Flow-Through Rates and Evaluation of Solids Separation of Compost Filter Socks versus Silt Fence in Sediment Control Applications

Harold M. Keener, Britt Faucette,* and Michael H. Klingman

ABSTRACT

Soil loss rates from construction sites can be 1000 times the average of natural soil erosion rates and 20 times that from agricultural lands. Silt fence (SF) is the current industry standard used to control sediment originating from construction activities. Silt fences are designed to act as miniature detention ponds. Research has indicated that SF sediment filtering efficiency is related to its ability to detain and pond water, not necessarily the filtration ability of the fabric. Design capacity and spacing is based on flow-through rate and design height. In addition, increased detention of runoff and pressure from ponding may increase the likelihood of overtopping or failure of SF in field application. Testing was conducted on compost silt socks (SS) and SF to determine sediment filtering efficiency, flow-through rate, ponding depth, overtopping point, design height, and design capacity. Results indicate flow-through rate changes with time, as does ponding depth, due to the accumulation of solids on/in the sediment filters. Changes in depth with time were a linear function of flow rate after 10 min of flow, up to the time the sediment filter is overtopped. Predicting the capacity of SF and SS to handle runoff without the filter being overtopped requires consideration of both runoff rate and length of runoff time. Data show SS half the heights of SF were less likely to overtop than SF when sediment-laden runoff water flow rates are less than 1.03 L^{-1} s^{-1} m^{-1} (5 gpm/ft, gal per minute per lineal foot). Ponded depth behind a 61.0-cm (24 in) SF increased more rapidly than behind a 30.5-cm diam. (12 in) SS, and at the end of the thirty minutes, the depth behind the SF was 75% greater than that behind the SS. Removal of solids by the SF and the SS were not shown to be statistically different. Results were used to create a Microsoft Excel-based interactive design tool to assist engineers and erosion and sediment control planners on how to specify compost SS relative to SF in perimeter sediment control applications.

Soil loss rates from construction sites can be 1000 times the average of natural soil erosion rates (Smoot et al., 1992) and 20 times that from agricultural lands (USEPA, 2000). In 2003, the federally mandated National Pollution Discharge Elimination System (NPDES) Phase II storm water rules went into effect extending the storm water pollution prevention plan requirement to any land-disturbing activity over 0.405 ha (1 acre). Violators can be held in noncompliance with the federal Clean Water Act and can be fined up to $100,000 (USD) per day per violation. Although equal attention should be placed on soil erosion prevention, deleterious effects to receiving water quality are the result of sedimentation. When eroded sediment is transported from its site of origin to nearby surface waters it also carries fertilizers, pesticides, fuels, and other contaminants and substances commonly spilled at construction sites that readily attach to soil particles (Risse and Faucette, 2001). Ehrhart et al. (2002) reported that high suspended sediment concentration discharges from construction activities into streams persisted 100 m (328 ft) downstream and negatively impacted macroinvertebrate populations. It is estimated that the national cost to society due to sedimentation of eroded soil is over $17 billion per year (Brady and Weil, 1996).

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 Jarrett, 1984; USEPA, 1993; Barrett et al., 1998; Britton et al., 2000). Geosynthetic silt fences, when installed correctly, function as temporary runoff detention storage areas (Robichaud et al., 2001), designed to increase ponding depth (Goldman et al., 1986) to allow suspended particulates to settle out of storm runoff before discharging the runoff down slope of the sediment barrier. Barrett et al. (1995) concluded that effective sediment trapping efficiency of silt fence is a result of increased ponding behind the silt fence, while Kouwen (1990) concluded that excessive ponding is largely due to eroded sediment clogging the fabric of the silt fence. Barrett et al. (1998) further concluded that sediment removal efficiency by silt fence was not attributable to the filtration by the fabric but due to settling of particles during detention behind the silt fence.

While this design may function well under relatively small runoff events, if runoff or ponding becomes excessive the silt fence may fail due to overtopping; in response, the design height of silt fence has steadily increased from 45.7 cm (18 in) to 61.0 cm (24 in) to 91.4 cm (36 in) over the past few years. Additionally, the force created by the increase in head and the prolonged detention of storm runoff may predispose silt fence to failure in field applications. Wyant (1981) and the USEPA (2005) recommend that silt fence have a sediment-laden water flow-through rate of 0.204 L m^{-2} s^{-1} (0.3 gal^{-1} ft^{-2} s^{-1}). Sediment-laden runoff water concentrations appropriate for testing silt fence according to ASTM D 5141 are 2890 mg L^{-1} (2890 ppm)(Barrett et al., 1995).

The USEPA (1993) reports as high as 80 to 90% of sand (particle size 0.05–2 mm) can be trapped by silt fence. Meanwhile, silt (0.002–0.05 mm) and clay (<0.002 mm), the fraction of eroded soil that typically remains in suspension, is trapped less than 20% when using silt fence. Horner et al. (1990) reported a 2.9% reduction in turbidity when using silt fence installed under field condi-

H.M. Keener and M.H. Klingman, Food, Agricultural, and Biological Engineering, The Ohio State Univ./Ohio Agricultural Research and Development Center, Wooster, OH 44691. B. Faucette, Filtrexx International, 1352 North Ave, NE Suite 10, Atlanta, GA 30307. Received 7 Sept. 2006. *Corresponding author (brittf@filtrexx.com).

Published in J. Environ. Qual. 36:742–752 (2007).
Technical Reports: Surface Water Quality
doi:10.2134/jeq2006.0359

Abbreviations: SS, SiltSoxx; SF, silt fence; SCD, sediment control device; PSLW, ponded sediment-laden water.

tions. Similarly, Barrett et al. (1998) concluded that silt fences are ineffective in reducing turbidity. While 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 in the storm water runoff. They observed 92% of the total suspended solids were clay and silt particles that were an order of magnitude smaller than the openings in the silt fence fabric. Due to very low settling velocities, these particles are normally not removed by sedimentation.

Although many new products have been designed to trap sediment, there is very little research literature on them relative to silt fence. Faucette et al. (2005) reported on mulch filter berms on a 10% slope, under hydroseed conditions during construction. The berms reduced total solids loads between 16 and 64% relative to silt fence. Demars et al. (2000) reported similarly that under a 1.91 cm (0.75 in) storm event mulch berms reduced total sediment loads by 80% relative to silt fence and by 97% relative to hay bales, respectively. Under an 11.2 cm (4.4 in) storm event mulch berms reduced total sediment relative to straw bales and silt fence by 91 and 92%, respectively. Ettlin and Stewart (1993) found that compost filter berms reduced total solids concentrations by 72% and suspended solids concentrations by 91%, relative to silt fence. Compost filter socks have been defined by the USEPA (2006) as contained filter berms, whereas the media used within the sock is the same (according to specifications) as that used in filter berms but the sock containment system allows for the practice to be used in concentrated flow situations. Due to the similar nature of the organic media used, compost filter socks should perform as good or better then loose filter berms.

Compost or mulch filter berms have filters that are of three-dimensional construction (as opposed to a planar construction for silt fence) and are designed to allow runoff to flow through at higher rates. The larger, three-dimensional construction of these sediment filters may allow the filter itself to trap suspended solids from runoff reducing the need to pond water to allow settling to occur. Less ponding and lower head pressure may reduce the propensity for failure from blowout and overtopping in the field.

The goal of this study was to develop the equations which would assist professionals in specifying sediment control devices such as SiltSoxx (SS) (Filtrexx International, LLC., Grafton, OH) or silt fence (SF) for erosion control, sediment control, or storm water pollution prevention. Specific objectives were:

Experimentally determine flow-through capacity and filtration efficiencies of SS and SF as a function of runoff flow rate and slope angles.

