

RUNOFF AND WATER QUALITY FROM INORGANIC FERTILIZER AND EROSION CONTROL COMPOST TREATMENTS ON ROADWAY SIDESLOPES

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ABSTRACT. Dairy manure compost mixed with wood chips (designated as erosion control compost, ECC) was examined as an erosion control material for stabilization of steep slopes on highway construction sites. Eight $0.9 \times 1.8 \times 0.2$ m plots were prepared with a clay loam soil on a custom-made steel bed. Paired plots were randomly assigned one of two treatments: ECC or inorganic fertilizer (IF). For ECC plots, the blend of dairy manure compost and woodchips was applied on top of the soil as a 50 mm layer (according to TxDOT specs) at a rate of 283 mt ha^{-1} , which resulted in nutrient application rates of $2002 \text{ kg N ha}^{-1}$, $1426 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$, and $3002 \text{ kg K}_2\text{O ha}^{-1}$. For the IF plots, granular fertilizer was hand broadcast at TxDOT and Texas AgriLife Extension specified rates of 112 kg N ha^{-1} as ammonium nitrate, $112 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ as triple superphosphate, and $112 \text{ kg K}_2\text{O ha}^{-1}$ as potassium chloride. Treatments were established 6 days prior to the first rainfall event, and all plots were seeded on the same day. The steel bed was set at a 3:1 slope, and treatments were subjected to simulated rainfall (88.9 mm h^{-1}) under non-vegetated and vegetated conditions from start of the rainfall until a period of 30 min after initiation of runoff. Results showed that time to initiate runoff was greater for ECC-treated plots than IF plots under both non-vegetated and vegetated conditions. Prior to establishment of vegetation, the ECC treatment substantially reduced loss of solids and provided greater erosion control during simulated runoff. However, ECC produced 4 to 10 fold greater TKN, ortho P, and total P and K mass losses under both vegetated treatments due to longer rainfall exposure time and greater total volume of runoff compared to IF. High levels of nutrients in the runoff from organic materials used for erosion control may potentially impact water resources and thus counteract erosion control benefits.

Keywords. Compost, Dairy manure, Erosion, Nutrients, Phosphorus, Runoff, Watershed.

Blankets of composted organics and mulches covering newly constructed and seeded or restored steep embankments and construction areas are used to control erosion and encourage vegetative establishment and growth. A number of studies (Demars et al., 2000; Richard et al., 2002; Risse and Faucette, 2003; Persyn et al., 2004) cite use of organic materials including composted animal manure and wood waste mulch for reducing runoff sediment loss and for revegetation of such sites. Faucette et al. (2004) compared a variety of composts and mulches applied to a sandy clay loam soil at 10% slope based on runoff, erosion, and nutrient losses obtained under simulated rainfall. Seven compost treatments including composted poultry litter, food and yard wastes, biosolids with peanut hulls, three grades of wood mulches, aged poultry litter, and a bare soil control were compared. Results showed that all treatments except aged poultry litter had less total sol-

ids loss compared to bare soil. Composted poultry litter treatments had less runoff, erosion, and nutrient loss than aged poultry litter and bare soil. Although not statistically significant, mulch treatments had less total solids loss and runoff volume than most compost treatments. Chemical analysis of composts, mulches, and bare soil showed that composts and poultry litter produced much greater runoff concentrations of total nitrogen (N), total P, potassium (K), and other metals than control (bare soil) and mulch treatments.

Glanville et al. (2004) studied water quality impacts of 5 and 10 cm deep erosion control blankets containing composted organics on newly constructed highway embankments with a 3:1 sideslope and subjected to simulated rainfall intensity of 100 mm h^{-1} . Three compost treatments, i.e., biosolids, yard waste, and bio-industrial byproducts (paper mill and grain processing sludge), were compared with two conventional runoff and erosion control methods (light tillage and seeding of native embankment soil, or application of 15 cm of imported topsoil followed by seeding) used by the Iowa Department of Transportation. Concentrations of nutrients (N, P, and K) and metals in the runoff from all treatments were compared. Composts contained much greater nutrient and metal concentrations than the two soils used in conventional treatments of this field study. Runoff from unvegetated plots treated with composts contained significantly greater concentrations of soluble and adsorbed zinc (Zn), P, and K, and adsorbed chromium (Cr) and copper (Cu), than runoff from the two conventional treatments. Compost plots also required significantly greater amounts of rainfall to produce 1 h of run-

