Erosion control and storm water quality from straw with PAM, mulch, and compost blankets of varying particle sizes

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Abstract: Compost and mulch blankets have been widely used for slope stabilization and erosion control at construction sites; however, the majority of research on these erosion control blankets has failed to meet state or federal specifications for particle size distribution. The primary objective of this study was to determine how blending wood mulch with compost may affect its performance as an erosion control practice relative to a straw blanket with polyacrylamide (PAM). The secondary objective of this study was to determine if particle size distribution of the organic erosion control blanket affects runoff, erosion, and vegetation establishment. Researchers concluded that the greater percent of compost used in an erosion control blanket, the lower the total runoff and the slower the runoff rate. Compost erosion control blankets retained 80% of the simulated rainfall applied and reduced cumulative storm runoff by 60%, while the wood mulch blankets reduced runoff by 34% and straw with PAM by 27%. Conversely, the greater the percent of mulch used in the erosion control blanket, the lower the sediment and suspended sediment load. However, any combination of compost and mulch reduced runoff volume, runoff rate, and soil loss relative to a straw blanket with polyacrylamide. The average cover management factor (C factor) for the straw with PAM was 0.189, the compost blanket was 0.065, and the mulch blanket was 0.013. Researchers also concluded that particle size distribution of the compost and mulch blankets was the leading parameter that reduced soil loss and runoff. If particle size distribution specifications are not followed, total soil loss can be four times greater, suspended solids can be five times greater, and turbidity can be eight times greater, relative to blankets that meet particle size distribution specifications. Nitrogen and phosphorus loading from mineral fertilizer used with conventional straw blankets may lead to increased nutrient loading of receiving surface water relative to the compost and mulch blankets. The straw blanket with fertilizer increased total Kjeldahl nitrogen loading by more than 8,000%, the compost blanket increased total Kjeldahl nitrogen by 340%, and the mulch blanket by 18% relative to the control. Although the bare soil and mulch blanket treatments did not contribute any soluble phosphorus (P) to runoff, relative to the compost blanket, the soluble P load from the straw blanket with PAM was 3,800% greater. Results from this study may be used to revise particle size specifications for compost erosion control blankets and to help regulators and design professionals determine which type of erosion control best management practice is best for their particular application.

Key words: compost blankets—erosion control—straw blankets—storm water—water quality

Soil loss from both agricultural and non-agricultural lands in the United States amounts to over 4×10^9 tons each year due to erosion (Brady and Weil 1996). Forested lands lose an average of 0.36 metric t ha^{-1} yr^{-1} (1 tn ac^{-1} yr^{-1}), agriculture loses an average of 5.5 metric t ha^{-1} yr^{-1} (15 tn ac^{-1} yr^{-1}), while construction sites average 73.3 metric t ha^{-1} yr^{-1} (200 tn ac^{-1} yr^{-1}) (Georgia Soil and Water Conservation Commission 2002). The most serious problem of erosion occurs once the sediment leaves the site of origin and enters surface waters. 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). It is estimated that the annual cost to society for on-site loss of soil, nutrients, water and yield reduction due to soil erosion is over $27 billion per year (Brady and Weil 1996).

The US Environmental Protection Agency (USEPA) has declared that sediment contamination of our surface waters is the greatest threat to our nation's water resources. Surface water that is loaded with sediments can lead to reduced drainage capacity, increased flooding, decreased aquatic organism populations, decreased commercial and recreational fishing catches, clogged and damaged commercial and industrial irrigation systems, increased expenditures at water treatment plants to clean the water, and decreased recreational and aesthetic value of water resources (Risse and Faucette 2001). It is estimated that the national cost to society due to sedimentation of eroded soil is over $17 billion per year, bringing the total cost of erosion and sedimentation to society in the United States to over $44 billion per year (Brady and Weil 1996).

Soil erosion is considered the largest contributor to non-point source pollution in the United States according to the federally mandated National Pollution Discharge Elimination System (NPDES) (USEPA 1997), while soil loss rates from construction sites can be 20 times that of agricultural lands (USEPA 2000). In 1987, amendments to the federal Clean Water Act mandated that construction sites must control storm water, erosion, and sediment originating from their site (USEPA 2000). In 1990, NPDES Phase 1 Rules mandated that all construction sites over 2 ha (5 ac) were required to have land-disturbing activity permits and pollution prevention plans. In 2003, NPDES Phase II went into effect extending the storm water pollution prevention plan requirement to any land disturbing activity over 0.4 ha (1 ac).

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Table 1
Particle size specifications for compost erosion control blankets.

Specifying agency	Percent pass 50 mm	Percent pass 25 mm	Percent pass 18 mm	Percent pass 6 mm
TX DOT*	95%	65%	65 (16 mm)	50% (9.5 mm)
AASHTO	100% (75 mm)	90% to 100%	65% to 100%	0 to 75%
US EPA	100% (75 mm)	90% to 100%	65% to 100%	0 to 75%
IN DNR	100%	99%	90%	0 to 90%
CONEG	100%	100%	100%	70% (13 mm), 50% (2 mm)

* 1:1 blend of compost and untreated wood chips (termed erosion control compost).

Runoff and Erosion Control with Organic Materials. The use of surface applied organic amendments has been shown to reduce runoff and erosion (Adams 1966; Meyer et al. 1972; Laflen et al. 1978; Vleeschauwer and Boodt 1978; Foster et al. 1985). Runoff from mulched soils can be reduced to only a fraction of that from unmulched soils, thereby nearly eliminating soil erosion (Meyer 1985; Meyer et al. 1972; Laflen et al. 1978; Foster et al. 1985; Epstein et al. 1966). Because of better soil contact and reduced susceptibility to movement from wind or water, mulches are superior to hay and straw mats (Lyle 1987). Shredded bark will intercept and dissipate the energy of raindrops and prevent soil surface crusting; they also break up overland flow of runoff and hold more water at the soil surface allowing more water to infiltrate the soil (Adams 1966; Gorman et al. 2000). Adams (1966) found that soils covered with mulch averaged less than 0.9 metric t ha^{-1} (1 tn ac^{-1}) soil loss compared to 18.3 metric t ha^{-1} (20.2 tn ac^{-1}) from uncovered soils during an 21.25 cm (8.5 in) storm event. Meyer et al. (1972) found on highway construction slopes of 20% and 46 m (150 ft) long during a 6.25 cm (2.5 in) storm event, wood mulches yielded less than 4.5 kg ha^{-1} (5 tn ac^{-1}) soil loss compared to over 90 kg ha^{-1} (100 tn ac^{-1}) soil loss from other management practices.