Develop predictive models of flow-through rates of SS and SF for clear water and sediment-laden water as a function of runoff flow rate and slope angle.

Illustrate use of developed models for selecting sizes of SS and/or SF as sediment control devices for a specific watershed and rainfall event.

Expected results will (i) provide insight on the effectiveness of various sediment control devices in mitigating pollution in the runoff from construction sites and material storage areas (i.e., open agricultural feedlots, commercial composting, departments of transportation) and (ii) assist in the specification and design of sediment-laden, runoff water control devices utilizing SS in place of SF.

MATERIALS AND METHODS

Research was conducted at the Ohio Agricultural Research and Development Center (OARDC) composting research center, Wooster, OH. For conducting the test a flume of nominal dimensions 0.610 m (2 ft) wide, 0.914 m (3 ft) sidewalls, and 2.44 m (8 ft) length was built from MDO (medium density overlay) plywood (Fig. 1). The frame on which it was mounted allowed the slope of the flume to be fixed at 10° or 20° by varying the length of the upslope legs. The base of the flume was designed with bolts on removable sidewall sections which could hold in place a 20.3-cm diam. (8 in) SS, 30.5-cm diam. (12 in) SS, or a 61.0-cm (24 in) SF.

The mounting system was designed to prevent short circuiting of flow under and around the filter being tested. This was accomplished by having the SS penetrate the removable sidewall section through a correspondingly sized hole and fixing it in place on the outside of the sidewall section. The ends of the soxx were then capped with a wooden sidewall plug so that the plane of the sidewall was maintained by the plug. The edges of the plug were sealed with a silicone sealant so that leakage was minimal. The silt fence was wrapped around the edge of the removable sidewall section and fixed to maintain a tight seal at the sidewall. The silt fence was mounted perpendicular to the slope and the SS was laid on the slope.

For the studies with clear water, a 151-L tank (40 gal) located at the exit of the flume was used to supply water to a pump and to capture outflow from the flume for recirculation. The water flow path (Fig. 1) was from the 151-L tank to the 0.373 kW (0.5 Hp) Dayton High Head Straight Centrifugal pump (W.W. Grainger, Inc., Lake Forest, IL) via a 5.08-cm diam. (2 in) line, and then from the pump through a filter, water meter, brass gate valve (for regulating flow) to a header pipe at the top of the flume made of 2.54-cm diam. (1 in) PVC. Two 2.54-cm diam. outlet openings delivered water to the flume. Preliminary studies on the sediment control devices with clear water showed that steady-state flow was achieved after 3 to 4 min test duration. Thus, tests were run for 7 min, and average flow was based on data points collected at 5, 5.5, 6, 6.5, and 7 min. Visual observations on flow distribution along the 61.0 cm wide sediment control device showed no apparent edge effect of flume sidewalls. Data was analyzed based on the full 61.0 cm (2 ft.) width of filter.

For the studies with sediment-laden water, a 643-L (170 gal) cone bottom tank provided water to the pump (Fig. 2). The water after the pump was split so a portion of the sediment-laden water was recirculated to the supply tank to maintain the soil in suspension and a portion was delivered to the header pipe at the top of the flume. For this study the header pipe had four 1.27-cm diam. (0.5 in) openings to evenly distribute the water across the flume at the lower flow rates. Water from the flume was discharged and not recirculated in these studies. For the sediment-laden water test requiring more than 568 L

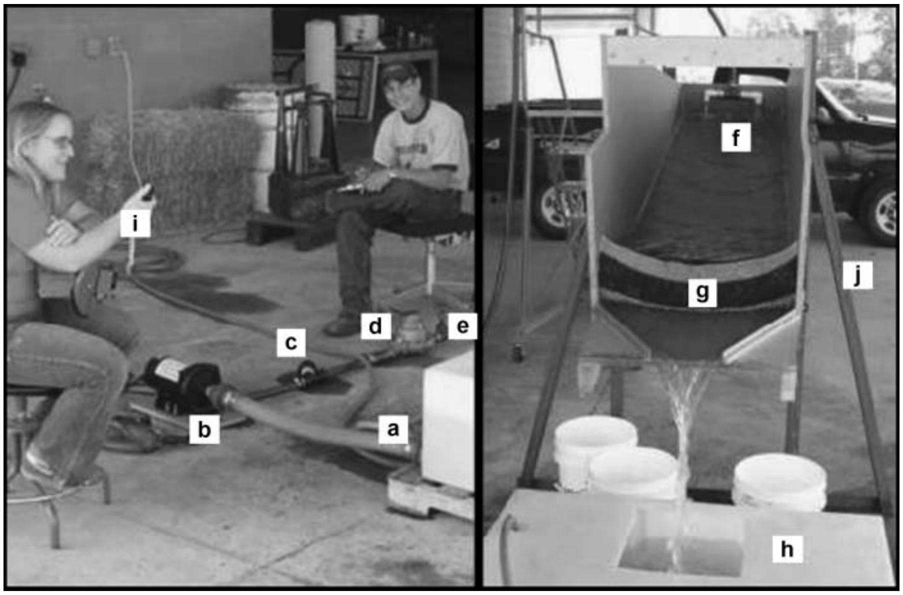

Fig. 1. Laboratory test setup using a flume 0.61-m width by 2.44-m length (2 by 8 ft.) to determine flow-through capacity of SiltSoxx and silt fence with clear water. (a) Outlet from supply tank, (b) pump, (c) filter, (d) flow meter, (e) valve, (f) header, (g) 20.3-cm diam. (8 in) SiltSoxx, (h) 151-L (40 gal) water tank, (i) timer, and (j) frame.

(150 gal) of water, the test was interrupted for 2.5 to 3.5 min during which time the tank was refilled with water from an 1893-L (500 gal) nurse tank with a 12.6 L^{-1}s^{-1} (200 gpm, gallons per min) pump, soil added, and mixed. The depth of the ponded water and time were recorded when the water to the flume was stopped. Following resumption of water flow, time measurements were resumed when the water depth retained by the sediment control devices reached the depth recorded at time of shut down.

The sediment-laden water was formulated by adding 6438.8 g of air-dried (7.4% moisture) Wooster silt loam soil (fine-loamy, mixed, active, mesic Oxyaquic Fragiudalfs) (sieved to a particle size less than 2 mm) to 644 L (170 gal) of water (solids content of 10 g L^{-1} or 1% w/w) and allowing the pump to recirculate the sediment-laden water for 10 to 15 min while hand stirring with a 2.54-cm diam. rod. The soil was sieved before use in the test because preliminary tests with a 1:1 mix of sand and Wooster silt loam soil showed the larger particles settled out at the top of the flume and never reached the quiescent water at the sediment control device.