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off (after 25 to 60 min of rainfall) than conventionally treated areas (after 5 to 7 min of rainfall). When runoff generated from the first 30 min of rainfall from all treatment plots was analyzed, total masses of nutrients and metals in runoff from conventionally treated areas were at least 5 and 33 times those in runoff from compost-treated areas. It was suggested that compost blankets reduce runoff and erosion from newly constructed embankments without increasing nutrients and metals in runoff from these sites.

Recently, Birt et al. (2007) conducted a laboratory study to compare runoff and erosion rates from a sandy loam soil for five compost and two control treatments (hydroseeding and a sandy loam topsoil) subjected to 92 mm h⁻¹ intensity simulated rainfall. Compost treatments included 100% yard waste compost (general use compost) applied at 5 cm depth, 50% untreated wood chips and 50% compost (erosion control compost or ECC) applied at 1.3 and 5 cm depths, and 75% topsoil and 25% compost (compost manufactured top soil) applied at 1.3 and 5 cm depths. Hydroseeding consisted of paper mulch with fertilizer and Bermuda grass seeds applied at 5 cm depth on a sandy loam soil. Results from the first flush (surface runoff collected after 5 min of rainfall) and steady state (runoff collected during the last 30 min of runoff) runoff samples showed that the first flush runoff from 5 cm depth general use compost treatment was significantly higher than all other treatments. All other treatments had significantly lower runoff and erosion rates compared to compost manufactured top soil and top soil treatments. Depth of compost application did not significantly impact runoff or erosion. These findings led to the conclusion that the Texas Department of Transportation (TxDOT) specification for ECC depth may be reduced from 5 to 1.3 cm.

Compost from cattle feedlot, dairy, and poultry manure mixed with woodchips, cotton burs, and yard trimmings has been utilized by many state transportation departments for erosion control on road right-of-ways and to encourage vegetation establishment on severely eroded soils (Storey et al., 1996; Mitchell, 1997; Block, 1999, 2000). Departments of transportation from several states have developed compost use specifications (USEPA, 2003) for construction-related projects. Water quality studies in the North Bosque River watershed in east central Texas indicated that P was the limiting nutrient and that dairy waste application fields (WAFs) and municipal waste treatment plants were the major nonpoint and point sources of P, respectively (McFarland and Hauck, 1999a, 1999b). Construction and erosion control applications of dairy manure compost could provide an opportunity to remove large quantities of manure from impaired watersheds such as the North Bosque and reduce the need for repeated applications to the same parcels of land and reduce P pollution from WAFs. However, little information is available regarding runoff quantity and quality resulting from the use of manure-based compost materials, particularly on steep slopes and disturbed soils associated with roadway construc-

tion. Therefore, the objective of this study was to compare two TxDOT specified methods (a dairy manure compost/woodchips blend designated as erosion control compost, ECC; and inorganic fertilizer, IF) for stabilization and revegetation of steep slopes. These two methods were evaluated with simulated rainfall on small plots under non-vegetated and vegetated conditions and compared based on runoff, erosion control, and constituent losses.

METHODS AND MATERIALS

PLOT CONSTRUCTION

Eight 0.9 × 1.8 m plots were established on a custom-built steel bed (9.1 × 1.8 × 0.2 m) divided with metal borders and lined with a 5 mm plastic tarp (fig. 1a). At the downslope end



(a)



(b)

Figure 1. (a) Custom-built steel bed lined with plastic tarp and (b) triangular tray with downspout for conveying runoff to sampling containers.