It is important to recognize the advantage of compost blankets over wood mulches to prevent erosion on hill slopes because they have a better ability to support vegetation. Both can help reduce runoff and soil loss but mulches can often have a detrimental effect on plant growth because of nitrogen immobilization (Meyer et al. 1972) while compost often has a carbon to nitrogen ratio optimum for plant uptake and can provide a slow release of nutrients (Maynard 2000; Granberry et al. 2001) that sustains prolonged healthy plant growth. Both have quality characteristics that if brought together in the correct blend, will increase their ability to reduce runoff while insuring that vegetation is established quickly to further protect soil from erosion.

The Georgia Department of Transportation (G DOT) and Georgia Soil and Water Conservation Commission only require that straw mats provide 70 to 75% soil cover (Georgia Soil and Water Conservation Commission 2002), but Adams (1966) claims 90% cover, relative to bare soil, is needed for appreciable differences in infiltration rates. Compost blankets, when applied correctly, provide nearly 100% surface coverage (Faucette 2004). Studies by Adams (1966) and Meyer et al. (1972) found that significant rilling can develop under straw mats, where most soil loss occurs. Similarly, while synthetic blankets and mats provide ground cover, they do not make 100% contact with uneven soil surfaces, as rilling is common underneath these practices. Compost blankets are designed and applied to fill uneven spaces to prevent rilling. Finally, heavier mulch materials, like compost, are less likely to blow off slopes in windy conditions, relative to the light weight of straw mulch, protecting the soil from wind erosion (Meyer et al. 1972).

While specifications for compost erosion control blankets (ECBs) have been accepted and reported (table 1) by the Texas Department of Transportation (TX DOT), the American Association of State Highway and Transportation Officials (AASHTO 2003), the USEPA (USEPA 2006), the Indiana Department of Natural Resources (IN DNR), the Coalition of Northeast Governors/Connecticut Department of Transportation (CONEG), and many other public agencies, no research has been conducted to evaluate the most critical component of the specifications: the particle size distribution of the compost used to make the erosion control blanket. Of the 23 compost blanket treatments evaluated by Demars and Long (1998), Glanville et al. (2001), Kirchhoff et al. (2003) and Faucette (2004), Faucette et al. (2005) none met any of the minimum particle size specification requirements for compost ECBs; therefore, the research literature has likely understated their true performance in the field. Additionally, it is unclear if these specifications have ever been scientifically evaluated. Mukhtar et al. (2004) reported that TX DOT specifications were followed, however, particle size distribution was not reported.

Larger particles are the primary material that prevents soil loss—like organic litter and debris on a forest floor, while the small particles (compost fines) are the primary material that absorbs rainfall thereby preventing runoff —like humus on a forest floor. Large particles prevent splash erosion and soil dislodgement by reducing the energy of raindrop impact; additionally, they reduce sediment transport in overland runoff by reducing runoff rates due to their size and weight. Small particles can absorb a significant volume of rainwater thereby increasing the infiltration capacity and allowing for more evaporation. Additionally small particles probably provide nutrients and enhance soil structure for plant root growth. Good plant root establishment will allow for healthy plant establishment and will help maintain necessary cover aiding erosion control/slope stabilization. It is also likely that any benefit of increased soil quality (in the future) will result mainly from the small particles in the compost erosion control blanket (and biota in the soil and compost).

The cover management factor (C factor) is one of six factors used in the Universal Soil Loss Equation (USLE). The C factor indicates how an erosion control practice, erosion control product, or conservation plan will affect average annual soil loss. Although determining C factors can be complicated, the erosion control industry has greatly simplified the process to quickly and inexpensively evaluate their erosion control products so equation users (designers, engineers, architects) can readily and easily insert specific product C factors into the USLE (Demars and Long 1998; ECTC 2004). To do this, product manufacturers (and/or their third party testing labs) determine the single-event soil loss ratio of the specific erosion control product relative to a bare soil under

Table 2
Reported C factors for various rolled and blown-on erosion control blankets.

Product/practice (reference)	C factor	Influencing factors
Hydraulic mulch + synthetic or fiber netting (ECTC 2004)	<0.10	5:1 slope; ECTC test method
Netless rolled erosion control blanket (bound by polymers or chemical adhesion) (ECTC 2004)	<0.10	4:1 slope; ECTC test method
Single net erosion control blanket (natural materials woven/mechanically bound) (ECTC 2004)	<0.15	3:1 slope; ECTC test method
Double net erosion control blanket (natural materials woven/mechanical bound between 2 layers) (ECTC 2004)	<0.20	2:1 slope; ECTC test method
Erosion control blanket/open weave textile (slow degrading, continuous weave double net ECB) (ECTC 2004)	<0.25	1.5:1 slope; ECTC test method
Turf reinforcement mat (permanent/nondegradable, 3-dimensional thickness, used in concentrated flows) (ECTC 2004)	None (usually tested for shear stress)	0.5:1 slope; ECTC test method
Straw blanket (Demars and Long 1998)	0.08	2:1 slope; natural rainfall (max. 1.6/24 hr); 10 ft x 35 ft test plot; on silty sand
Straw blanket w/pam (Faucette n.d.)	0.19	10:1 slope; 4 in/hr 1hr rainfall; 3 ft x 16 ft test plot; clay subsoil; 2 in blanket
Mulch blanket (Demars & Long 1998)	0.075	2:1 slope; natural rainfall (max. 1.6/24 hr); 10 ft x 35 ft test plot; on silty sand; 3 in blanket
Mulch fines (Faucette et al. 2004)	0.16	10:1 slope; 3.2 in/hr 1 hr rainfall; 3 ft x 3 ft test plot; clay subsoil; 1.5 in blanket
Mulch overs (Faucette et al. 2004)	0.11	10:1 slope; 3.2 in/hr 1 hr rainfall; 3 ft x 3 ft test plot; clay subsoil; 1.5 in blanket
Wood chips @ 7 tn ac^{-1} (GA SWCC 2000)	0.08	
Wood chips @ 12 tn ac^{-1} (GA SWCC 2000)	0.05	
Wood chips @ 25 tn ac^{-1} (GA SWCC 2000)	0.02	
Compost blanket (Demars 1998)	0.05	2:1 slope; natural rainfall (max. 1.6/24 hr); 10 ft x 35 ft test plot; on silty sand; 3 in blanket
Compost blanket (Demars et al. 2000)	0.02	2:1 slope; natural rainfall, 10 ft x 35 ft test plot; on silty sand; 3 in blanket
Compost blanket (Mukhtar et al. 2004)	0.008	3:1 slope; 3.6 in/hr 30 min runoff; 3 ft by 6 ft test plot; on clay soil; 2 in blanket
Compost blanket (Faucette et al. 2005)	0.01	10:1 slope; 3.2 in/hr 1 hr rainfall; 3 ft x 16 ft test plot; clay subsoil; 1.5 in blanket
Forest duff layer (GA SWCC. 1993)	0.001 to 0.0001	