The SS fabric, SF, and compost materials used in the studies were obtained from Filtrexx International, Grafton, OH. The SS materials were standard products of 20.3-cm diam. (8 in) and 30.5-cm diam. (12 in). It was made of HDPE plastic and has a 0.953 cm (0.375 in) knitted mesh. The silt fence was 61.0 cm (24 in) in height with a #30 apparent opening size (ASTM-4751), a 122 kg (260 lbs) warp tensile strength (ASTM D-4632), and measured flow rate of 24.6 L m^2 min^{-1} (70 gal/ft^{-2}/min). For

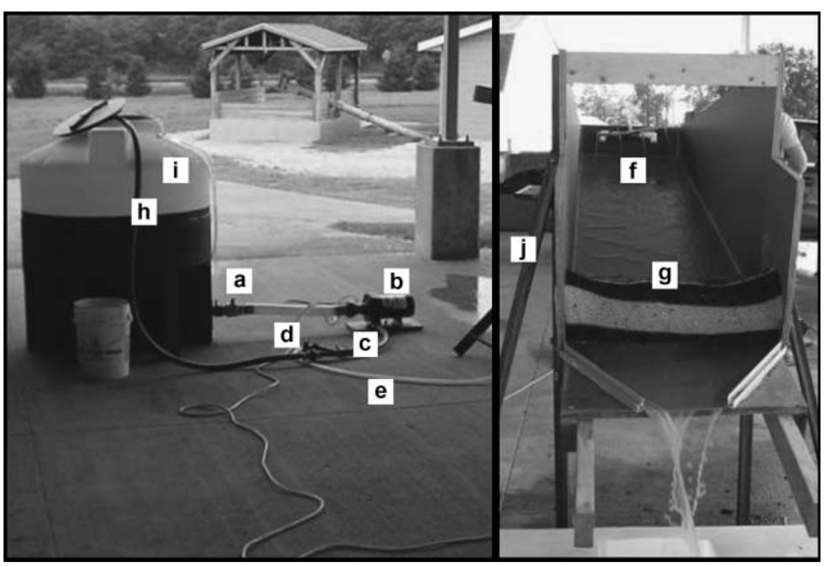

Fig. 2. Laboratory test setup using a flume to determine filtration and flow-through capacity of SiltSoxx and silt fence using sediment-laden water. (a) Outlet from supply tank, (b) pump, (c) Y tee, (d) valve in recirculation line, (e) delivery line, (f) header, (g) 20.3-cm diam. (8 in) SiltSoxx, (h) by-pass flow line, (i) 643-L (170 gal) cone bottom tank, and (j) frame.

test purposes the 61.0-cm SF was mounted with only 45.7 cm (18 in) extending above and perpendicular to the bottom of the flume, as 15.2 cm (6 in) is normally buried below ground in field application.

The compost material used in these studies was yard trimmings compost and consisted of two grades, a fine grade and a coarse grade, which were separated by screening with a 0.953-cm (0.375 in) trommel screen. Particle sizes of the materials used in the test were determined using a roto-tap shaker and six standard sized sieves ranging from 1.27 cm (0.5 in) opening down to 0.168 cm (0.0661 in) (#12 ASTM sieve size). Distributions of fine and coarse material for the compost are presented in Table 1. The compost was air-dried to below 20% moisture before screening. Results show the fine compost had about 81% of particles less than 0.794 cm (0.313 in) and 8% particles greater than 1.27 cm (0.5 in). The coarse compost had 41% of particles less than 0.794 cm (0.313 in) size and 27% greater than 1.27 cm (0.5 in).

Filling of the SS with compost was done by mounting the SS in the holder and plugging one end in the flume sidewall. Then compost was packed in the SS through the open end until the SS was stretched to the desired tension (as defined by Filtrexx International, LLC) and based on their guideline "no free play in the SS material when pinched." For the clear water studies, the SS was filled horizontally. For the sediment-laden water studies, the SS was filled vertically (Fig. 3) by rotating the flume on its side with a forklift. Going to vertical filling was done as it proved to be a quicker and easier method to achieve uniform packing. After filling a 1.91 cm (0.75 in) thick plug was inserted in the end of the SS to contain the compost and prevent end flow of water.

Test Procedure

The 61.0-cm (24 in) SF was used as a control in all studies. In the clear water test, flow-through rates for each SS (20.3-cm diam. fine, 20.3-cm diam. coarse, 30.5-cm diam. fine, and 30.5-cm diam. coarse) were tested by applying three fixed flow rates measured in terms of L $s^{-1}m^{-1}$ (gpm/ft, gal per minute per lineal foot) at the top of the flume for slopes of 18 and 36% (10° and 20°). Test duration lasted until the depth of the ponded water retained by each sediment control device stabilized or 30 min had elapsed, whichever occurred first. The depth of the ponded water retained by the SS or SF was determined at steady state for each test and was measured perpendicular to the slope at the leading edge of the filter. Also, a flow rate which defined system failure (flow over the top) was determined for each product by increasing flow rates until

Table 1. Particle size distribution of compost used in flow-through studies (weight basis).

ASTM sieve no.	Size of openings		Weight fractions retained by each sieve: Fine Avg†	Fine Std dev‡	Coarse Avg§	Coarse Std dev¶
	cm	in	%			
1/2	1.270	1/2	7.7	1.7	27.2	6.6
5/16	0.794	5/16	10.8	1.5	30.9	3.2
#3.5	0.566	0.223	12.3	1.3	12.7	1.3
#5	0.399	0.157	13.4	0.3	7.5	1.9
#7	0.282	0.111	12.7	0.5	5.4	2.0
#12	0.168	0.0661	13.3	0.8	5.6	2.1
Pan	–	–	29.3	1.9	10.0	4.1

† 12 samples from four tests.
‡ Standard deviation of four means.
§ 15 samples from five tests.
¶ Standard deviation of five means.

Fig. 3. Filling of 30.5-cm diam. (12 in) SiltSoxx with coarse material.

water flowed over the top of the sediment control device. Flow rates for the clear water test were determined using flow meter readings taken at 30-s intervals both before starting and during the test. Actual flow rates were set by adjusting a valve. Each flow rate test was repeated three times for the same SS or SF setup resulting in 120 test runs (five filters, four flow rates, two slopes, three replications). Results for SS or SF flow-through capacities were evaluated as a function of flow rate to each sediment control device (L s^{-1} m^{-1}).

For the sediment-laden water studies, flow-through capacity was evaluated as a function of time (min) and flow rate to the sediment control device (L s^{-1} m^{-1}) by measuring the depth of the ponded sediment-laden water (PSLW) retained by the 20.3-cm diam. coarse SS, 30.5-cm diam. coarse SS, and the 61.0-cm SF over a 30-min test period. Input flow rates of 0.126, 0.252, 0.315, and 0.946 L s^{-1} (2, 4, 5, and 15 gpm) were used. PSLW retained by the SS and SF were measured at 5-min intervals. Figure 4 shows the three sediment control devices being tested at 0.126 L s^{-1} flow rates. For these tests, the sediment-laden water entering the flume was split into four streams to achieve sheet flow conditions down the flume.

Treatments were run for the 20.3-cm diam. and 30.5-cm diam. coarse SS and the 61.0-cm SF at a 10° slope. No studies using the fine particle compost were conducted because the extremely low flow rates found during the clear water studies relative to the SF made such tests impractical. Fresh SS or SF materials were used each time. In addition, two tests were run at 0.946 L s^{-1} (15 gpm) for the 30.5-cm diam. coarse SS and the 61.0-cm SF. The total number of tests conducted with the sediment-laden water was 29 (three filters, three flow rates, one slope, three replications + two filters, one slope, one flow rate, one test).

For the sediment-laden water studies, flow rate was set before a test by using a stop watch and measuring flow into a graduated 1000-L cylinder. Then the valve was adjusted until the desired flow rate was achieved. During the actual test period, the sediment-laden water volume in the supply tank was recorded initially and at 5-min intervals. The change in volume was used to calculate flow rates.