Table 1. Chemical analysis of composite soil utilized to prepare sediment bed.^[a]

Soil Texture	pH	EC (μmohs cm ⁻¹)	NO ₃ + NO ₂ (ppm)	P ^[b] (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	SO ₄ -S (ppm)	Na (ppm)	B (ppm)	OM (%)
Clay loam	7.73 ±0.1	2153 ±81.71	51 ±9.0	8 ±1	233 ±5.5	8813 ±597	418 ±7.2	1490 ±364	213 ±30.6	0.44 ±0.03	1.57 ±0.04

[a] Averages and standard deviations.

[b] Extractable P.

of each plot, a triangular tray and downspout (fig. 1b) were constructed to convey runoff to a sampling container. Procedures used to prepare the individual plots for rainfall simulation were consistent with those utilized by the Texas Transportation Institute (TTI) for bed preparation when conducting rain simulation studies on organic and inorganic erosion control materials (M. Li, personal communication, September 7, 2005). Soil used to fill each plot was excavated from a constructed hillside at the Riverside campus in College Station, Texas, used by TTI for runoff studies. Three composite soil samples were collected for laboratory analysis. Samples were oven-dried at 65 °C and ground to pass a 2 mm sieve. Soil texture as determined using the hydrometer method (Day, 1965) was a clay loam with 27%, 35%, and 38% sand, silt, and clay, respectively (fine, smectitic, thermic, Udic Haplustert). Additional analyses (table 1) included soil pH (1:2 soil:deionized water; Schofield and Taylor, 1955); electrical conductivity (EC; Rhoades, 1982); soil organic carbon (OM; according to Giovannini et al., 1975, but modified to include fine grinding to pass a 100 mesh sieve and a temperature of 650 °C); NO₃-N (1 M KCl extraction; modified Keeney and Nelson, 1982); and extractable P, K, Ca, Mg, Na, and S (1.4 M NH₄OAc and 0.025 M EDTA, pH 4.2; Hons et al., 1990).

Each of the eight plots received one of two treatments: ECC or IF. The erosion control compost (ECC) treatment consisted of 50% untreated wood chips blended with 50% dairy manure compost measured by volume according to TxDOT Specification 161 (TxDOT, 2004a). The ECC was applied on top of the soil as a 50 mm layer equivalent to 283 mt ha⁻¹ (204 mt ha⁻¹ dairy manure compost + 78 mt ha⁻¹ woodchips) (fig. 2). The inorganic fertilizer (IF) treatment was applied at rates of 112 kg N ha⁻¹ as ammonium nitrate, 112 kg P₂O₅ ha⁻¹ as triple superphosphate, and 112 kg K₂O ha⁻¹ as potassium chloride. The IF rate for N application was based on TxDOT Specification 166 (TxDOT, 2004b). It was decided to use the same rate (112 kg ha⁻¹) for P₂O₅ and K₂O applications for IF plots. These application rates for P₂O₅ and K₂O are standard recommendations by the Texas AgriLife Extension Service Soil, Water, and Forage Testing Laboratory for vegetation establishment on disturbed soils. The rates are slightly greater than the typical establishment recommendations for agronomic soils because disturbed soils typically have lower organic matter content (thus, less N mineralization), lower P and a higher P fixation capacity, and lower K availability. Treatments were replicated four times using a randomized complete block design.

To prepare each plot, soil was added to a depth of 180 mm and tamped down to a depth of 100 mm with an 11.4 kg hand tamper. For ECC plots, the bed was then filled to 50 mm below the top of the bed by adding more soil to the previously tamped layer. A 68 kg hand drum roller (558 mm wide) was used to break clods and level the soil surface. A similar procedure was used for IF plot preparation, except that soil was filled to the top of the bed for this treatment. The disparate soil thickness for the two treatments was necessary because of the bed depth used by the highway materials testing program in state of Texas (TTI). Elevation of the ECC material above the triangular tray lip would have resulted in residue blockage of the discharge point. Likewise, lowering the depth of soil in the IF treatment by 5 cm would have resulted in excessive ponding of water, sediment deposition at the release point, and increased contact time between water and



Figure 2. Metal bed plots with the IF treatment incorporated into soil and the ECC treatment applied on the soil surface.

