{ mL}^{-1}$ for TC and *E. coli*. The FS plus BactoLoxx treatments resulted in significantly lower total coliform concentration values relative to the control. Mean runoff load from the control was $2.68 \times 10^{10}/100 \text{ mL}^{-1}$ and 2.28×10^{10} for TC and *E. coli*, respectively (Table 2). The FS removal efficiency for TC and *E. coli* was 74 and 75%,

respectively. Removal efficiency by the FS was likely due to their ability to remove sediment and the affinity bacteria have for attaching to sediment particulates. Previous studies have reported that these microorganisms can be transported on runoff sediment particles, particularly suspended clay sediments (Guber et al., 2005a, 2005b; Roodsari et al., 2005), which in turn were effectively trapped by the FS as previously reported by Faucette et al. (2008). The highest removal efficiency was observed with the FS plus BactoLoxx treatment, which removed 99% of both TC and *E. coli* from the simulated runoff. The elevated removal efficiency found in this treatment is likely from the flocculation of bacteria provided by the BactoLoxx. Bulson et al. (1984) similarly reported removal of these microorganisms due to flocculation processes resulting from the reaction of flocculation agents with the natural hydroxide alkalinity of water. These reactions form a hydroxide complex that entraps the bacterial cells.

Metals

Average metal load transported in runoff to the treatments ranged from 0.49 to 1.699 mg (Table 3). Removal efficiencies for the six metals by the FS ranged from 37 to 71% where the FS treatment significantly reduced all metals except Cr. Removal efficiencies for Pb and Zn for grass filter strips up 46 m wide range from 40 to 55% for Zn, and 25 to 50% for Pb (Yu et al., 1993; Florida Department of Transportation (1994). Metals removal efficiencies using bioretention systems range from 66 to 98% for Pb (Hsieh and Davis 2005), 56 to 99% for Cu and Zn (Hunt and Lord, 2006), and 88 to 97% for Cd, Cu, and Zn (Sun and Davis 2007). Average removal efficiency for soluble metals in runoff ranged from 17 to 72%, where the FS treatment significantly reduced all metals in solution except Cr; while metals sorbed to sediment particulates ranged from 42 to 82%. Removal of sediment-bound metals by FS was likely due to the treatment's ability to remove sediment particulates from runoff. Removal of metals in solution by the FS was likely due to ionic adsorption of metals by organic matter in FS. Average removal efficiencies of the six metals by the FS with MetalLoxx addition ranged from 47 to 73%, where all metals were significantly reduced relative to the control. Average removal efficiency for metals in solution ranged from 22 to 79%, where all metals significantly lower with the exception of Cr; and metals sorbed to sediment particulates ranged from 45 to 84%. The increase in metal removal by the MetalLoxx addition was likely due to increased adsorption provided by the physical structure and high surface area of this material, which also exhibits a high cation-exchange-capacity and, thus, an affinity for heavy metals (Pitcher et al., 2004; Widiastuti et al., 2008).

Petroleum Hydrocarbons

Mean PHC concentration in runoff from the controls was 5400, 1410, and 74 mg L⁻¹ for diesel fuel, motor oil, and gasoline. Mean concentration from the FS treatment was 8.23, 272.63, and 49 mg L⁻¹ for the three PHCs, respectively. Mean concentration for the three PHCs for FS plus PetroLoxx was 9.93, 11.67, and 38.67 mg L⁻¹. Both treatments significantly

Table 2. Pollutant load and removal efficiency for each treatment for Exp. I, II, III, and V.