Because PSLW depth changed behind the sediment control device as material accumulated at/on the sediment control device, measurement of PSLW depth at the sediment control device was made at 5-min intervals over the 30-min test periods. Also, solids content of sediment-laden water entering the flume and exiting the sediment control device were determined by collecting approximately 250-g samples of sediment-laden water at a time = 0, 10, 20, and 30 min. Solids were analyzed

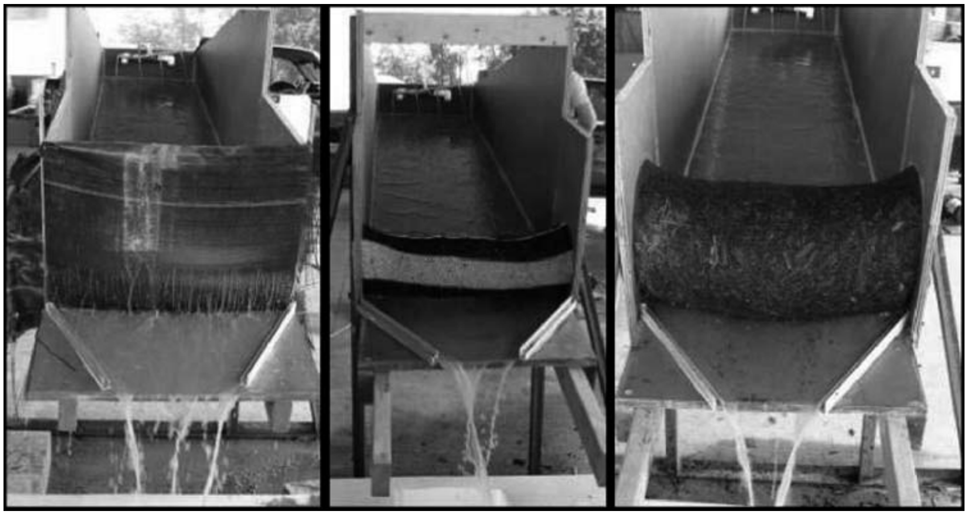

Fig. 4. Flow of sediment-laden water through sediment control devices at 0.126 L s^{-1} (2 gpm) at t = 10 min. From left to right, 61.0-cm (24 in) silt fence mounted 45.7 cm (18 in) above flume bottom, 20.3-cm diam. (8 in) coarse SiltSoxx, and 30.5-cm diam. (12 in) coarse SiltSoxx.

by oven-drying each sample for 48 h at 90°C. The samples were weighed to the nearest 0.01 g. Three replicates of each treatment were collected. Results of the analysis of 12 samples (four samples per replicate) taken during each treatment gave average dry matter contents of the incoming sediment-laden water to the flume of 0.51 to 0.78% dry wt. for 20.3-cm diam. SS, 0.58 to 1.04% for the 30.5-cm diam. SS, and 0.72 to 0.93% for the 61.0-cm SF test.

RESULTS AND DISCUSSION

Clear Water Test

Results with clear water showed (i) the 20.3-cm diam. SS and 30.5-cm diam. SS gave similar flow-through rates as a function of ponded water depth when filled with the same material; (ii) the SS with fine compost had flow-through rates that were approximately 1/4 that of the SS with coarse compost (see equations in Fig. 5) as a function of ponding depth when depth exceeded 5.08 cm (2 in); (iii) the SF had flow-through rates that were more than 50% greater than the coarse compost SS over the 5.08-cm (2 in) to 20.3-cm (8 in) depths tested; and (iv) flow rates through the sediment control devices were a power function of depth and didn't change appreciably with time. Results suggested that a 20° slope caused flow rates through sediment control devices to be slightly higher than for the 10° slope at the same water depth.

Equations which define output flow-through rates (q_o) as a function of depth of ponded water (d_f) for sediment control devices are illustrated in Fig. 5. Since the 20.3-cm diam. and 30.5-cm diam. SS gave similar q_o at a given water depth, data for a specific compost (fine or coarse) were pooled and plotted on the same graph. A power function would be expected, ie., as water depth increases the pressure increases vertically along the filter (Vennard, 1963). A theoretical analysis for flow through a uniform porous media gives 1.5 for the exponent on depth (d_f), ie., $q_o = Cd_f^{1.5}$, where d_f = depth of the ponded water (cm) retained by the sediment control device measured perpendicular to slope. From the regression equations for the pooled data for the 10° and 20° slopes, the exponents on d_f were 1.249, 1.492, and 1.285 for the fine SS, coarse SS, and SF, respectively.

Results with clear water showed large differences in q_o for the different sediment control devices tested. For example, when water depth was 20.3 cm the SS with fine compost had about 16% of the flow-through rate of the SF (or about 20% of the coarse SS) while the coarse compost SS had about 75% of the SF.

Sediment-Laden Water Test

Results with the nominal 1% sediment-laden water (measured 0.5–1% dry matter) showed the 20.3-cm diam. SS coarse and 30.5-cm diam. SS coarse gave similar flow rates as a function of PSLW depth when depth was less than 7.6 cm (3 in) and that depth steadily increased with time at a given in-flow rate for both SS and SF. Depth vs. time of application of sediment-laden water to the 30.5-cm diam. coarse SS and 61.0-cm SF are given in Fig. 6. It is postulated the PSLW depths retained by the sediment control devices (SCD) increased with time as the suspended solids in the water plugged the smaller pores of the filter. However, PSLW retained by the SF increased more rapidly than the PSLW retained by the 30.5-cm diam. SS. As a result, by the end of the 30-min test, the depth of the PSLW for the SF was 75% greater than that of the SS. In particular, at 0.95 L s^{-1}, the 30.5-cm diam. coarse SS overtopped at 20+ minutes with a PSLW depth slightly above 22.9 cm (9 in) and the 61 cm (45.8 cm effective) high SF overtopped at 20 min with a PSLW depth slightly less than 40.6 cm (16 in). The lower overtopping depths were due to the SS sagging to a more elliptical shape and the SF bowing and sagging. The ratio of the overtopping depth to the height (diameter) of the SCD is defined as ψ where