Table 2. Application rates of nitrogen (N), phosphorus (P₂O₅), and potassium (K₂O) per plot and per hectare for each treatment.

Treatment	N		P ₂ O ₅		K ₂ O	
	kg/plot	kg/ha	kg/plot	kg/ha	kg/plot	kg/ha
ECC	0.34	2000	0.24	1425	0.50	2999
IF	0.018	112	0.018	112	0.018	112
ECC:IF ratio	18.5:1		13.3:1		27.8:1	

soil with the potential for greater dissolution of nutrients. The confounding influence of this difference was assumed to be minimal. Granular fertilizer was then hand broadcast and lightly raked into the soil surface (fig. 2). Total amounts of nutrients per plot and per acre for each treatment are presented in table 2.

All treatments were applied 6 days prior to the first rainfall event. Immediately after application, all plots were seeded with a TxDOT-approved seed mix including tall fescue, wheat, and oats. Annual ryegrass was also added to the mixture to increase the likelihood of vegetation establishment. The seed mixture was hand broadcast and lightly raked into the surface of each plot.

Table 3. Laboratory analytical methods for runoff and tap water.

Parameter	Method ^[a]	Equipment Used
Total Kjeldahl nitrogen (TKN)	EPA 353.2	Autoanalyzer
Potassium (K)	EPA 200.7	ICP ^[b]
Calcium (Ca)	EPA 200.7	ICP
Magnesium (Mg)	EPA 200.7	ICP
Sodium (Na)	EPA 200.7	ICP
Manganese (Mn)	EPA 200.7	ICP
Iron (Fe)	EPA 200.7	ICP
Copper (Cu)	EPA 200.7	ICP
Ortho P	EPA 365.2	Spectrophotometer
Total P	EPA 365.2.4	Autoanalyzer
Total solids (TS)	SM 2540C	Analytical balance and oven
Total suspended solids (TSS)	SM 2540D	Analytical balance and oven
Total dissolved solids (TDS)	TS - TSS	Mathematically
pH	EPA 150.1	pH meter
Conductivity	EPA 120.1	Conductivity meter

[a] EPA = EPA laboratory analytical methods (Budde, 1995);

SM = Standards methods (APHA, 2005).

[b] ICP = Inductively coupled plasma.

DATA COLLECTION

Vegetation Response

Average plant heights were measured from 10 individual plants randomly selected in each plot 47 days after planting. Percent canopy cover was measured by using a point method and ranking system: 1 for vegetation and 0 for no vegetation. Twenty-four individual points, 152 mm apart on the two 2.1 m diagonals crossing each plot, were ranked. Measurements were made starting 15 cm away from plot borders to eliminate edge effects.

Rainfall Simulation

In the fall of 2005, an indoor rainfall simulation facility owned and operated by TTI at the Texas A&M University Riverside campus located in College Station, Texas, was used to conduct rainfall simulations and runoff sampling experiments on non-vegetated and vegetated ECC and IF plots on 26 September and 15 November, respectively. A detailed description of this facility is provided by Li et al. (2003).

An oscillating rain rack, suspended 4.3 m above the test surface (ECC and IF plots) was equipped with drip emitters



Figure 3. Rainfall simulation on vegetated ECC and IF treatment plots.

that produced 3 to 4 mm droplets to mimic a rainfall intensity of 88.9 mm h⁻¹. Similar rainfall intensities have been used in previous such studies (Glanville et al., 2004; Birt et al., 2007). Oscillation of the rack provided a randomized rain-drop pattern for uniform coverage of treatment plots. The steel bed with established treatments was hoisted under the rain rack (fig. 3) at a 3:1 slope to mimic road right-of-way sideslopes. Tap water was used for both rainfall simulation events. Tap water samples collected at the time of each rainfall simulation event were analyzed with the methods listed in table 3.