Note: ECTC = Erosion Control Technology Council.

the same test conditions. Consequently, the lower the soil loss from an erosion control practice/product relative to bare soil, the lower the soil loss ratio, and therefore the lower the C factor. The lower the C factor the better the erosion control practice/product is at preventing soil loss. See table 2 for a list of reported C factors for compost ECBs, rolled ECBs, wood mulch, straw mulch, and natural forest duff.

Research Objective. The primary objective of this study was to determine how blending wood mulch with compost may affect the compost's performance as an erosion control best management practice (BMP) relative to a straw blanket with polyacrylamide (PAM [industry standard BMP]). Because vegetation establishment is the primary goal for permanent slope stabilization, wood mulch was blended with compost in varying ratios to determine the maximum possible inclusion rates without detrimental effects to plant establishment. The secondary objective of this study was to determine if particle size distribution of the organic erosion control blanket affects runoff and erosion. To determine the effectiveness of the ECBs, analysis of storm water quantity and quality included total runoff volume, peak runoff rate, percent of runoff from rainfall, elapsed time until runoff commencement, total sediment load, suspended solids load, average turbidity, nitrogen load, and phosphorus load. Results from vegetation analysis will be reported in a follow up study.

Materials and Methods

Site Description. Research test plots were constructed at Spring Valley Farm in Athens/Clarke County, Georgia, at 33°57'N latitude and 83°19'W longitude. The soil was mapped as an eroded Pacolet Sandy Clay Loam (USDA 1968) and has a high soil erodibility factor (K value) of approximately 0.36 (Wischmeier and Smith 1978). The area receives an average annual rainfall of 1,215 mm (48 in), with January through March as the wettest period. The average annual high temperature for the area is 22°C (72°F), the average low is 11°C (52°F), with a mean annual temperature of 17°C (63°F) (Weather Channel 2005). The field experiment was conducted in the summer of 2005.

The testing area was cleared of vegetation and graded to a 10% slope with a grading blade mounted skid steer, exposing a semi-compacted (from the skid steer) subsoil (Bt

Table 3
Chemical and physical characteristics of treatments as applied to the research site.

Treatment	C	N	C:N	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	OM (percent ash)	Particle size (percent passing) 1.25 cm	0.625 cm	0.313 cm	0.156 cm
100% wood mulch	49.08%	0.23%	213	5.2	0.2	3.05%	64%	30%	3%	1%
1:2 blend	43.29%	0.61%	71	9.9	0	25.46%	85%	67%	41%	32%
2:1 blend	33.33%	1.14%	29	9.9	0.6	36.84%	89%	76%	52%	38%
100% compost*	20.84%	1.16%	18	12.5	1.4	50.44%	99%	95%	79%	60%

*Did not meet AASHTO specification for erosion control blanket particle size distribution (0 to 75% passing 0.625 cm).

horizon) to simulate construction site conditions. Test plot borders were installed to prevent cross contamination of plots. Fifteen cm (6 in) wide stainless steel borders were trenched 7.5 cm (3 in) into the soil. The plots were sized to fit the effective rainfall distribution from the rainfall simulator, 1.0 m (3.3 ft) wide by 4.8 m (16 ft) long, for a total plot area of 4.8 m^2 (53 ft^2). A removable flume was installed at the base of each plot prior to each simulated rainfall event. A removable stainless steel border was carefully inserted at the base of each plot, once the flume was removed after each storm event, to maintain the structure and integrity of the soil in the plot. The soil was carefully compacted around the removable flume and the removable border after each one was installed for use. Nine cumulative non-recording rain gauges were installed in each plot to measure rainfall quantity. Three each were spaced evenly across the width of the plot at 1.2 m (4 ft), 2.4 m (8 ft) and 3.6 m (12 ft) from the top of the plot.

Treatments. Treatments included (1) 100% chipped wood mulch blanket; (2) 100% yard waste compost blanket; (3) 2:1 compost:wood mulch blended blanket (2:1 blend); (4) 1:2 compost:wood mulch blended blanket (1:2 blend); (5) 1:2 compost:wood mulch blended blanket with clover seed added; (6) straw blanket with PAM and 10-10-10 fertilizer; (7) 100% compost blanket with a proprietary PAM blend (PAM1); (8) 100% compost blanket with another proprietary PAM (PAM2); (9) 100% compost blanket with a proprietary biopolymer derived from corn starch (Bio-Floc); and (10) a bare soil (control). Compost and wood mulch were accepted as-is from suppliers. Compost was blended with the wood mulch to aid in vegetation establishment—the primary goal for permanent erosion control/slope stabilization. The straw blanket with fertilizer and PAM represents an industry standard BMP commonly used in this type of application under the conditions described in the previous section, as specified by G DOT. The primary difference between PAM1 and PAM2 is that PAM2 is attached to a pigmented paper fiber carrier to allow for easy material application. PAM and Bio-Floc products were manually surface applied to the compost blankets to determine if there may be a potential water quality benefit from reduced soil erosion by using these materials in combination with organic blankets. All ten treatments were randomly assigned to field test plots. Each treatment was replicated in triplicate.