$$\psi = D_f^*/D_f \quad [1]$$

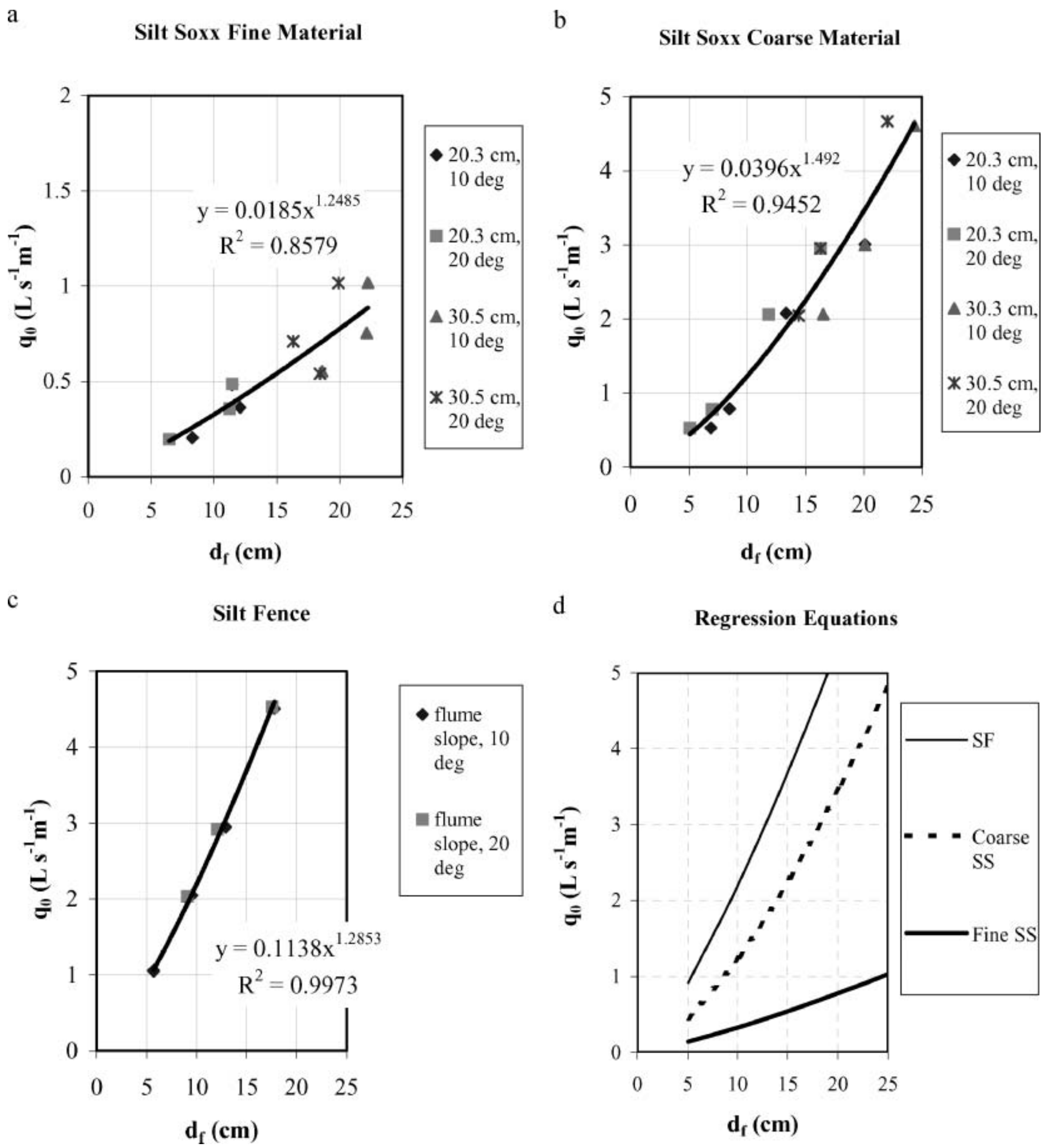

Fig. 5. Flow-through rates (q_0) for clear water vs. ponding depth of water for: (a) SiltSoxx (SS) using fine compost (see Table 1) for both 10° and 20° slopes vs. depth, (b) SS using coarse compost (see Table 1) for both 10° and 20° slopes vs. depth, (c) silt fence (SF) for both 10° and 20° slopes vs. depth, and (d) fine SS, coarse SS, and SF using regression equations.

where D_f^* = overtopping depth of PSLW retained by the SCD measured perpendicular to slope (cm), and D_f = height or diameter of the SCD (cm).

For these studies ψ was evaluated at 0.85 for the SF and 0.80 for the SS.

Because ponding depth changed with time as well as flow rate, the PSLW depths (d_f) at 30 min vs. flow rates (q_f) were plotted (Fig. 7) instead of q_o vs. d_f, as was done for the clear water test (Fig. 5). As before with clear water, since the 20.3-cm diam. and 30.5-cm diam. SS gave similar depths for a given flow, data was pooled and plotted on the same graph. Results showed that ponding depths vs. flow rates for the sediment-laden water could be approximated by a power function. The exponents on flow were 0.698 and 1.0 for the SF and coarse SS, respectively.

Because the depth of the PSLW retained by the porous SCD changed with time when the inflow was sediment-laden water, the flow rate to overtop either the SS or SF could not be calculated by using the simple power functions given in Fig. 7. Observation of the data for sediment-laden water flow indicated ponding depth at the SCD increased rapidly at the start of flow and then leveled off to where it increased at approximately a linear rate over time until the SCD was overtopped (Fig. 8a, 8b).

Recognizing this effect allowed formulating the following relationship for ponding depth as a function of time.

$$d_f = A(q_f)t + B(q_f) \quad [2]$$

where d_f = ponding depth (cm), q_f = sediment-laden water flow rate (L s^{-1} m^{-1}), t = time (min), $A(q_f)$ = rate of increase in ponding depth as a function of sediment-laden water flow rate and suspended solids (fixed in this

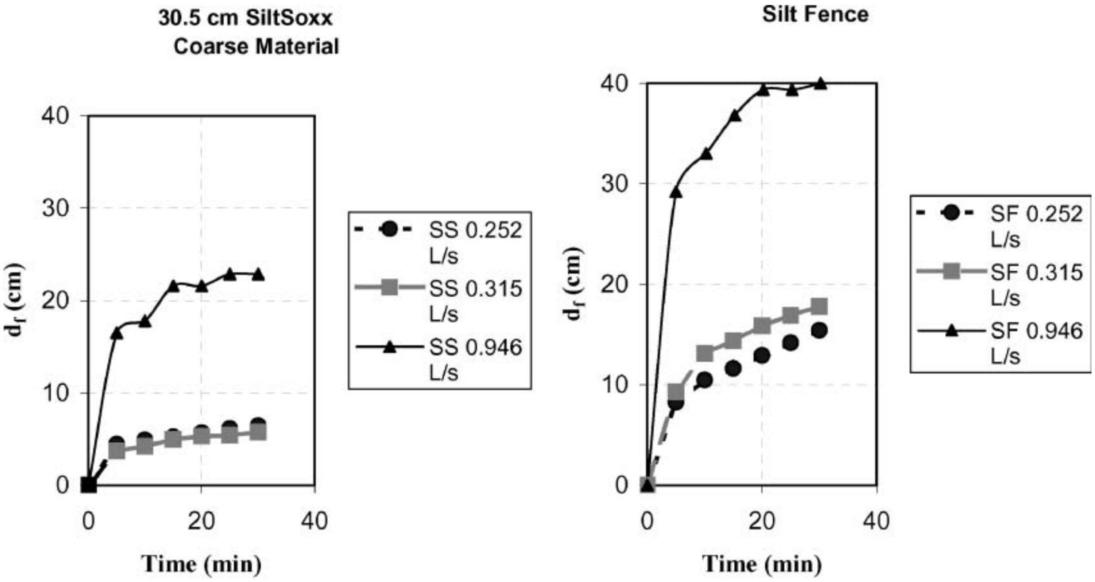

Fig. 6. Effect of time on depth of sediment-laden water retained by the 30.5-cm diam. (12 in) coarse SiltSoxx and silt fence.

study) concentration (cm/min), and $B(q_f)$ = initial ponding depth behind the SCD before it begins to plug (cm).

A and *B* were estimated for SF and SS for the flow rates 0.207, 0.517, and 1.55 L s^{-1} m^{-1} (1, 2.5, and 7.5 gpm/ft) over a 10 to 30 min time period. Results for the SF gave *A* and *B* as linear functions of flow rate (Fig. 8c, 8e), whereas results for the 30.5-cm diam. SS gave *A* and *B* as exponential functions of flow rate (Fig. 8d, 8f). The very high R^2 values (0.9844, 1.00, 0.9891, 0.9938) were partly the result of having only limited test results to evaluate, but did show the data fit the model. To have $t \rightarrow \infty$ when $q_f \rightarrow 0$, an additional term of $(1 - \exp(-Cq_f^{\,n}))$ was included in the *A* term. More tests would be needed to accurately evaluate *C* and *n*, but values of $C = 120$ and 560 and $n = 3$ and 2 for the SF and SS respectively, were found to satisfy the data for q_f = zero and $q_f \geq 0.207$ L s^{-1} m^{-1}.

Based on these results the following equations were derived for time to overtop a SCD (See Appendix for equations in English units).