At the downstream end of each plot, a reinforced 50 mm diameter plastic hose was connected to the downspout to collect the first flush (first liter of runoff) and the subsequent total runoff for a period of 30 min following runoff initiation. For both rainfall events, time to initiate runoff (time difference between start of simulated rainfall and beginning of overland flow) from each plot was recorded. Runoff was collected for a total of 30 min from the beginning of overland flow. The first flush sample was collected directly in a 1 L plastic bottle, and subsequent runoff from each plot was collected into individual clean 113 L plastic containers and weighed for total runoff volume. After weighing, the contents of each container (varied from 20 to 47.6 L) were thoroughly agitated to re-suspend solids, and a representative subsample of 1 L was collected in a plastic bottle. This procedure of weighing and sampling was repeated for each plot following both rainfall events. Table 3 lists analytical methods and equipment used for analyses of nutrients, solids, and metals in runoff water samples.

Because the sediment beds were placed outdoors between rainfall events, three small incisions (approx. 30 mm in length) were made in the plastic lining under each plot. The cuts aided drainage of natural rainfall and irrigation water applied to the bed between simulations. Similar amounts of water were applied to all treatment plots to ensure vegetative growth in all sediment beds. Prior to the second rainfall event, each incision was sealed to avoid leaks during rainfall simulation.

STATISTICAL ANALYSIS

A randomized complete block was used to compare ECC and IF treatment effects on vegetation response, rainfall-runoff characteristics (time to initiate runoff, rainfall amount, runoff volume, runoff rate), and runoff quality (solids, EC, pH, nutrients, and metals) of first flush and total event runoff for vegetated and non-vegetated conditions. The data were analyzed using the ANOVA procedure in StatView software (SAS Institute, Inc., Cary, N.C.). Means were separated using Fisher's least significant difference (LSD) method. Means were considered significantly different from one another at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

VEGETATION RESPONSE

Vegetation response data are presented in table 4. Average plant height for the ECC plots (396 mm) was significantly greater than that for the IF (297 mm) plots. This may have been influenced by moisture conservation due to the mulching effect of the ECC and/or by the greater nutrient levels in that treatment. However, percent canopy cover was not affected by treatment, averaging 98% for both ECC and IF.

Table 4. Plant height (mm) and canopy coverage (%) data.

Treatment	Plant Height (mm) ^[a]				Mean ^[b]
	Rep 1	Rep 2	Rep 3	Rep 4	
ECC	368 ±38.9	381 ±40.4	414 ±36.1	417 ±33.3	396 a ±41.4
IF	335 ±44.2	297 ±50.3	310 ±49.5	246 ±30.0	297 b ±53.8
Treatment	Canopy Cover (%) ^[c]				Mean
	Rep 1	Rep 2	Rep 3	Rep 4	
ECC	98	96	97	99	98 a
IF	97	98	98	98	98 a

^[a] Averages and standard deviations.

^[b] Means in this column followed by different letters are significantly different at the 5% level.

^[c] Averages.

RAINFALL-RUNOFF CHARACTERISTICS

Time to initiate runoff, rainfall amount, runoff volume, and runoff rate from ECC and IF treatment plots resulting from simulated rainfall under non-vegetated and vegetated conditions are presented in table 5. The statistical analysis compares differences between ECC and IF treatments only and not between vegetated and non-vegetated conditions. Both treatments (IF and ECC) received the same intensity of rainfall (88.9 mm h⁻¹). However, due to the inherent hydrophilic property of the compost material and prevention of soil surface sealing by the 50 mm thick ECC treatment, considerably more time was required to initiate runoff from ECC plots compared to IF plots. Such delay in runoff initiation from compost treatments has also been reported by Faucette et al. (2005) and Persyn et al. (2004). Thus, the ECC plots received simulated rainfall for a longer duration than the IF plots, and consequently a greater amount of total rainfall under both vegetated and non-vegetated conditions.