Compost, wood mulch, and compost/wood mulch blankets were manually applied at a 3.75 cm (1.5 in) depth over the entire area of the plot. Application depth of the blankets followed AASHTO specifications for erosion and sediment control (AASHTO 2003). Straw blankets were applied at a 3.75 cm (1.5 in) depth over the entire area of the plot, according to G DOT specifications. A 10-10-10 commercial fertilizer was applied according to G DOT specifications at 1,344 kg ha^{-1} (1,200 lbs ac^{-1}) (G DOT 2004), the PAM with straw blanket and PAM2 with compost blanket was applied at 370 kg ha^{-1} (330 lbs ac^{-1}), PAM1 with compost blanket was applied at 34 kg ha^{-1} (30 lbs ac^{-1}), and the Bio-Floc was applied at 112 kg ha^{-1} (100 lbs ac^{-1}). All polymer product application rates followed their manufacturer's specifications. Compost blanket application specifications for vegetation establishment do not require additional fertilizer (the specifications assume there is adequate nutrients within the compost) therefore the straw blanket with PAM treatment was the only treatment to receive additional fertilizer.

Each treatment, including the control, was seeded with hulled Common Bermuda (*Cynodon dactylon*) grass seed applied at 22 kg ha^{-1} (20 lb ac^{-1}), specified by the G DOT as an erosion and sediment control vegetative measure for slopes 3:1 or less for the Athens, Georgia region. A 1:2 (compost:wood mulch) blend received a mixture of red clover (*Trifolium pratense*) 7 kg ha^{-1} (6 lb ac^{-1}) and common bermuda grass 16 kg ha^{-1} (14 lb ac^{-1}) in order to alleviate potential N immobilization due to the high C addition created by the wood mulch. Results from vegetation analysis will be reported in part two of this study. The compost, mulch, and compost/mulch treatments were physically and chemically characterized prior to application in the test plots (table 3). It should be noted that the 100% compost treatments did not meet particle size distribution specifications (this is how it was received from supplier), while all other treatments using compost or mulch met particle size specifications.

Rainfall Simulator. A Norton Rainfall Simulator with four variable speed V-jet oscillating nozzles originally obtained from the USDA ARS National Soil Erosion Research Lab was used to simulate rain events as described and previously used for erosion control experiments by Faucette et al. (2005). During rain events water pressure to the nozzles was maintained at 0.42 kg cm^{-2} (6 psi), according to manufacturer's specifications, producing an intensity of 10 cm (4.0 in) hr^{-1} for 1 hr duration. This is equivalent to the one-hour storm event for a 100-year return period for the Athens, Georgia, region, based on historical rainfall records (US Department of Commerce 1961). It was our intention to evaluate these treatments under a "worst-case" scenario because most runoff and erosion occurs during these large rainfall events. Municipal tap water was used in this study containing NO_3-N of 0.673 mg L^{-1} and PO_4-P of 0.093 mg L^{-1}.

Two simulated rainstorms were conducted: one at the beginning of the experiment and one three months later. These time intervals were chosen based on the predicted establishment of the vegetation. The first runoff event was intended to provide information on the performance of the treatments prior to vegetation establishment. The second runoff event was intended to provide information on how the performance of the treatments changed when vegetation was newly established. All of the plots were subjected to natural rainfall between the simulated rainfall events. A total of 24 cm (9.6 in) of precipitation accumulated between the two simulated runoff events, which will be described in the following section (Weather Channel 2005).

Compost and Mulch Sampling and Analysis. Physical and chemical analyses of the treatments were performed at Auburn University. Total C and total N were analyzed on a Perkin Elmer 2400 (Perkin-Elmer 2400 series II CHNS/O analyzer; Perkin-Elmer Corp., Norwalk, Connecticut); organic matter was determined by weight difference after loss on ignition at 500°C (932°F). Nitrate-N and ammonium-N samples were first extracted using a 100 mL (3.4 fl oz) solution of 2 M KCl, placed on a shaker for 1 hr, and then filtered with Whatman 42 filter paper before colorimetric analysis using a microplate reader (Bio-Rad Model 450 microplate reader, Bio-Rad Laboratories, Hercules, CA.) (Sims et al. 1995). Particle size analysis for compost, wood mulch, and compost/mulch treatments used 300 g (0.67 lb) dried subsamples and followed the Test Methods for the Examination of Composting and Compost (USCC 1997) for distribution of particle sizes for compost. Size of sieves included 25.4 mm (1 in), 19.05 mm (3/4 in), 15.88 mm (5/8 in), 12.7 mm (1/2 in), 9.52 mm (3/8 in), 6.35 mm (1/4 in), 4 mm (#5), 3.18 mm (1/8 in), 2.0 mm (#10), 1.0 mm (#18), 500 µm (#35), 53 µm (#270), 25 µm (#500).

Runoff Sampling and Analysis. Sampling and analyses for storm water included rainfall amount, time until start of runoff, time until steady state of runoff flow rate, total runoff volume, percent of rainfall as runoff, peak runoff rate, total solids concentrations and loads, suspended solids concentrations and loads, turbidity, total nitrogen concentrations and loads, and total phosphorus concentrations and loads.

Runoff sampling procedures and calculation methods followed procedures used for the Water Erosion Prediction Project developed by the USDA National Soil Erosion Research Lab which have been used in similar studies (Glanville et al. 2001; Faucette et al. 2004). Runoff samples were collected from a flume placed at the base of each plot. The first sample was taken once water began to "trickle" from the flume aperture, the point determined to be the start of runoff. After the first sample was collected, samples were taken every five minutes until the 60-minute storm was finished. To obtain samples of runoff quantity and total solids, we used one 500 mL (16.9 fl oz) Nalgene bottle per 5-minute interval sample, and "seconds-to-fill" bottle times were recorded to obtain runoff flow rates. Laboratory analysis of the nutrients in runoff water was conducted at Auburn University and the University of Georgia. Phosphorus was analyzed on all samples. For phosphorus (P) water samples were first filtered with a 0.45 micron filter and then processed on a Dionex ion chromatograph (Sunnyvale, California). Total Kjeldahl nitrogen (TKN) was analyzed on the first and final samples.

