Flow-Through Rates And Evaluation Of Solids Separation Of Compost Filter Media Vs. Silt Fence In Sediment Control Applications

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Abstract

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. SiltSoxx™, a compost filter media, is an alternative to silt fence. This paper reports on testing of compost filter socks (SS) and silt fence to determine sediment filtering efficiency, flow-through rate, ponding depth, overtopping point, design height, and design capacity. Results showed changes in depth with time were a linear function of flow rate after ten minutes of flow, up to the time the sediment filter topped. Data showed SS 1/2 the height of SF is less likely to overflow than SF when sediment-laden runoff flow is less than 5 gpm/lineal ft., but predicting the capacity of SF and SS to handle runoff without the filter being topped requires consideration of both runoff rate and length of runoff time. Removal of solids by the SF and the SS were not shown to be statistically different. Results were used to create an MS Excel™ based interactive design tool to assist engineers in designing sediment control structures.

Introduction

Silt fence is the current industry standard used for sediment control in construction activities and its performance has been widely evaluated (Wyant, 1981; Fisher and Jarret, 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.

SiltSoxx™, a compost filter media, is an alternative to silt fence. Faucette et al (2005) reported that for a 10% slope, under hydroseed conditions, compost, mulch filter berms reduced total solids loads 16 to 64%, relative to silt fence. Demars and Long (2000) reported that, during a ¾ inch storm event, mulch berms reduced total sediment by 80% relative to silt fence and by 97% relative to hay bales, respectively. During a 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. However, only limited information is available for designing filtration systems using these new systems

Objectives

- Evaluate the flow-through rate, sediment removal efficiency of silt fence (SF) and SiltSoxx™ (SS) in controlled studies.
- Develop the theory characterizing flow-through capacity and filtration efficiencies of SF and SS as a function of runoff flow rate and slope angles.
- Develop an Excel™ based design tool for selecting the appropriate size of SF or SS for a given storm event and watershed size for erosion and sediment control or storm water pollution prevention.

Materials & Methods

Research was carried out at the Ohio Agricultural Research and Development Center (OARDC) Composting Research Center, Wooster, Ohio. For the study, a flume of nominal dimensions 2 ft wide, 3 ft length was built from MDO plywood (Figure 1). The base of the flume was designed to mount removable fixtures which could hold in place an 8 in. SS, 12 in. SS, or 24 in. SF. For the studies with clear water, a 40 gallon tank, located at the exit of the flume was used to supply water to a pump and to capture outflow from the flume for recirculation (Fig. 1). For the studies with sediment-laden water, a 170 gallon cone bottom tank provided water to the pump (Figure 2). In this case 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. During a test water from the flume was discharged.

Figure 1.
Laboratory test setup using a flume (2 ft. width by 3 ft. length) to determine flow-through capacity of SiltSoxx™ and Silt Fence with clean water. (a) outlet from supply tank, (b) pump, (c) filter, (d) flow meter, (e) valve, (f) header, (g) 8 in SiltSoxx™, (h) 40 gallon water tanks, (i) timer, (j) frame.

Figure 2.
Laboratory test setup using a flume to determine filtration and flow-through capacity of SiltSoxx™ and Silt Fence using soil laden water. (a) outlet from supply tank, (b) pump, (c) Yee, (d) valve in recirculation line (e) delivery line, (f) header, (g) 8 in. SiltSoxx™, (h) by-pass flow line, (i) 170 gallon cone bottom tank, (j) frame.

The sediment-laden water was made by adding 6.4388 kg of air dried (7.4% moisture) Wooster silt loam soil (A horizon), particle size less than 2000 micron, to 170 gallon of water (solids content of 10,000 mg L^{-1}) and allowing the pump to circulate the slurry for 10-15 minutes while hand stirring with a 1 in. diameter rod.