Non-Vegetated Conditions

The average time to initiate runoff from non-vegetated ECC plots was nearly twice that of the IF plots but was not significantly different due to large within-treatment variation for ECC plots (table 5). The within-treatment variation observed for ECC during the non-vegetated simulation was attributed in part to preferential flow or channeling along borders of selected plots, which was corrected for the vegetated simulation. Regardless, average total runoff volume

Table 5. Time to initiate runoff, runoff volume, and runoff rate from non-vegetated and vegetated ECC and IF treatment plots.^[a]

Parameters	Non-Vegetated		Vegetated	
	ECC	IF	ECC	IF
Time to runoff ^[b] (min)	15.1 a ±11.0	8.84 a ±1.28	26.50 a ±1.34	4.82 b ±1.57
Total rain amount (L)	112.4 a ±27.4	96.80 a ±3.19	140.40 a ±3.10	86.80 b ±3.65
Total runoff volume (L)	24.8 a ±7.68	48.6 b ±5.3	48.4 a ±5.69	21 b ±3.26
Runoff rate (mm h ⁻¹)	29.7 a ±0.92	58.1 b ±0.64	57.9 a ±0.68	25.1 b ±0.39

^[a] Means and standard deviations. ECC and IF treatment means within a row for non-vegetated and vegetated conditions followed by different letters are significantly different at the 5% level.

^[b] Time to runoff was calculated by determining the amount of time lapsed between the rainfall simulation system being fully charged and the point at which runoff from the plot began. The rainfall simulation system was fully charged within 1 min 45 s and 1 min 15 s of first drop during the first and second rainfall simulation events, respectively.



Figure 4. Post-rainfall IF and ECC treatment plot surface conditions for the non-vegetated simulation event.

from IF was significantly greater ($P \leq 0.05$) than that from ECC, indicating that more water infiltrated or was captured by the ECC for the ECC plots than IF plots (table 5).

Runoff rates (mm h^{-1}) from ECC and IF plots were calculated from total runoff water volume, surface area (1.67 m^2), and the time (30 min) for runoff collection from each plot. During the non-vegetated rainfall event, the average runoff rate for ECC was significantly lower than for IF (table 5). Surface sealing due to raindrop impact on the bare soil surface of IF plots reduced water infiltration and resulted in more rapid initiation of overland flow, as compared to ECC plots where the soil surface was protected by woodchips and compost. Figure 4 illustrates post-rainfall evidence of sealing and rill formation due to detachment and transport of sediment on IF plot surfaces, as compared to no visible structural damage to the soil protected by ECC treatment. In addition, the significantly higher organic matter content ($5.96\% \pm 1.68$ for ECC vs. $1.85\% \pm 0.05$ for IF, $n = 4$) and the hydrophilic nature of compost in the ECC treatment resulted in a significantly lower runoff rate and less total runoff volume from ECC plots as compared to IF plots.

Vegetated Conditions

Vegetated ECC plots required significantly greater average time (>20 min longer) to initiate runoff compared to vegetated IF plots (table 5). Thus, the ECC plots again received a much greater amount of simulated rainfall. Under vegetated conditions, the total volume of runoff water and the runoff rate from ECC plots were significantly greater than those from IF plots, despite the fact that ECC plots absorbed and retained more of the simulated rainfall. The substantial delay in initiation of runoff from ECC plots indicated that such treatments may completely prevent runoff when exposed to rainfall of this intensity for short periods of time (<20 min).

Comparison of Non-Vegetated and Vegetated Conditions

Vegetated IF plots initiated runoff sooner (about half the time observed for non-vegetated IF plots) but had less than

half the runoff rate and total volume of runoff water as compared to the non-vegetated IF plots (table 5). Surface sealing from raindrop impact on the exposed soil of the non-vegetated IF plots likely explains this result. In addition, established vegetation on the IF plots slowed runoff rate and improved water infiltration.

Vegetated ECC plots required longer rainfall periods to initiate runoff (26.5 min) compared to non-vegetated ECC plots (15.1 min), which created longer total rainfall times (nearly 56 min for vegetated ECC versus 45 min for non-vegetated ECC.) As a result, both runoff rate and total runoff volume were greater for vegetated versus non-vegetated ECC plots (table 5). Although no data were collected to determine the saturation point of the plots, the behavior of the ECC plots during the second rainfall simulation event implies that the plots reached a saturation point (recall that all plots had an impervious bottom) prior to producing runoff. This suggests that once runoff was initiated, the amount of runoff collected was directly proportional to the amount of rainfall applied, which contributed to greater runoff volume.