A subsample from each 500 mL (16.9 fl oz) runoff/solids sample was weighed and oven dried at 105°C (221°F) until constant weight was achieved to determine the total solids content. The total solids were measured using methods 2540 B total solids dried at 103°C to 105°C (217°F to 221°F) (USEPA 1983). Total suspended solids were determined following methodology outlined by the USEPA (1999). Turbidity (NTUs) was measured using a LaMotte model 2020 turbidity meter. The peak runoff rate (once flow reached steady state conditions) was determined once runoff rates were equal for three consecutive time adjacent samples. The runoff rate (known volume per measured time) sampled at 5-minute intervals during the simulation was plotted and the total runoff volume was calculated by summing the area under the runoff curve.

Total solids and total suspended solids loads were calculated by summing the average concentration of two time-adjacent concentration samples multiplied by the average of the same two time-adjacent samples for runoff volume. C factors were determined for each treatment based on total solids loads from the first storm event. C factors were not determined for the final storm event as it was assumed results would be more reflective of the vegetation and not the original erosion control blanket. C factors were determined based on the single-event soil loss ratio of each treatment relative to the control (Demars and Long 1998; ECTC 2004).

Statistical Analysis. SAS version 8.2 (SAS Institute 2001) was used for statistical analysis. Separation of means was determined by PROC ANOVA using Duncan's multiple range test to determine any significant differences between treatments ($p \leq 0.05$). Prior to means separation using Duncan's multiple range test, Type 1 error was controlled for at the $p \leq 0.05$ level and any resultant $p_r > F$ values > 0.05 were not deemed to be significant.

Results and Discussion

Runoff Volume. Most ECBs are not designed to hold a tremendous amount of rainwater. However, an ECB with a greater water holding capacity is likely to produce less runoff and possibly prevent runoff under low to medium rainfall intensity and/or short duration storms. A quantifiable reduction in storm water runoff by an ECB can reduce the design size of storm water management or sediment retention ponds and therefore offer a cost savings to developers and builders; furthermore it can increase the available footprint for development, recreation or conservation opportunities. Additionally, an ECB that reduces sheet runoff will likely have less soil erosion due to a reduction in soil transport and erosivity wrought by storm runoff.

During the first runoff event, relative to the bare soil, the 100% compost blanket reduced storm water runoff by 52%, the 2:1 blanket by 54%, the 1:2 blanket by 42% (mean of treatments with and without clover prior to germination), the 100% wood mulch blanket by 23%, and the straw blanket with PAM by 12% (table 4). The PAM and Bio-Floc additions to the compost blankets had no effect on runoff volume. The compost blends retained between 84% and 90% of the total rainfall applied to the area, while the wood mulch and straw blanket treatments only retained 74%. The 100% compost and compost blended blankets were significantly lower in runoff volume (and retained rainfall volume) relative to the 100% wood mulch, straw blanket with PAM, and bare soil treatments.

By the second runoff event, once vegetation was established, the 100% compost blanket reduced storm water runoff by 69%, the 2:1 blanket by 81%, the 1:2 blanket by 67%, the 1:2 blanket with clover by 69%, the 100% wood mulch blanket by 45%, and the straw blanket with PAM by 45%. Additionally, the compost and compost blended treatments retained approximately 70% of the total rainfall volume applied while the 100% wood mulch and straw blankets retained approximately 50%. Statistically, the 100% compost and compost blended treat-

Table 4
Runoff volume and percent runoff from rainfall for two storm events and seven treatments.

Treatment	Runoff 1 (L)	Runoff 2 (L)	Total runoff (L)	Percent runoff 1	Percent runoff 2	Average percent
Bare soil	251a	227a	478	52%a	54%a	53%
Straw w/ PAM	222ab	125abc	347	26%ab	49%bcd	38%
100% wood mulch	193abc	124abc	317	26%abc	46%bcd	36%
1:2 blend	126bcd	71bc	197	16%bcde	31%bcd	24%
1:2 blend w/ clover	164cd	75bc	239	16%de	31%bcd	24%
2:1 blend	115cd	44c	159	10%cde	28%d	19%
100% compost	120cd	70bc	190	14%de	28%cd	21%

Note: Treatments with same letter are not significantly different at α = 0.05 using Duncan's multiple range test.

ments were significantly lower than the bare soil in total runoff, while the straw and 100% wood mulch blankets were not; additionally, the 100% compost and 2:1 compost blankets retained significantly more rainfall than the straw and 100% wood mulch blankets, while all treatments retained significantly more rainfall than the control.

Over both runoff events, the 100% compost blanket reduced total storm water runoff by 60%, the 2:1 blanket by 67%, the 1:2 blanket by 54%, the 1:2 blanket with clover by 55%, the 100% wood mulch blanket by 34%, and the straw blanket with PAM by 27%. The erosion control treatments with a greater percentage of compost retained an average of 80% of the cumulative total rainfall volume, the treatments with a greater percentage of wood mulch retained an average of 75%, and the 100% wood mulch and straw blankets retained an average of approximately 65% and 60%, respectively. These results were likely due to the higher water holding capacity of compost, presumably because of its higher humus content, relative to the other treatments.

Time until Start of Runoff and Peak Runoff Rate. Measuring the elapsed time until runoff commencement is a way to evaluate how an ECB BMP may perform under specific storm conditions. The longer an ECB can prevent the occurrence of runoff, the longer it is preventing sediment transport, particularly under low to medium rainfall intensity storms. During the first runoff event, relative to the bare soil, the 100% compost blanket increased the time to runoff commencement six fold, the 2:1 blanket 9 fold, the 1:2 blanket 5 fold, the 100% wood mulch blanket 4 fold, and the straw blanket with PAM2 fold (table 5). Reduction in runoff time was likely due to the higher water holding capacity of compost, presumably because of its higher humus content, relative to the other treatments. Statistically, the 100% compost and compost blended blankets took significantly longer to commence runoff relative to the straw blanket and bare soil. While the 100% wood mulch blanket was significantly different from the control it was statistically similar to the straw blanket. The PAM and Bio-Floc additions to the compost blanket had no affect on runoff commencement.

