Report as of FY2007 for 2006GA118B: "Using compost to control soil erosion and manage stormwater under concentrated flow conditions"

Publications

Project 2006GA118B has resulted in no reported publications as of FY2007.

Report Follows

Investigating the Use of Compost for Sediment and Erosion Control under Concentrated flow Conditions

Final report

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Abstract: To investigate the process of rill erosion on compost blankets, yard waste compost, commercial erosion control compost and a Cecil soil were tested under laboratory conditions. Four slope levels and four sequential inflows were tested. Erosion rate and shear stress of the flow were calculated and the shear stress model was fit for each material. The results indicated that rill erosion on both Cecil soil and yard waste compost conform to the shear stress model. There was not significant difference between Cecil soil and yard waste compost for critical shear stress, however erodibility values appeared to be higher for the yard waste compost under our experimental conditions. The commercial erosion control compost produced very little erosion under steady-state conditions and did not fit the shear stress model. Because of the larger particle size and greater porosity, this compost dispersed and filtered the water flow, effectively reducing the shear stress and erosion under steady flows.

KEYWORDS: Compost blankets, critical shear stress, rill erodibility

BACKGROUND

Soil erosion is considered the biggest contributor to nonpoint source pollution in the United States according to the federally mandated National Pollution discharge Elimination System (NPDES). The U.S. Environmental Protection Agency recently released major new regulations to control erosion and runoff from farms, construction sites, and roads in an effort to make over 20,000 rivers, lakes, and estuaries safe for swimming and fishing. Georgia enacted some of the nation’s toughest regulations on erosion and runoff from construction sites in an effort to improve water quality in the state’s surface waters.The new regulations label development as “point sources” requiring better erosion control practices and new permitting programs.

Compost is the product resulting from the controlled biological decomposition of organic material, occurring under aerobic conditions, which has been sanitized through the generation of heat and stabilized to the point that it is appropriate for particular application. Compost has been widely used as a soil conditioner to improve the properties of soils and support the growth of vegetation. Compost is recognized as being beneficial in erosion control and is commonly used as blankets in many sites, some of which were exposed to concentrated flow(Ghomas and Bruce, 2006). While previous studies have shown that compost blankets are effective in reducing interrill erosion, little knowledge is available on how effective of this practice is and the limits of using compost blanket under concentrated flow conditions.

OBJECTIVES

The overall objective of this study was to investigate the process of rill erosion on compost blankets and improve our understanding of the effectiveness and limitations of using compost blankets under concentrated flow conditions. The specific objectives included:

1. To determine the hydraulic shear stress and erosion rate of compost materials caused by concentrated flows.
2. To evaluate the applicability of shear stress model to compost blankets.
3. To determine the critical shear stress and erodibility of compost material.

LITERATURE REVIEW

Currently, most research regarding compost application as erosion control practices focused on its effectiveness of reducing interrill erosion. Bresson et al. (2001) tested the impact of compost application on soil surface structure degradation, the resulting runoff and erosion process. They concluded that utilization of MSW compost stabilized the aggregates and delayed crust formation and runoff generation, sediment concentration in runoff was decreased. Risse et al. (2004) investigated the amounts of runoff, erosion, and nutrient losses under simulated rainfall using a variety of composts and mulch materials. The results indicated that the loss of total solids was reduced from soil plots treated by compost blankets. Glanville (2004) compared the concentration and total mass of nutrients and metals contained in runoff from compost-treated and conventionally treated highway embankments with typical 3:1 side slope. Results indicated that the total mass of most pollutants measured in runoff produced from compost treated plots was significantly less than that from conventionally treated soils.

Persyn et al. (2005) tested rill erosion from 3 types of compost blanket at a 33% slope, using both simulated rainfall and inflow. They attempted to fit their data to the shear stress model and the results suggested that the shear stress model was not valid for the rill erosion on compost. They cited considerable uncertainty in that paper due to floatation of compost particles on the flow; the narrow width of the test plots (0.2m) which resulted in preferential flow along the plot boundaries, and "movement of compost down the slope in bulk rather than as individual particles."

Rill erosion on soil can be represent using shear stress model (Foster et al., 1982; Nearing, 1994) which can be expressed as

$$Dr = Kr \times (\tau - \tau_c)^n \qquad (1)$$

Where

Dr = rill detachment rate (g s^{-1} m^{-2})

Kr = rill erodibility (g N^{-1} s^{-1})

τ= hydraulic shear stress (N m^{-2})

τ_c = critical shear (N m^{-2}).

n = exponent assumed to be equal to unity 1(Foster et al., 1984; King et al., 1995).