In comparing IF and ECC treatments, ECC delayed initiation of runoff and retained greater amounts of simulated rainfall than IF under both vegetated and non-vegetated conditions. This indicates that the ECC treatment could substantially reduce runoff from equal intensity and relatively short duration rainfall events, especially under vegetated conditions.

A final observation following non-vegetated and vegetated rainfall simulation events occurred when the incisions were made in the plastic lining to allow for drainage after and between rainfall or irrigation events. Water immediately drained from all plots, indicating thorough infiltration. In deeper profiles, it is possible that added water would percolate more deeply, resulting in less runoff. However, it is believed that plots in the constructed sediment bed effectively mimic conditions possible on road right-of-ways with profile limiting conditions, such as shallow soils (e.g., depth to bedrock) or compacted subsoil.

Table 6. Total mass or concentration of physicochemical constituents in first flush, total runoff, and tap water samples.^[a]

Parameters	Non-Vegetated				Vegetated				Tap Water 1 L <i>n</i> = 2 ^[b]
	First Flush		Remaining Runoff		First Flush		Remaining Runoff		
	ECC	IF	ECC	IF	ECC	IF	ECC	IF	
pH	8.6 a ±0.0001	7.9 b ±0.096	8.4 a ±0.29	7.9 b ±0.0001	8.2 a ±0.082	8.6 b ±0.082	8.0 a ±0.0001	8.4 b ±0.082	8.1
EC (µmhos cm ⁻¹)	1742 a ±387	1343 a ±48	2183 a ±623	1248 a ±65	2365 a ±525	907 b ±38	2885 a ±176	903 b ±76	843
Na (mg L ⁻¹)	285 a ±28.9	223 b ±3.58	283 a ±18.6	224 b ±2.25	303a ±56.8	202 b ±4.18	299 a ±37.75	200 b ±2.82	219 ±22
TS (kg)	0.003 a ±0.0001	0.019 b ±0.01	0.084 a ±0.03	0.671 b ±0.147	0.0024 a ±0.0004	0.0027 a ±0.003	0.132 a ±0.003	0.034 b ±0.004	0.0005 ±0.0001
TDS (kg)	0.002 a ±0.0006	0.001 a ±0.0001	0.061 a ±0.036	0.048 a ±0.0005	0.0022 a ±0.0005	0.0005 b ±0.0002	0.128 a ±0.005	0.013 b ±0.003	0.0005 ±0.0001
TSS (kg)	0.0017 a ±0.0003	.0182 b ±0.006	0.026 a ±0.005	0.6 b ±0.002	0.0004 a ±0.0002	0.0025 a ±0.002	0.011 a ±0.003	0.027 b ±0.006	--
TKN (mg L ⁻¹)	48.7 a ±19.9	6.65 b ±0.73	52.1 a ±10.64	5.90 b ±0.00	15.18 a ±2.29	4.83 b ±1.09	17.53 a ±2.91	4.98 b ±0.8	2.7 ±0.42
NNN (mg L ⁻¹)	0.63 a ±0.68	1.52 a ±0.24	1.36 a ±0.99	0.42 a ±0.06	0.81 a ±0.54	2.97 b ±1.11	0.95 a ±0.42	1.54 b ±0.48	0.2 ±0.16
Ortho P (mg L ⁻¹)	1.59 a ±0.27	0.84 a ±0.36	1.57 a ±0.49	0.94 b ±0.19	1.92 a ±0.68	0.38 b ±0.19	2.36 a ±0.40	0.40 b ±0.14	0.047 ±0.024
Total P (mg L ⁻¹)	13.25 a ±3.39	5.49 a ±3.12	11.61 a ±2.72	5.36 b ±1.34	1.89 a ±0.38	0.46 b ±0.17	2.29 a ±0.30	0.40 b ±0.08	0.21 ±0.02
K (mg L ⁻¹)	219 a ±95.65	8.11 b ±2.16	229 a ±26.64	6.7 b ±0.89	104.4 a ±43.27	10.3 b ±1.32	117 a ±33.55	8 b ±1.41	3.2 ±0.87
Ca (mg L ⁻¹)	11.7 a ±2.76	172 b ±54.74	124 a ±135.88	126 a ±20.02	278 a ±78.94	34.0 b ±8.37	411 a ±64.98	30.1 b ±12.84	3.15 ±0.28
Mg (mg L ⁻¹)	3.80 a ±1.052	10.40 b ±2.51	14.12 a ±12.45	7.33 a ±0.96	27.7 a ±9.25	2.05 b ±0.51	39.1 a ±4.96	1.81 b ±0.75	0.53 ±0.007