Silt fence:

$$t = \frac{d_f - (14.641q_f + 3.3003)}{0.3827q_f + 0.0739(1 - \exp(-120q_f^{\,3}))} \qquad [3]$$

SiltSoxx:

$$t = \frac{d_f - 0.8282\exp^{1.2385q_f}}{0.014(1 - \exp(-560q_f^{\,2}))\exp^{1.5131q_f}} \qquad [4]$$

Equation [3] was solved for SF with heights of 61.0 cm (24 in), 76.2 cm (30 in), and 91.4 cm (36 in), assuming effective SF height would be 85% of the total above ground height. Equation [4] was solved for SS with diameters of 20.3 cm (8 in), 30.5 cm (12 in), and 45.7 cm (18 in), assuming effective height was 80% of the total diameter. Results (Fig. 9) indicate that when flows are less than 1.03 L s^{-1} m^{-1} (5 gpm/ft) the 30.5-cm diam. and 45.7-cm diam. SS with coarse compost will out perform (less likely to overtop) the 91.4-cm SF (76.2 cm

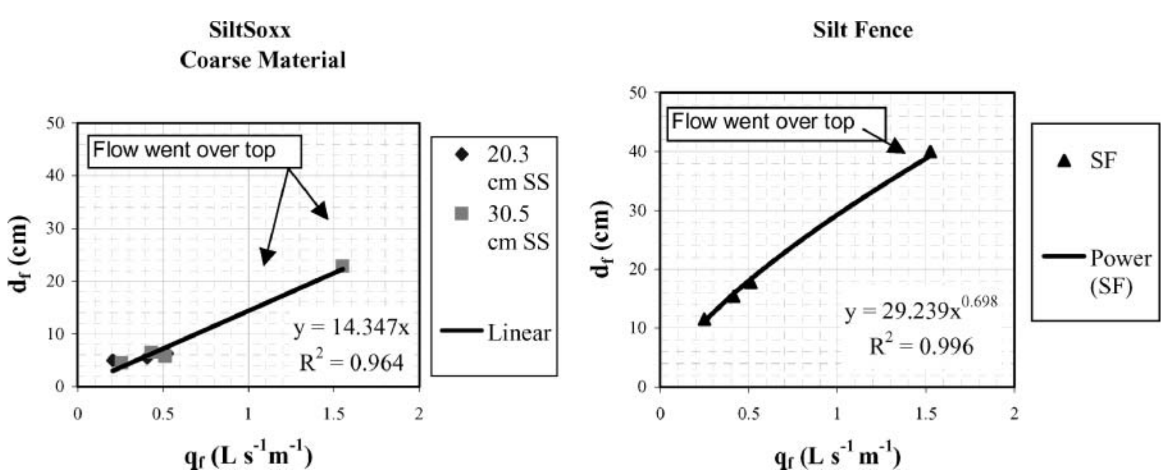

Fig. 7. Depth vs. sediment-laden water flow rate after 30 min of run time for the 20.3-cm diam. (8 in) coarse SiltSoxx (SS), 30.5-cm diam. (12 in) coarse SS, and 61.0-cm (24 in) silt fence mounted 45.7 cm (18 in) above flume bottom.

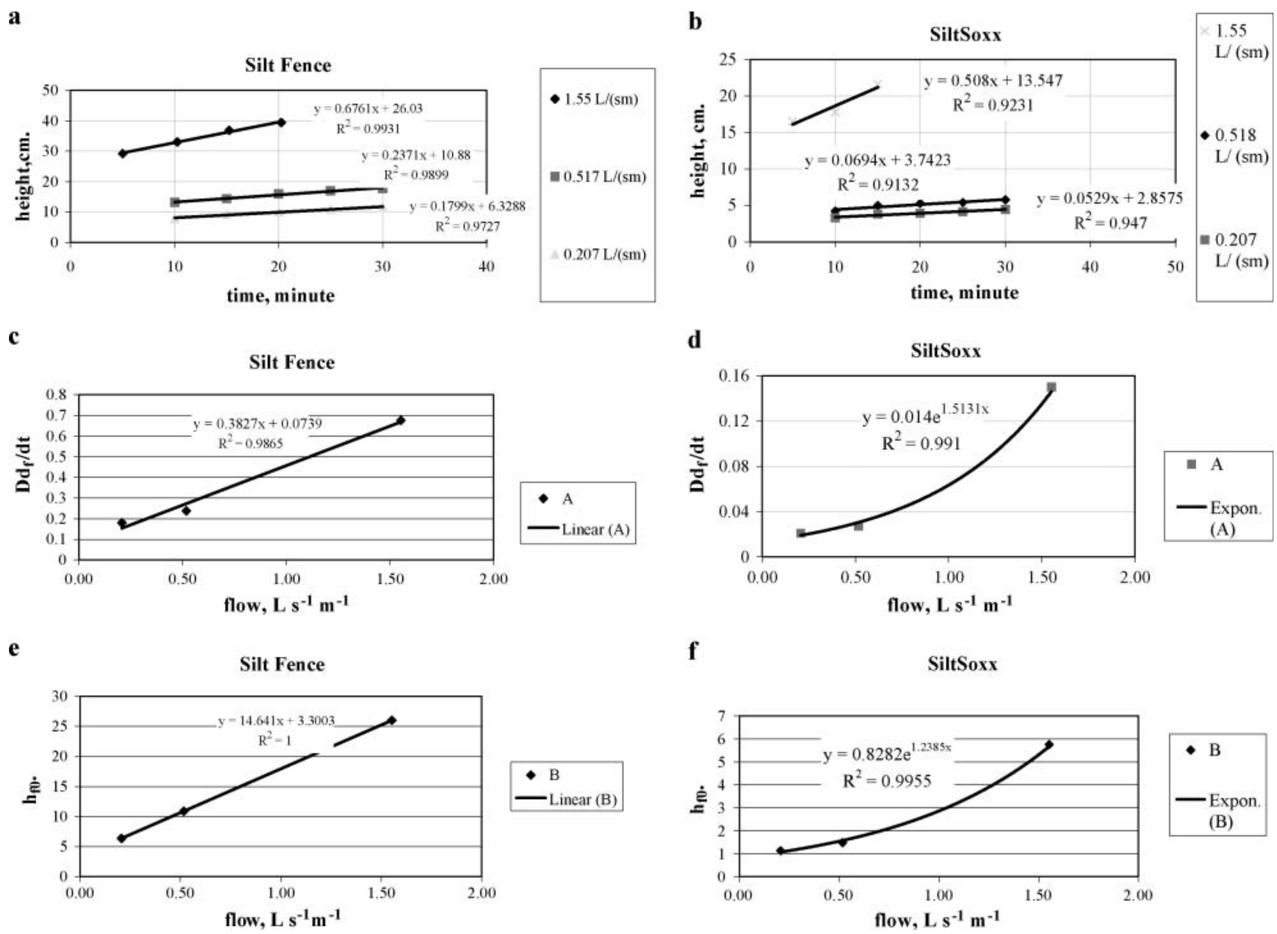

Fig. 8. (a–f) Evaluation of pond depth retained by a silt fence and SiltSoxx as a function of flow rate and time for sediment-laden water runoff.

above ground). Results also indicated the 20.3-cm diam. SS is approximately equivalent to the 61.0-cm SF (45.7 cm above ground).