Both the Kr and τ_c can be obtained by fitting the shear stress model, the slope is erodibility Kr and X-intercept is critical shear stress value τ_c.

The hydraulic shear stress can be calculated using equation 2(Forster et al., 1984;

King et al., 1995)

$\tau = \gamma R S$ ……………………………………………………… (2)

Where γ = the weight density of the flowing fluid (N m^{-3}), R = hydraulic radius (m), and S = slope of the channel (m/m).

Although erodibility is defined as a soil property and is quantified in terms of sediment loss, composts should display a similar property relative to the solids loss from a surface cover(Risse et al., 2004). Due to the soil like texture of most compost materials, it was hypothesized that the erosion mechanism of blanket-applied compost would be similar to the mechanism of soil erosion.

METHODS AND MATERIALS

Experimental design

The experiment was conducted in the Fluid Mechanics Laboratory at the Department of Biological and Agricultural Engineering at University of Georgia. A 3 m, 1 m and 0.7 m (length × width × height) aluminum hydraulic flume was built (fig 1). A 0.8 m × 0.2 m × 0.2 m aluminum box with a reversed vaulted face was built and set on the head of the flume as flow distributor to direct the water flow on the tested material.The slope of the flume was changed by tilting the upstream end. Concentrated flow was generated by pumping clean water from a water tank.

Materials

Two types of composts and a Cecil soil as a control were tested. Yard Waste Compost (YWC) was collected from the University compost facility; Commercial Erosion Control Compost (CECC) that met standards of the Seal of Testing Assurance as outlined by the United State Composting Council was obtained from a commercial composting facility; and a Cecil Soil was collected from the USDA Agricultural Research Service site at Watkinsville, Georgia, the same location where WEPP erodibility experiments were conducted for Cecil Soil sample.

Basic physical properties and organic matter content were analyzed for the three materials based on methods outlined in Test Methods for Examination of Compost and Composting (TMECC). The results are shown in Table 1 and 2.

Data collection

Materials were placed on the flume as 5 cm blankets. A trapezoidal channel was manually created along the center of blankets. Materials were pre-wetted by ponding water on it for 10 minutes. Four slope levels (1%, 3%, 5% and 7%) were used and four sequential inflow rates were applied for each slope level. The lowest flow rate was determined based on previous trials on which rilling was initiated. The subsequent flow rates on soil were increased between 5 and 10 L/min and between 8 and 15 L/min for yard waste compost depending on the slope level. Flow was controlled using a rotameter and manual gate valve. The duration for each inflow rate was 30 minutes. Steady state flow conditions were assumed to occur after 3 minutes of constant flow. This was considered first flush and no sample was taken. The last 27 minutes were used to collect discharge samples which were used to determine erosion rate. Discharge samples were taken at 3 minute intervals using 500mL bottles. A total of 10 samples were collected for each flow rate and 40 total samples were taken for each slope and treatment combination.

Sediment samples were weighed and oven dried at 104 till constant weight was reached. The erosion rates were calculated as the dried sediment weight divided by the test duration and the rill area.

Discharge was determined by recording the time required to fill a 2 liter bucket. Surface velocity of flow was measured using a dye tracer. The dye was injected into the flow and the time required for the leading edge to travel one meteralong the central part of the channel was recorded. The travel time for the leading edge was multiplied by 0.7 to calculate average velocity from the surface velocity(Elliot et al., 1989; Persyn et al., 2005). Width measurements within the rill were taken at 10 testing points which were evenly assigned along the channel. The measurements of discharge, velocity and width of rill were conducted every 3 minutes.

Shear stress values were calculated using equation 2 ($\tau = \gamma$ R S), Where specific weight of water γ was assumed 9800 N m^{-3}, and the average channel slope equated to the flume slope; hydraulic radius were calculated using equation 3 and assuming a rectangular cross-section:

$$R = \frac{A}{Wp} \tag{3}$$

Where

R = hydraulic radius (m)

A = cross-sectional area of flow (m^2)

W_P = wetted perimeter (m) = width + 2 × depth.

Cross section area was calculated using the continuity equation:

$$Q = \frac{V}{A} \tag{4}$$

Where

Q = flow discharge ($m^3\ s^{-1}$)

V = average flow velocity ($m\ s^{-1}$)

A = cross-section area of flow (m^2) = width × depth

RESULTS

Observations

Rills were quickly formed for both the CS and YWC. However, the progression of rill formation was different for the two materials (figure 2). The head cut on CS channel began at downstream end and moved up the slope. Both the walls and bottom of the channel were eroded resulting in both widening and deepening of the rill for CS. Once rilling initiated on YWC, the flow kept scouring the bottom till reaching the flume bed. Side scour seldom occurred before the floor of flume was exposed, resulting in a relatively small rill of uniform width for the YWC. This phenomenon may due to the higher content of organic matter and coarse materials in the YWC which stabilized the sides of the rills. The YWC also had a higher infiltration capacity than the CS may have resulted in flow occurring between the compost blanket and channel floor creating upward pressure on the blanket material and less shear stress being required

to initiate transport of materials down the rill.