During the second runoff event, the compost blanket and 2:1 blend delayed the onset of storm runoff by nearly 40% relative to the straw blanket/PAM and 100% wood mulch treatments. Statistically, only these two ECBs were significantly different from the control.

An important component of an effective ECB is its ability to reduce surface runoff rates. Lower runoff rates are generally less likely to dislodge and transport soil particles, and are therefore less erosive. In some cases slower runoff is more likely to infiltrate. During the first runoff event, relative to the bare soil, the compost blanket reduced runoff rates by 34%, the 2:1 blanket by 32%, the 1:2 blanket by 33%, the wood mulch blanket by 20%, and the straw blanket with PAM by 7%. The PAM and Bio-Floc additions to the compost blanket had no affect on runoff rates. Statistically, the compost blanket significantly reduced runoff rates relative to the straw blanket and control, while no other differences were statistically significant.

By the second runoff event, the compost blanket reduced storm water runoff rates by 51%, the 2:1 blanket by 53%, the 1:2 blanket by 52%, the 1:2 blanket with clover by 55%, the wood mulch blanket by 32%, and the straw blanket with PAM by 33%. Statistically, the compost and compost/wood mulch ECBs significantly lowered runoff rates relative to the control, while the straw and wood mulch blankets did not.

Over both runoff events, the compost blanket and 2:1 blanket reduced average peak runoff rate by 43%, the 1:2 blanket by

Table 5
Elapsed time to start of runoff (min) and peak runoff rate for two storm events and seven treatments.

Treatment	Start 1 (minutes)	Start 2 (minutes)	Average start (minutes)	Runoff rate 1 ($mL\ s^{-1}$)	Runoff rate 2 ($mL\ s^{-1}$)	Average rate ($mL\ s^{-1}$)
Bare soil	2e	3b	3	88a	85a	87
Straw w/ PAM	4de	14ab	9	82a	56abcd	69
100% wood mulch	7dc	15ab	11	70ab	58abcd	64
1:2 blend	10c	16a	13	53abc	38bcd	46
1:2 blend w/ clover	11c	26ab	19	66bc	41cd	54
2:1 blend	17b	24ab	21	60abc	40bcd	50
100% compost	11c	22a	17	58bc	42bcd	50

Note: Treatments with same letter are not significantly different at α = 0.05 using Duncan's multiple range test.

Table 6
Total solid loads, suspended solid loads, and turbidity for two storm events and ten treatments.

Treatment	TS 1 (kg ha^{-1})	TS 2 (kg ha^{-1})	TS total (kg ha^{-1})	TSS 1 (kg ha^{-1})	TSS 2 (kg ha^{-1})	TSS total (kg ha^{-1})	Turbidity 1 (NTU)	Turbidity 2 (NTU)	Average turbidity (NTU)
Bare soil	5,575a	1,271a	6,846	3,215a	2,083a	5,279	12,935a	2,437a	7,686
Straw w/ PAM	1,054b	56b	1,110	613b	42b	654	1,828b	51b	940
100% wood mulch	73b	23b	96	31b	21b	52	53b	19b	36
1:2 blend	108b	21b	129	13b	48b	60	65b	54b	60
1:2 blend w/ clover	148b	19b	167	21b	21b	42	65b	27b	46
2:1 blend	185b	23b	208	29b	35b	65	127b	46b	87
100% compost	363b	46b	408	194b	90b	283	470b	105b	288
Compost w/ PAM1	ND	ND	ND	298b	94b	392	228b	175b	202
Compost w/ PAM2	ND	ND	ND	373b	77b	450	512b	104b	308
Compost w/ Bio-Floc	ND	ND	ND	106b	108b	215	121b	157b	139

Notes: TS = total solid load. TSS = total suspended solid load.Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's multiple range test. ND = no data.

38%, the 1:2 blanket with clover by 47%, the wood mulch blanket by 26%, and the straw blanket with PAM by 21%. The reduction in peak runoff rate by the ECB treatments with a greater ratio of compost is likely due to the heterogeneous mixture of particle sizes which help to disrupt and slow overland sheet flow.

Total Solids and C Factors. After the first runoff event, the smaller particles in the compost blanket showed evidence of movement downslope, creating horizontal formations across the slope (as opposed to rill formations vertically downslope characteristic to soils), while the larger particle sizes did not move and appeared to prevent the further movement of the smaller particles. This did not occur in the compost/wood mulch blends or 100% wood mulch blankets, providing evidence that the compost blankets likely would be more effective if the particle size distribution had a greater percentage of large particles, particularly when exposed to intense storms—characteristic of this study. It should be noted that the particle size distribution of the 100% compost ECBs did not meet specifications for compost ECBs according to AASHTO (2003), as 95% of the particles passed a 0.625 cm (1/4 in) sieve, whereas, according to the AASHTO specifications this should be 0 to 75%. It is the opinion of the researchers that failure to meet this specification likely resulted in greater solids loss relative to compost ECBs that meet the specification, and that a higher percentage of larger particles would greatly reduce the loss of solids under most storm conditions. It should also be noted that all other treatments utilizing compost or mulch met particle size distribution specifications.

Total solids load reduction, relative to bare soil, during the first runoff for the compost blanket was 93%, the 2:1 blanket was 97%, the 1:2 mix was 98%, the wood mulch blanket was 99%, and the straw blanket with PAM was 81% (table 6). All treatments had 96% or greater reduction of total solids during the final runoff event. All treatments were significantly different from the control but not from each other for both runoff events.

Cover management factors, commonly used by the erosion control industry to evaluate the erosion control performance of blanket or mat technology, were determined. Table 7 lists C factors that were determined for the ECBs in the study. Faucette et al. (2005) reported a C factor for compost blankets over two storm events on a 10% slope to be 0.008, and hydroseed with a silt fence (used for additional sediment control—not erosion control) was 0.044. Demars and Long (1998) reported a C factor of 0.05 for compost blankets, 0.075 for mulch blankets, and 0.08 for straw blankets. Based on the site and rainfall characteristics used in this study, compost blankets had a C factor of 0.065, wood mulch was 0.013, blending the materials together generated a C factor between 0.023 and 0.033, and straw blankets generated a C factor of 0.189. C factors for this study were likely higher relative to those reported in the literature due to the high rainfall intensity that was simulated.