Fig. 10 shows total solids removal (TSR) efficiency (dry solids removed per liter divided by initial dry solids per liter) over the 30-min test periods for all three sedi-

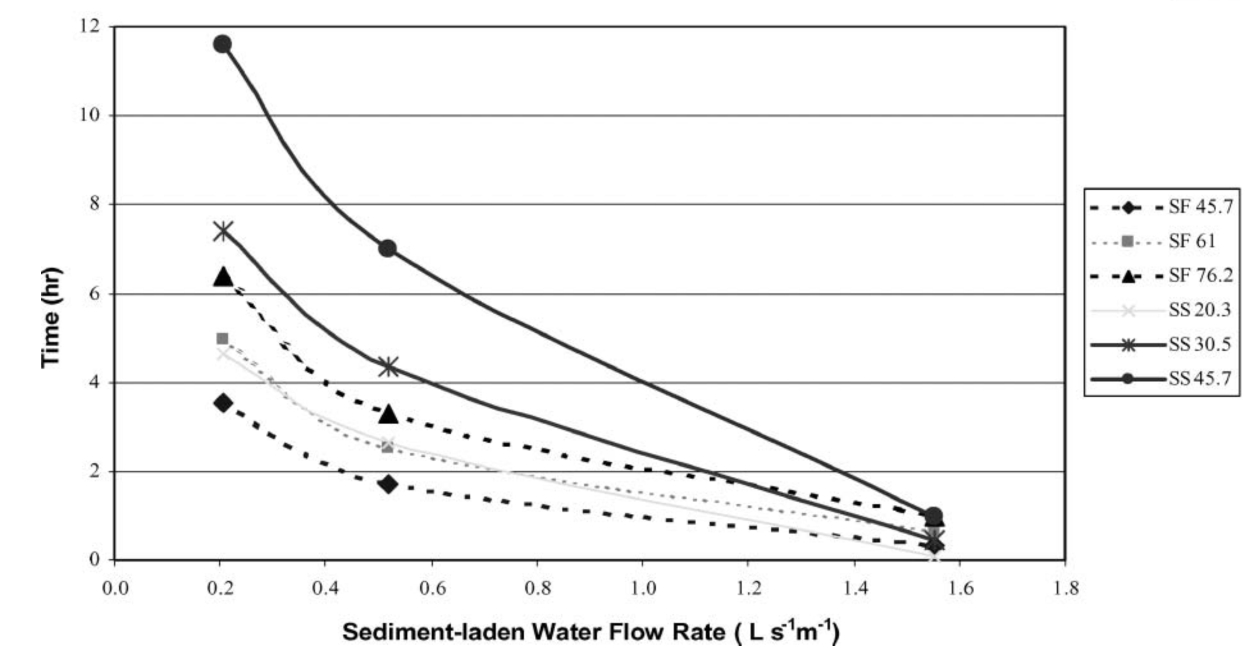

Fig. 9. Time to overtop silt fence (SF) and SiltSoxx (SS) as a function of sediment-laden water flow rate. $\psi = 0.85$ for SF and 0.80 for SS.

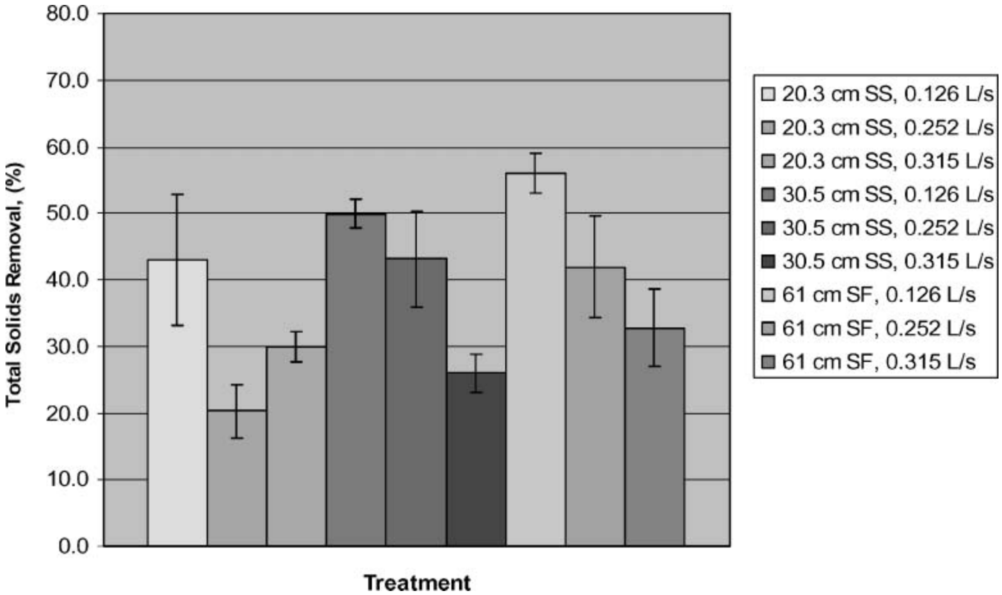

Fig. 10. Total solids removal efficiency for 20.3-cm diam. (8 in) coarse SiltSoxx (SS), 30.5-cm diam. (12 in) coarse SiltSoxx, and 61-cm (24 in) silt fence (SF) with a height of 45.7 cm (18 in) above the flume. The standard error of the means for each treatment is shown.

ment control devices. TSR efficiency was 50.0, 34.7, and 29.3% at in-flow rates of 0.126, 0.252, and 0.315 L s^{-1} (2, 4, and 5 gpm), respectively, when test results were averaged over all three SCDs. TSR efficiency was 30.7, 39.7, and 43.0% for the 20.3-diam. cm SS, 30.5-cm diam. SS, and 61.0-cm SF, respectively, when results were averaged over all three in-flow rates. Removal efficiency for the SF was higher than the 20.3-cm diam. coarse SS in these tests, but based on standard errors was not significantly higher than the coarse 30.5-cm diam. SS. For in-flow rates of 0.946 L s^{-1} (15 gpm) (three times as high as any previous rate tested), average TSR efficiency was highly variable within the test run and is not reported as no replication was done.

A question that came out of the test procedures was: "Is there a correct filling procedure or density for the SS and how does it correlate with what industry is doing (eg., measure the diameter of the sock after filling)." It should be noted that removal efficiencies for SS and SF in this experiment were lower than those reported in the literature review. This is likely because the sediment used in this study was composed of screened Wooster silt loam soil less than 2 mm in particle size.

Comparison of the flow rates for clear water and sediment-laden water through SS and SF showed there was a complete reversal in results. The SF had higher flow rates than the SS for clear water at a given depth (eg., over 50% lower at d_f = 20.3 cm), whereas for the sediment-laden water, the SS had much higher flow rates for a given depth (eg., 236% higher for 1.39 L s^{-1} m^{-1} (6.84 gpm/ft) vs. 0.59 L s^{-1}m^{-1} (2.87 gpm/ft) at d_f = 20.3 cm). However, changes in packing or density of compost or changes in particle size would affect these overall results. During the study, the amount of compost added per 30 cm (1 ft) for the 20.3-cm diam. and 30.5-cm diam. SS was not based on a unique weight, but rather was based on a subjective volume determined by the tension in the SS fabric.

Design of Runoff Control Structure

Runoff from a sloped surface is shown schematically in Fig. 11. The equations for runoff are:

$$Q_f = \frac{IWL\cos(s)\ 10}{3600} = 0.002778IWL\cos(s) \quad [5]$$

$$q_f = \frac{Q_f}{W} = 0.002778IL\cos(s) \quad [6]$$

where Q_f = flow rate to SCD (L s^{-1}), I = rainfall intensity (cm h^{-1}), t = storm duration (h), W = width, i.e., length of SCD (m), L = length of slope (m), s = angle of slope (degrees), and q_f = flow rate to SCD per unit of SCD length (L s^{-1} m^{-1}).

Selection of a SCD height or diameter (D_f) can be done by calculating q_f using Eq. [6] and then using Eq. [3] or [4] (or Fig. 9) for either SS or SF with a known effective height (d_f*) and an expected storm duration t.

For example, consider a 2-h storm with total rainfall of 6 cm. Slope angle is 5° and slope length is 60 m. q_f = 0.50 L s^{-1}m^{-1}. From Fig. 9, it is found that a 45.7 cm SF would overtop at approximately 1.9 h whereas a 20.3-cm diam. SS would not overtop. Equations [3], [4], [5], and [6] have been incorporated into a Microsoft Excel-based interactive spread sheet which allows assessment of the adequacy of the design of a SF or SS for a particular runoff control problem.