Erosion on CECC only occurred when inflow rate was increased. When this occurred, there was considerable erosion and particle movement, however, it appeared that eroded particles were deposited quicklyand dams were formed along the channel resulting in a new equilibrium condition with little erosion (figure 3). Flow was divided and ponded by dams, resulting in more flow into the walls and sides of the channel and lower flow velocities and shear stresses. These dams would fail when the flow rate was increased, however, the particles deposited again quickly and new dams were formed at this new equilibrium condition. Only under the extreme conditions of 60 L/min at 7% slope were these micro-dams wash out completely. Under the steady state conditions, it was very rare that any measurable solids could be detected in the flow coming off the flume. Only small portion of discharge measured at the flume outlet ran over the blanket surface because most of the water flowed beneath or through the blanket layer, resulting in high uncertainty when equation 2 was used to calculate the shear stress. Both interlocking of the coarser materials and high infiltration capacity contributed to the formation of dams and low erosion on the CECC blanket.

Statistical Analysis

Because of the uncertainty in calculating shear stress and extremely low amounts of eroded solids detected under our experimental method, most of our analysis did not included the CECC blanket material. Essentially, very little of the flow on this material actually occurred in the rills, so the cross section area and shear stresses could not be calculated using the assumptions inherent to the shear stress model.

Table 3 shows the mean values of discharge, shear stress and erosion rate for the three tested materials. The lower value of discharge for CECC represented considerable uncertainty which might due to the severe leakage of flume bed at the later test period. The highest inflow rate of 60 L/min for the CECC generated almost all the erosion on it. The erosion rate for CECC was obtained by collecting the first flush because after that no sediment was detected.

Shear stress model was fit to every replication for each slope level, the correlation coefficients, critical shear stresses and erodibility values are summarized in table 4. Only replications having a positive slope and x-intercept (without bold) were used to determine the average values for the critical shear stress and rill erodibility parameters. Student t-test was conducted ($p<0.05$) for the mean values of critical shear stress and eordibility for YWC and CS. No significant difference was found between YWC and CS for either the critical shear stress or erodibility values. The R^2 value for both CS and YWC suggested the shear stress model was likely valid both on CS and YWC.

Figure 4 shows the overall fit of shear stress model for YWC and CS. Data from the 4 different slope levels were included together in this regression. Even thought the difference of critical shear stress was not significant, the discrepancy of slopes presented in this figure suggests a slightly higher potential rill erodibility for the CS compared to YWC.

CONCLUSIONS

This study shows that the erosion rates for compost under concentrated flow conditions may vary by compost material and are probably different than those for standard soils. While the shear stress model appeared valid for the Cecil soil and the yard waste compost, the inclusion of coarser materials and the higher infiltration capacity of the CECC compost resulted in a failure to apply the shear stress model. The erosion rates were much lower for the CECC compost, however, since the flow was not constrained to the rill and tended to flow through the material rather than over it, the shear stress model could not be applied. The comparison of critical shear stress and erodibility parameters concluded that there were no statistically significant differences between yard waste compost and Cecil soil under our experimental conditions, however, the rill erodibility for the YWC did appear higher. The shear stress model is likely valid for rill erosion both on Cecil soil and yard waste compost. Since there was no difference in the critical shear stress required to initiate erosion, the yard waste compost may not be suitable to apply on sites where concentrated flow is expected. The commercial erosion control compost had higher infiltration capacity and was capable of transmitting larger volumes of flowing water down the surface, and may be able to withstand some level of concentrated flow. Further work is needed to define the limits of flow that could be allowed.

FUTURE WORK

1. Conduct field test to validate the applicability of shear stress model for erosion on yard waste compost and commercial erosion control compost by including the first flush samples.
2. Determine the critical shear stress and erodibility parameters for yard waste compost and commercial erosion control compost under field conditions.
3. Determine the critical inflow rate under a various slope levels for these two types of compost materials.