The SS fabric and compost materials used in the studies were obtained from tFiltrexx International, Grafton, Ohio. The SS material were standard products of 8 in. and 12 in. diameter. It was made of HDPE plastic and has a 3/8 in. knitted mesh. The compost material used in these studies was yard trimmings compost and consisted of two grades, a fine grade < 1/8 in. size, and a coarse grade consisting of the overs from screening with a 3/8 in. trommel screen. The SF was of 24 in. height and was mounted with 18 in. extending above and perpendicular to bottom of flume. SF is buried 6 in. in normal field application.

Test Procedure

The 24 in. SF was used as a control in all studies. In the clean water test flow-through rates for each SS (8 in. fine, 8 in. coarse, 12 in. fine and 12 in. coarse) were achieved by applying 3 fixed flows (gallons per minute per lineal foot) at the top of the flume for slopes of 10 and 20 degrees. Test duration lasted until the depth behind the fence stabilized or 30 minutes had elapsed, whichever occurred first. Water depth behind the SS or SF was determined at steady state for each test. Also, a flow rate for failure of filter (flow over top) was determined by increasing flows until the flow overtopped the sediment control device. Flow rates for the clean water test were calculated using flow meter readings taken at 1/2 minute intervals prior to starting and during the test. Each test was replicated 3 times. The number of tests run were 120 (5 filters, 4 flow rates, 2 slopes, 3 replications).

For the sediment-laden water studies, flow rate was set prior to a test by using a stop watch and measuring flow into a graduated 1000 L cylinder and then adjusting the valve until the desired flow was achieved. Flow rates of 2, 4, 5 and 15 gpm were used and ponding depth of the sediment-laden runoff was measured at 5 minute intervals. For the SS, 8 and 12 in. coarse filters were tested at a 10 degree slope. Total number of tests conducted with the sediment-laden runoff was 29 (3 filters, 3 flow rates, 1 slope, 3 replications + 2 filters, 1 slope, 1 flow rate, 1 replication).

Results

Clean Water Test

Compost Particle Sizes The fine compost material had about 8% coarse particles > ½ in., while the coarse compost had 27%. Over 58% of the coarse compost was greater than 5/16 in. size while the fine compost had 82% less than 5/16 in.

Flo Preliminary studies with clean water showed that steady state flow was achieved after 3-4 minutes test duration. Thus, tests were run for 7 minutes, and average flow was based on data points collected at 5, 5.5, 6, 6.5 and 7 minutes.

Output flow rate, q_f, versus depth of water for the sediment control devices is given in Figure 3. Because the 8 in. and 12 in.SS gave similar q_f at a given water depth, data for a specific compost (fine or coarse) were pooled and plotted on the same graph. Results showed that the flow rates for clean water was a power function of water depth, which would be expected since 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$_f$), i.e. $q_o = C\, d_f^{1.5}$. From the regression equations, the exponents on d$_f$ were 1.054, 1.313 and 1.202 for the fine SS, coarse SS and SF, respectively. Results also suggest that a 20 degree slope causes flow rates to be slightly higher than for the 10 degree slope at the same water depth

Figure 3.
Flow through rates versus depth of clean water on SiltSoxx™ and Silt Fence. (a) Flow rate for SS using fine compost for both 10 and 20 degree slopes vs. depth. (b) Flow rate for SS using coarse compost for both 10 and 20 degree slopes vs. depth. (c) Flow rate for SF for both 10 and 20 degree slopes vs. depth. (d) Flow rate versus depth using regression equations for fine SS, coarse SS and SF.

Slurry Test

Sediment-laden runoff Results of analysis of 12 samples (4 samples per replicate) taken during each treatment gave average dry matter contents of the incoming sediment-laden runoff to the flume of 0.51% to 1.04% for the SS and SF test.

Compost For the SS treatments, only the coarse particle size compost, described earlier under the clean water test section, was used.

Flow Rates Figure 4 shows the three sediment control devices being tested at the 2 gpm flow rates. Depth versus time of application of sediment-laden runoff to the 12 in. coarse SS and 24 in. SF are given in Figure 5 for the flow rates 4, 5 and 15 gpm. For a given flow rate, depth behind the sediment control devices increased with time as the suspended solids in the sediment-laden runoff plugged the smaller pores of the filter and depth behind the SF increased more rapidly than behind the SS. Because the SS sagged to a more elliptical shape after being put in place, actual topping depth was less than the design height.