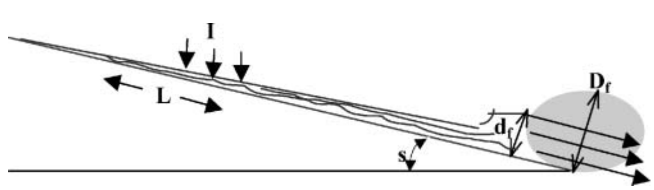

Fig. 11. Diagrammatic representation of control structure in operation and variables used to calculate water runoff rates. I = rainfall intensity, L = slope length, s = angle of slope, d_f = height of water retained by the filter perpendicular to slope, D_f = filter height or diameter.

CONCLUSION

Results of this study showed that the SF and SS behaved differently under clear water and sediment-laden water runoff (approximately 0.9% solids) conditions. For clear water, flow-through rate was relatively constant over time. This can be represented by a simple power function of ponding depth. For the sediment-laden water, flow-through rate and ponding depth were changing with time due to the accumulation of solids on/in SCD. After 10 min of flow, PSLW depth increased with time as a linear function of flow-through rate up to the time the SCD was overtopped. Prediction of capacity of the SF and SS to handle runoff without the SCD being overtopped requires consideration of both runoff rate and length of time. Results showed SS half the height of SF would be less likely to overflow than SF when sediment-laden water flow is less than 1.03 L s^{-1} m^{-1}. It should be noted that packing density and particle size distribution of the compost would likely effect magnitudes of both flow-through rate and solids removal. Also, studies to determine effects of varying concentration on coefficients used in Eq. [3] and [4] are needed to further clarify the relationships between solution and design of filter systems and potential soil loss for a particular application.

ACKNOWLEDGMENTS

The authors acknowledge the contributions of Evan Kamenik and Meaghann Bolin, summer students who ably assisted in the running of experiments, technical assistance from Roger Mass, Research Assistant, and editorial review of paper by Dr. Robert Hansen, Research Scientist, Department of Food, Agricultural, and Biological Engineering, OARDC/OSU, Wooster, OH. Salaries and research support were provided by Filtrexx International, LLC, 35481 Grafton Eastern Rd. Grafton, OH and State and Federal funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State Univ.. Use of a commercial trade name or company in this paper does not imply endorsement of the products but is included only to assist the reader.

REFERENCES

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 Tech. Rep. 261. Univ. of Texas at Austin, Austin, TX.

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

Brady, N.C., and R.R. Weil. 1996. The nature and properties of soils, 11th ed. Prentice Hall, Inc., New Jersey.

Britton, S.L., K.M. Robinson, B.J. Barfield, and K.C. Kadavy. 2000. Silt fence performance testing. Presented at the July 2000 ASAE Annual International Meeting, Paper 00-2162. ASAE, St. Joseph, MI.

Demars, K.R., R.P. Long, and J.R. Ives. 2000. New England Transportation Consortium use of wood waste materials for erosion control. April 2000. New England Transportation Consortium, Fall River, MA.

Ettlin, L., and B. Stewart. 1993. Yard debris compost for erosion control. BioCycle 34:12:46–47.

Ehrhart, B.J., R.D. Shannon, and A.R. Jarrett. 2002. Effects of construction site sedimentation basins on receiving stream ecosystems. Transactions of the American Society of Agricultural Engineering 45:3:675–680.

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. J. Soil Water Conserv. 60(6):288–297.

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

Goldman, S.J., K. Jackson, and T.A. Bursztynsky. 1986. Erosion and sediment control handbook. McGraw-Hill, Inc., New York, NY.

Horner, R.R., J. Guedry, and M.H. Kortenhof. 1990. Improving the cost effectiveness of highway construction site erosion and pollution control. Washington State Transportation Center, Washington State Transportation, Seattle, WA.

Kouwen, N. 1990. Silt fences to control sediment movement on construction sites. Report MAT-90-03. Research and Development Branch, Ontario Ministry of Transportation, Downsview, Ontario.

Risse, L.M., and B. Faucette. 2001. Compost utilization for erosion control. Univ. of Georgia Cooperative Extension Service Bull. 1189. CAES-UGA, Athens, GA.

Robichaud, P.R., D.K. McCool, C.D. Pannkuk, R.E. Brown, and P.W. Mutch. 2001. Trap efficiency of silt fences used in hillslope erosion studies. *In* Proceedings International Symposium, Soil Erosion Research for the 21st Century, Honolulu, HI. 701P0007, 541–543. ASAE, St. Joseph, MI.

Smoot, J.L., T.D. Moore, J.H. Deatherage, and B.A. Tschantz. 1992. Reducing nonpoint source water pollution by preventing soil erosion and controlling sediment on construction sites. Tech. Rep. R01-2512-39-001-92.Transportation Center, Univ. of Tennessee, Knoxville, TN.

USEPA. 1993. Guidance specifying management measures for sources of nonpoint pollution in coastal waters. EPA 840-B-92-002. USEPA, Office of Water, Washington, DC.

USEPA. 2000. Storm Water Phase II Final Rule: Construction site runoff control minimum control measure. Office of Water (4203). EPA 833-F-00-008, Fact Sheet 2.6. USEPA, Washington, DC.

USEPA. 2005. Silt fence: Construction site storm water runoff. National Menu of Best Management Practices. USEPA, Washington, DC. Available at http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm (verified 23 Jan. 2007).

USEPA. 2006. Compost filter socks: Construction site storm water runoff. National Menu of Best Management Practices. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm (verified 23 Jan. 2007).

Vennard, J.K. 1963. Elementary fluid mechanics. John Wiley & Sons, New York.

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

Wyant, D.C. 1981. Evaluation of filter fabrics for use in silt fences. Transp. Res. Record 832(6):6–12.

APPENDIX

Design Eq. 3 and 4 in English Units
Silt fence:

$$t = \frac{d_f - (1.1932q_f + 1.2993)}{0.0312q_f + 0.029(1 - \exp(-5q_f^3))} \quad [A1]$$

SiltSoxx:

$$t = \frac{d_f - 0.8282\exp^{0.2564q_f}}{0.014(1 - \exp(-5q_f^2))\exp^{0.3132q_f}} \quad [A2]$$

where d_f = ponding depth (in), q_f = sediment-laden water flow rate (gpm/ft), and t = time (min).

Table A1. Predicted time and total flow to overtop filter.

	Equations A1 and A2				Regression Eq. Fig. 8a, b	
q_f	Depth†	Eff. depth†	Time	Total flow	Time	Total flow
gpm/ft	in	in	hr	g/f	hr	g/f
Silt fence						
1.00	24.00	15.30	3.56	213	3.02	181
2.50	24.00	15.30	1.72	257	1.97	295
7.50	24.00	15.30	0.32	144	0.32	142
1.00	30.00	20.40	4.97	298	4.22	253
2.50	30.00	20.40	2.51	377	2.88	432
7.50	30.00	20.40	0.64	289	0.64	286
1.00	36.00	25.50	6.39	383	5.42	325
2.50	36.00	25.50	3.30	496	3.79	569
7.50	36.00	25.50	0.97	435	0.95	430
SiltSoxx						
1.00	8.00	6.40	4.64	278	4.23	254
2.50	8.00	6.40	2.63	394	3.01	451
7.50	8.00	6.40	0.08	38	0.07	33
1.00	12.00	9.60	7.42	445	6.79	408
2.50	12.00	9.60	4.37	655	4.96	744
7.50	12.00	9.60	0.45	201	0.43	193
1.00	18.00	14.40	11.60	696	10.64	638
2.50	18.00	14.40	6.98	1047	7.89	1184
7.50	18.00	14.40	0.99	447	0.96	433

† Depth of silt fence is total height. Effective depth assumes 15.2 cm (6 in) is buried in ground when calculating.