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TABLES AND FIGURES

Table 1. Particle size distribution for YWC and CECC

Sieve size, mm	YWC, % passing	CECC, % passing
19.00	100.00	98.15
8.00	92.93	89.01
4.00	79.85	69.97
2.00	58.28	47.23
1.00	35.76	23.74

Note: All the materials were dried at 75 for 1.5 hours before being tested

Table 2. Bulk density, organic matter content and water holding capacity

Material	**Bulk Density, g/cm3**	**Organic matter content,%**	**Water holding capacity, g/g**
CS	1.24	0.71	0.102
YWC	0.44	9.85	0.112
CECC	0.17	10.12	0.123

Note: All the materials were dried at 75 for 1.5 hours before being tested

Table 3. Discharge, shear stress and erosion rate

Materials	Discharge L/min		Shear stress, Pa		Erosion rate, g/s/m^2	
	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
CS	18.23	7.79	3.16	2.23	10.71	13.53
YWC	26.77	20.71	3.47	1.98	4.23	3.79
CECC	21.9	9.7	4.33	4.1	0.34	0.51

Table 4. Rill erodibility, critical shear stress, and R^2 values for CS and CECC for each replication

	1%			3%			5%			7%				
	1	2	3	1	2	3	1	2	3	1	2	3	Mean	Std.Dev
Kr.(Kg $s^{-1}N^{-1}$)														
CS	0.0031	0.0097	0.0340	0.0002	0.0028	0.0032	**-0.0001**	0.0049	0.0261	0.0022	0.0003	0.0082	0.0140	0.0130
YWC	0.0003	0.0005	0.0016	**-0.0029**	0.0012	0.0004	0.0023	0.0004	0.0013	**-0.0042**	0.0055	0.0021	0.0012	0.00067
τc (Pa)														
CS	1.4625	0.1211	0.6937	**-3.8000**	0.6196	2.4534	18.8333	**-1.1296**	1.4611	3.0833	**-1.6786**	1.3675	0.9517	0.5574
YWC	0.5326	0.3369	0.6969	5.2551	0.7840	**-13.4000**	1.9596	**-2.4900**	1.5530	6.9788	4.1172	2.7981	1.1167	0.9226
R^2														
CS	0.94	0.94	0.99	0.85	0.85	0.67	0.04	0.63	0.978	0.854	0.965	0.86	0.8065	0.2644
YWC	0.89	0.9	0.96	0.95	0.43	0.18	0.31	0.52	0.99	0.69	0.71	0.079	0.6332	0.2856

Figure 1: Experimental setup

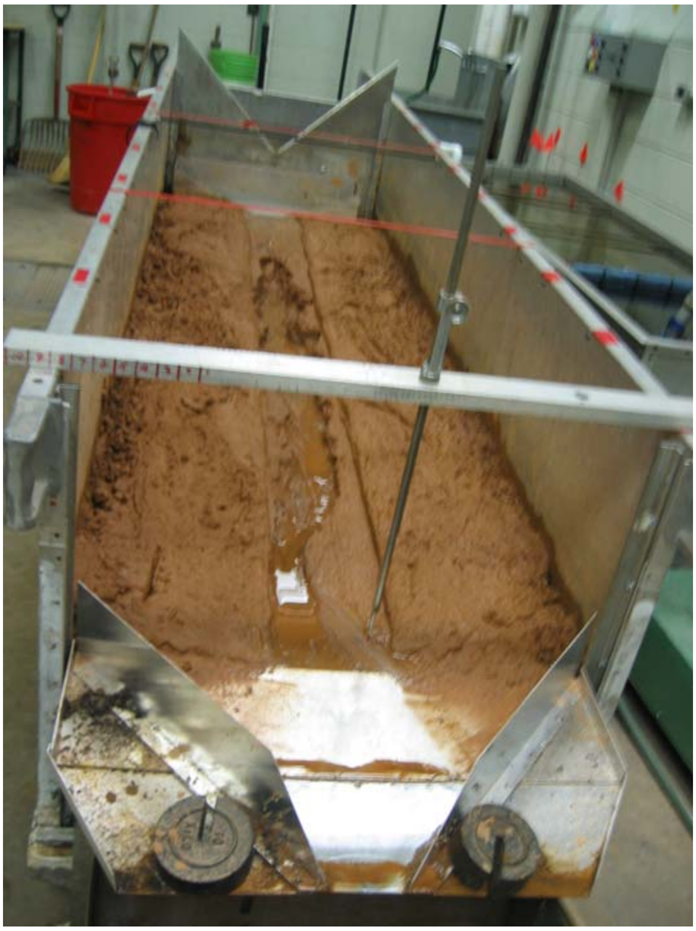

Figure 2: Rill process of on Yard waste compost and Cecil soil

Figure 3: Erosion process on commercial erosion control compost

Figure 4: overall fit of shear stress model for erosion on YWC and CS