Figure 4.
Flow of sediment-laden runoff through sediment control devices at 2 gpm at 10 minutes time. From left to right, 24 in. silt fence (mounted with 18 in. above flume bottom), 8 in. coarse SiltSoxx™, and 12 in. coarse SiltSoxx™.

Figure 5.
Effect of time on depth of slurry behind the 12" coarse SiltSoxx™ and Silt Fence.

Observation of the data for sediment-laden flow indicated pond depth at the sediment control device increased rapidly at the start of flow and then leveled off to where it increased at approximately a linear rate over time until the sediment control device was topped (Figure 6). Recognizing this effect allowed formulating the following relationship for depth as a function of time.

$$d_f = A(q_f)\, t + B(q_f) \qquad (1)$$

where
d_f = pond depth, inches
q_f = slurry flow rate, gpm/$_f$
t = time, min
$A(q_f)$ = rate of increase in depth as a function of slurry flow rate and slurry suspended solids concentration, inches/min
$B(q_f)$ = initial pond depth behind filter before filter begins to plug, inches.

Evaluation of A and B for the SF and SS were done for the flow rates 1, 2.5 and 7.5 gpm/f and time 10-30 minutes. Results for the SF gave A and B as linear functions of flow rate, whereas, results for the 12 in. SS gave A and B as exponential functions of flow rate. The very high R$_2$ values (0.9844, 1.00, 0.9891, 0.9938) are partly the result of having only limited test to evaluate, but does show the data fits the model. In order to have the A term go to zero, an additional term of $(1-\exp(-5q_f^n))$ was added, where $n = 3$ for silt fence and $n = 2$ for SiltSoxx™.

Based on these results the following equations were derived for time to top a filter.

Silt Fence:

$$t = \frac{d_f - (1.1932 q_f + 1.2993)}{0.0312 q_f + 0.029(1-\exp(-5q_f^3))} \qquad (2)$$

Silt Soxx:

$$t = \frac{d_f - 0.8282\,\exp\,0.2564 q_f}{0.014(1-\exp(-5q_f^2))\exp^{0.3152q_f}} \qquad (3)$$

Figure 6.
Evaluation of pond depth behind a Silt Fence and SiltSoxx™ as a function of flow rate and time

Equations 2 and 3 were incorporated into an Excel™ spreadsheet for selection of SF and SS for given rainfall events (Figure 7). The effective height for the SF was set at 85% of the total above ground height and at 80% for the SS. Results using the spreadsheet indicate that when flows are less than 5 gpm/f the 12 in. and 18 in. SS with coarse compost will out perform even the 36 in. SF (30 in. above ground) and the 8 in. SS is approximately equivalent to the 24 in. SF (18 in. above ground).

Figure 7.
Excel™ Design Tool to predict time to top Silt Fence and Silt Soxx™ as a function of sediment-laden runoff flow rate.

Figure 8 shows the average removal efficiency over the 30 minute test periods for the three sediment control devices. Filtration efficiency for the SF was found to be higher than the 8 in. coarse SS in these tests, but based on standard errors was not significantly higher than the coarse 12 in. SS.

Figure 8.
Removal efficiency of 8 in. coarse SiltSoxx™, 12 in. coarse SiltSoxx™, and 24 in. Silt Fence.

Conclusions

Results of this study showed that for clean water, flow-through rate is relatively constant over time and can be represented by a simple power function of pond depth. For the sediment-laden (~0.9% solids) runoff water, flow-through rate is changing with time, as is pond depth, due to the accumulation of solids on/in sediment control devices. Changes in depth with time were a linear function of flow rate after ten minutes of flow, up to the time the sediment control device is topped. Prediction of capacity of the SF and SS to handle runoff without the filter being topped requires consideration of both runoff rate and length of time. Removal of solids by the SF and the SS were not shown to be statistically different and were 30-50% in most tests. An excell™ spreadsheet was developed to allow selection of SF or SS based on construction site and rainfall considerations.

Acknowledgements

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