Table 7
Treatment C factors.

Treatments	C factors
Bare soil	1.0
Straw w/ PAM	0.189
100% wood mulch	0.013
1:2 blend	0.023
2:1 blend	0.033
100% compost	0.065

Suspended Solids and Turbidity. The percent reduction in loading of suspended solids during the first runoff event for the straw blanket with PAM was 81%, compost blanket was 94%, compost blanket with PAM1 was 88%, compost blanket with PAM2 was 91%, compost blanket with Bio-Floc was 97%, and the 2:1, 1:2, and wood mulch blankets were all 99% effective (table 6). All treatments had 96% or greater reduction of suspended solids during the final runoff event. All treatments were significantly different from the control but not from each other for both runoff events. However, all treatments containing wood mulch had significantly lower suspended solids concentrations relative to the straw/PAM blanket for the first runoff event.

The percent reduction in turbidity during the first runoff event for the straw blanket with PAM was 86%, compost blanket was 96%, compost blanket with PAM1 was 96%, compost blanket with PAM2 was 98%, and the compost blanket with Bio-Floc, the 2:1, 1:2, and wood mulch blankets were all 99% effective. All treatments had 98% or greater reduction of turbidity during the final runoff event, with the exception of the compost blanket which had 96%. All treatments were significantly lower in turbidity, relative to the control, for both runoff events.

The superior performance of wood mulch blankets to prevent erosion is prob-

Table 8
Soil loss and particle size distribution for compost and mulch erosion control blanket treatments.

Treatment	Soil loss (kg ha^{-1})	Suspended solids (kg ha^{-1})	Turbidity (NTU)	Particle size % passing		
				25 mm	12 mm	6 mm
100% wood mulch	95.8	52.1	36	99	64	30
1:2 blend*	129.2	60.4	60	99	85	67
2:1 blend*	208.3	64.6	87	99	89	76
100% compost†	408.3	283.3	288	99	99	95

* Did not meet TX DOT specification for erosion control compost particle size distribution.

† Did not meet TX DOT, USEPA, IN DNR, or CONEG specification for erosion control blanket particle size distribution.

ably attributable to their ability to reduce raindrop impact energy and soil particle dislodgement, due to complete cover of the soil surface, and to a relatively high ratio of large particle sizes in the blanket—which are also less likely to be lost to runoff transport. The researchers feel that if the compost ECB had met the particle size specification requirement (needing a greater percentage of large particles), the sediment loss results would be similar to the wood mulch. The greater soil loss from the straw blankets may be attributable to a lower ability to reduce raindrop impact energy, runoff volume, and flow rate.

Under these rainfall, soil, and site conditions, total soil loss can be four times as high, suspended solids can be five times as high, and turbidity can be eight times as high if compost ECB particle size distribution does not meet specifications relative to a compost ECB that does meet particle size distribution specifications (table 8). Additionally, depending on which specification is followed (TX DOT, AASHTO, USEPA, IN DNR, CONEG), total soil loss and turbidity can be twice as high from one compost specification relative to another.

Table 9
Total Kjeldahl nitrogen loads and soluble phosphorus loads for two storm events and seven treatments.

Treatment	TKN load 1 (kg ha^{-1})	TKN load 2 (kg ha^{-1})	TKN total (kg ha^{-1})	P load 1 (g ha^{-1})	P load 2 (kg ha^{-1})	P load total (kg ha^{-1})
Bare soil	1.7b	0.7a	2.4	0b	43.8d	43.8
Straw w/ PAM	136.4a	0.8a	137.2	154,616.7a	154.2d	154,770.9
100% wood mulch	2.0b	1.3a	3.3	0b	18.8d	18.8
1:2 blend	2.7b	7.4a	10.1	1,716.7b	289.6cd	2,006.3
1:2 blend w/ clover	4.5b	7.4a	11.9	3,035.4b	304.2cd	3,339.6
2:1 blend	4.7b	1.7a	6.4	4,706.3b	454.2cd	5,160.4
100% compost	5.8b	4.7a	10.5	4,058.3b	552.1cd	4,610.4

Note: Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's multiple range test.

Nitrogen and Phosphorus Loss. Nutrient loss from fertilizers used to establish vegetation for erosion control at construction sites has not been well documented (although it has been for agriculture). While the bare soil contributed to TKN loading during the first runoff event (1.71 kg ha^{-1} [1.53 lb ac^{-1}]), the straw blanket with PAM contributed 8,000% more TKN than the bare soil, the compost blanket contributed 340% more, the 2:1 blanket contributed 277% more, the 1:2 blanket contributed 209% more, and the wood mulch released 18% more (table 9). Statistically, the straw/PAM blanket was significantly greater than all other treatments, with no statistical difference between the remaining blankets and the control. Increased nitrogen loss from all treatments, relative to the control, was due to leaching and transport from intensive rainfall and runoff conditions. Because mass loading was evaluated, as opposed to concentrations, values were greatly affected by runoff volume, whereas, treatments that reduce runoff volume will likely emit lower N loads relative to those that may not reduce runoff volume to the same extent. Additionally, N from fertilizer (like that specified for vegetation establishment for straw blankets) is generally in mineral/inorganic form and is more likely to be transported under runoff conditions, relative to organic N typically supplied by compost ECBs.

By the second runoff event, TKN loss from all ECBs was much lower relative to the first simulated storm, suggesting that N loss may only be a serious concern during the first runoff event after treatment application. Although TKN loads from the compost blankets appeared to be greater than the remaining treatments, TKN concentrations of the storm runoff were less than 5 mg L^{-1} (5 ppm). There were no statistically significant differences between treatments during the second runoff event.

In addition to nitrogen, phosphorus loading and its potential eutrophication effects to receiving waters has become an increasing concern. Soluble phosphorus (P) is of greatest concern as it is often immediately available to aquatic plants once it enters surface water, leading to algal blooms. While the bare soil and the wood mulch blanket treatments did not contribute any soluble P from runoff, relative to the compost ECB, the soluble P load from the straw blanket with PAM was 3,800% greater, the 2:1 blanket was 16% greater, and the 1:2 blanket was 41% less. The reduction in P load from the 1:2 blanket is likely because of the high ratio of wood mulch relative to compost, as the wood mulch releases very little soluble P. Statistically, the straw/PAM blanket was significantly greater than all other treatments, with no statistical difference between the remaining blankets and the control.