Experiment	Treatment	Clay		Silt		NH ₄ -N		NO ₃ -N		Total coliform		Escherichia coli		Motor oil		Diesel		Gasoline	
		g	Rem (%)	g	Rem (%)	mg	Rem (%)	mg	Rem (%)	MPN/100 mL	Rem (%)	Rem (%)	Rem (%)	mg	Rem (%)	mg	Rem (%)	mg	Rem (%)
I	Bare soil	8.16a ± 4.3†	0	25.84a ± 13.7	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	FS	2.86a ± 0.47	65	8.79a ± 1.47	66	*	*	*	*	*	*	*	*	*	*	*	*	*	*
II	Bare soil	*	*	*	*	54.0a ± 16	0	55.0a ± 27	0	*	*	*	*	*	*	*	*	*	*
	FS	*	*	*	*	44.8a ± 14	17	49.0a ± 16	11	*	*	*	*	*	*	*	*	*	*
	FS+ NitroLoxx	*	*	*	*	39.4a ± 17	27	53.4a ± 21	3	*	*	*	*	*	*	*	*	*	*
III	Bare soil	*	*	*	*	*	*	*	*	2.68 × 10 ¹⁰ b	0	2.28 × 10 ¹⁰ a	0	*	*	*	*	*	*
	FS	*	*	*	*	*	*	*	*	± 2.64	± 2.3	± 2.3	75	*	*	*	*	*	
V	FS+ BactoLoxx	*	*	*	*	*	*	*	*	0.7 × 10 ¹⁰ ab	74	0.57 × 10 ¹⁰ a	99	*	*	*	*	*	*
	Bare concrete	*	*	*	*	*	*	*	*	± 1.04	± 0.87	± 0.87	99	*	*	*	*	*	
V	FS	*	*	*	*	*	*	*	*	0.03 × 10 ¹⁰ a	99	0.02 × 10 ¹⁰ a	99	*	*	*	*	*	*
	FS+ PetroLoxx	*	*	*	*	*	*	*	*	± 0.035	± 0.031	± 0.031	99	*	*	*	*	*	
															20.820b	0	77.440b	0	1070b ± 94
															± 12,616	± 33,184			
															1239a ± 5768	84	208a ± 3	99	610a ± 43
															774a ± 132	99	208a ± 52	99	492a ± 61

† Means with same letters were not significantly different at the P ≤ 0.05 level.

Table 3. Soluble and sediment-bound pollutant load and removal efficiency for each treatment for Exp. IV.

Experiment	Treatment	Metal form		Cd		Cr		Cu		Ni		Pb		Zn	
		mg	Rem (%)	mg	Rem (%)	mg	Rem (%)	mg	Rem (%)	mg	Rem (%)	mg	Rem (%)	mg	Rem (%)
IV	Bare soil	Soluble	0.742b ± 0.105†	0	0.312a ± 0.078	0	1.257b ± 0.075	0	0.976b ± 0.255	0	0.684b ± 0.070	0	1.428b ± 0.26	0	
		Sediment	0.060b ± 0.041	0	0.179b ± 0.089	0	0.224b ± 0.160	0	0.079b ± 0.052	0	0.268b ± 0.241	0	0.304b ± 0.253	0	
		Total	0.812b ± 0.146	0	0.49ab ± 0.089	0	1.625b ± 0.209	0	1.054b ± 0.306	0	0.94b ± 0.199	0	1.699b ± 0.488	0	
FS	Soluble	Sediment	0.266a ± 0.036	64	0.258a ± 0.125	17	0.405a ± 0.118	68	0.381a ± 0.072	61	0.191a ± 0.026	72	0.667a ± 0.078	53	
		Total	0.016ab ± 0.005	73	0.045a ± 0.016	75	0.129b ± 0.03	42	0.031a ± 0.007	60	0.079a ± 0.013	70	0.111ab ± 0.017	64	
FS+ MetalLoxx	Soluble	Sediment	0.282a ± 0.039	64	0.303ab ± 0.140	37	0.534a ± 0.144	67	0.412a ± 0.078	61	0.270a ± 0.037	71	0.778a ± 0.091	54	
		Total	0.210a ± 0.057	72	0.221a ± 0.05	29	0.383a ± 0.054	70	0.301a ± 0.101	69	0.144a ± 0.023	79	0.621a ± 0.044	57	
		Sediment	0.014a ± 0.005	77	0.039a ± 0.003	78	0.122b ± 0.012	45	0.029a ± 0.008	63	0.105a ± 0.024	61	0.161a ± 0.086	47	
MetalLoxx	Total	Sediment	0.224a ± 0.062	73	0.260a ± 0.049	47	0.505a ± 0.067	70	0.330a ± 0.106	69	0.249a ± 0.024	73	0.782a ± 0.074	53	

† Means with same letters were not significantly different at the $P \leq 0.05$ level.

reduced all PHC concentrations, relative to the control. Mean PHC loads from the controls was 77,440; 20,820; and 1070 mg for diesel, motor oil, and gasoline, respectively. Both treatments removed 99% of diesel fuel (Table 2). The FS removal of motor oil was 84%, however, when PetroLoxx was added to the FS removal efficiency increased to 99%. The FS removal of gasoline was 43%. When PetroLoxx was added to FS removal efficiencies increased to 54%. Hsieh and Davis (2005) report oil/grease removal for bioretention systems were >96%. Both treatments significantly reduced all PHCs relative to the control. The high removal efficiencies of diesel and motor oil by the FS were likely due to physical filtration. The high surface area of the compost filter media matrix within the FS coupled with the viscosity and high molecular weight relative to water of these PHCs help to physically extract them from runoff water. The FS plus PetroLoxx likely increased removal of these PHCs due to increased physical surface area provided by the PetroLoxx additive. Removal of these PHCs from runoff can reduce their transport and loading in surface waters. This can be critical near national section 303(d) listed water bodies, marine and boat storage areas, and urban parking lots and roadways.

Summary and Conclusions

This study concludes that FS may be an effective means to filter pollutants commonly found in urban runoff, particularly, coliform bacteria, metals (with the exception of Cr), and petroleum hydrocarbons; while significant reduction of N with this technology was inconclusive. Removal of these pollutants by FS combines physical removal of particulate-bound pollutants and chemical removal of soluble pollutant forms through ionic adsorption processes. Furthermore, the addition of these flocculation agents can be used to target specific pollutants and increase their removal from stormwater runoff. Based on these results this technology may be used to reduce loading of harmful bacteria, metals, and hydrocarbons to receiving waters and performance may be similar or better than grass filter strips and bioretention systems. This may assist NPDES permit holders with stormwater quality discharge compliance; TMDL and watershed managers stay within TMDL requirements for stream segments or even help to remove stream segments from TMDL designation; reduce the incidence of suspension of recreational water use; decrease stormwater treatment costs by removing these pollutants before entry into stormwater sewer systems or containment systems; or replace other low impact development management practices, such as grass filter strips and bioretention systems, particularly where constraints on land area or footprint requirements exist.

Future research should be conducted to evaluate pricing, breakthrough curves, and removal capacity (longevity) for FS exposed to these various pollutants. Cost data for application of these materials will need to be determined on a project-by-project basis, based on size/scale of project, region of the country, and type of application. These criteria will help designers specify appropriate application rates and reapplication schedules (maintenance) based on pollutant load exposure to

the system and assist the manufacturer in price development. Pollutant concentration, flow rate variations, and their effect on removal efficiency should also be explored.

Acknowledgments

The authors would like to thank Nick Strazar and Randy Rowland for their assistance conducting experiments, along with Kerry Sefton, Dominic Brose, Valerie McPhatter, and Mebrat Gesese, who also assisted with processing and analysis of samples. The authors also thank Dr. Carrie Green and Dr. Patricia Millner at the USDA-ARS for experimental design and analysis consultations. Finally, the authors would like to thank Rod Tyler and Alex Marks for donating and supplying materials. Product names are used for the benefit of the reader and do not imply endorsement or approval by research organization or investigators.

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