By the second runoff event, soluble P loads for all treatments were greatly reduced relative to the first simulated storm. Most soluble P probably migrated off-site from the initial runoff event, while some may have been adsorbed to soil colloids or taken up by the vegetation. There were no statistically significant differences between treatments during the second runoff event.

The results of the experiment indicate nutrient loading to receiving waters from conventional seeding (and fertilizer) applications for conventional ECBs may be a significant issue. Wood mulch ECBs offer an alternative that may significantly reduce nutrient loading. However, due to its inability to support vegetation wood mulch ECBs can only be viewed as a temporary erosion control/slope stabilization practice. Adding compost to wood mulch, or using only compost ECBs, is a viable alternative due to its ability to supply organic nutrients to plants. The lower amount of N and P loading is likely because compost significantly reduces runoff volume, which reduces total nutrient loading, and because nutrients are typically in organic form which makes them less mobile than soluble inorganic nutrients (characteristic of fertilizers) under storm runoff conditions.

Summary and Conclusions

During the first simulated storm event the compost blanket reduced storm water runoff by 52%, the 2:1 blanket by 54%, the 1:2 blanket by 42%, the wood mulch blanket by 23%, and the straw blanket with PAM by 12%. The compost blends retained between 84% and 90% of the total rainfall applied to the area, while the wood mulch and straw blanket treatments retained 74% of the total rainfall volume applied. Over both runoff events, the compost blanket reduced cumulative storm water runoff by 60%, the 2:1 blanket by 67%, the 1:2 blanket by 54%, the 1:2 blanket with clover by 55%, the wood mulch blanket by 34%, and the straw blanket with PAM by 27%. In addition, the erosion control treatments with a greater percentage of compost retained an average of 80% of total rainfall, while the treatments with a greater percentage of wood mulch retained an average of 75%, and the wood mulch and straw blankets retained an average of approximately 65 and 60%, respectively.

During the first runoff event the compost blanket increased the time to runoff commencement sixfold, the 2:1 blanket ninefold, the 1:2 blanket fivefold, the wood mulch blanket fourfold, and the straw blanket with PAM twofold. After vegetation was established, ECBs that were all or mostly compost delayed the onset of storm runoff by nearly 40% relative to the straw blanket/PAM and wood mulch treatments.

During the first runoff event, the compost blanket reduced peak runoff rates by 34%, the 2:1 blanket by 32%, the 1:2 blanket by 33%, the wood mulch blanket by 20%, and the straw blanket with PAM by only 7%. Averaged over both runoff events, the compost blanket and 2:1 blanket reduced average peak runoff rate by 43%, the 1:2 blanket by 38%, the 1:2 blanket with clover by 47%, the wood mulch blanket by 26%, and the straw blanket with PAM by 21%.

Total soil loss reduced (relative to bare soil) during the first runoff for the straw blanket with PAM was 81%, the compost blanket was 93%, the 2:1 blanket was 97%, the 1:2 blanket was 98%, and the wood mulch blanket was 99%. All treatments had 96% or greater reduction of total solids during the final storm event. The C factor for the straw blanket with PAM was 0.189, the compost blanket was 0.065, the 2:1 blanket was 0.033, the 1:2 blanket was 0.023, and the 100% pine mulch blanket was 0.013.

The percent reduction in suspended solids loading during the first runoff event for the straw blanket with PAM was 81%, the compost blanket was 94%, compost blanket with PAM1 was 88%, compost blanket with PAM2 was 91%, compost blanket with Bio-Floc was 97%, and the 2:1, 1:2, and wood mulch blankets were all 99% effective. All treatments had 96% or greater reduction of suspended solids during the final runoff event. The percent reduction in turbidity during the first runoff event for the straw blanket with PAM was 86%, compost blanket was 96%, compost blanket with PAM1 was 96%, compost blanket with PAM2 was 98%, and the compost blanket with Bio-Floc, the 2:1, 1:2, and wood mulch blankets were all 99% effective. All treatments had 98% or greater reduction of turbidity during the final runoff event, with the exception of the compost blanket which was 96% effective.

During the first runoff event, the straw blanket with PAM contributed 8,000% more TKN than the bare soil, the compost blanket contributed 340% more, the 2:1 blanket contributed 277% more, the 1:2 blanket contributed 209% more, and the wood mulch blanket released 18% more. While the bare soil and the wood mulch blanket treatments did not contribute any soluble P from runoff, relative to the compost blanket, the soluble P load from the straw blanket with PAM was 3,800% greater, the 2:1 blanket was 16% greater, and the 1:2 blanket was 41% less. Nitrogen and phosphorus loading from mineral fertilizer used to establish vegetation in conventional straw ECBs can be a serious threat to receiving surface water and should be addressed by the regulatory community.

Under these site and environmental conditions, any combination of compost and mulch reduced runoff volume, peak runoff rate, and soil loss relative to a straw blanket with PAM. The greater the percent of compost used in an ECB, the lower the total runoff, the greater the percent of rainfall absorption, and the slower the runoff rate. Conversely, the greater the percent of wood mulch used in the erosion control blanket, the lower the sediment and suspended sediment load. These results indicate that particle size distribution, not necessarily wood mulch or compost specifically, is probably the main characteristic of an organic ECB that will influence runoff and/or sediment loss. The greater the percent of small particles, the greater the ability to reduce runoff, but the greater the percent of large particles, the slower the runoff rate and the lower the sediment loss. This indicates that current particle size distribution specifications for compost ECBs probably have too great a percentage of small particles and should be revised to decrease soil loss.

Due to the extraordinary ability of compost blankets to absorb rainfall and reduce storm runoff, in the future they should be evaluated as storm water reduction tools for construction and post construction soil applications. Assigning appropriate runoff curve numbers to compost blankets may assist hydrologic engineers in reducing design footprints for sediment retention, storm water management, and bioretention ponds.

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