^[a] Means and standard deviations. Means within a row of non-vegetated and vegetated categories and sampling periods (first flush or remaining runoff) followed by different letters are significantly different at the 5% level.

^[b] For tap water, *n* = 1 for pH and EC.

RUNOFF QUALITY

The physicochemical parameters analyzed in the tap water used for the rainfall simulation and for first flush and remaining runoff samples during non-vegetated and vegetated rainfall simulation events on ECC and IF plots are presented in table 6. All analytes in runoff water were determined from either the first flush (1 L) or the remaining runoff samples from the ECC and IF treatments under non-vegetated and vegetated rainfall simulation events. All solids are total quantities determined from either the first flush or the total volume of remaining runoff from ECC and IF treatments. Analysis of the tap water revealed alkaline water (pH = 8.1) with trace amounts of total Kjeldahl nitrogen (TKN), nitrite + nitrate-N (NNN), P, K, and calcium (Ca). The total solids (TS) content of tap water was primarily composed of dissolved solids. Na was a major constituent of the tap water total dissolved solids (TDS).

pH, Sodium, and Electrical Conductivity

Under non-vegetated conditions, the pH of first flush and remaining runoff samples from ECC plots was significantly greater than that in corresponding samples from IF plots (table 6). Elevated Na and TS concentrations resulting from the compost component of the ECC treatment likely were contributing factors. In contrast, pH values for both first flush and remaining runoff samples from vegetated plots were greater for IF than ECC. However, Na and TS levels were greater in ECC plots. The transition in pH, therefore, was likely due to two modifying factors related to the compost.

First, organic matter decomposition, which likely occurred in ECC plots, results in the release of organic acids, which can have a direct impact on runoff pH. Organic acids can chelate certain inorganic minerals, thereby reducing effective salt loads and altering the pH effects typically associated with soluble salts. Secondly, substantially greater N concentrations in the ECC plots, as evidenced by elevated runoff TKN concentrations, may have resulted in lower pH levels due to nitrification of ammonium.

Total Solids, Total Dissolved Solids, and Total Suspended Solids

Under non-vegetated conditions, TS and TSS were significantly lower in the first flush and remaining runoff from the ECC plots compared to IF plots (table 6). Total dissolved solids in ECC runoff tended to be slightly higher but were statistically similar to IF runoff. Within-treatment variations in the concentration of solids for ECC plots could have resulted from preferential flow or channeling of runoff along plot borders, which resulted in more rapid runoff from two of the four replicates. Most of the TS from ECC runoff was in the form of dissolved solids, while most TS from IF runoff was in the form of TSS. This suggests that a majority of solids in the runoff from the ECC plots were constituents in dairy manure compost that dissolved in the rainwater, while most solids in the IF runoff were eroded soil sediment detached due to the direct impact of the simulated rainfall. Overall, lower sediment yield in the first flush and remaining runoff from ECC followed a trend similar to the runoff rate and total volume

of runoff water for this treatment (table 5). ECC plots showed no visual evidence of soil disturbance due to raindrop impact, while the IF plots had clear signs of surface soil erosion after simulated rainfall under non-vegetated conditions (fig. 4).

Following establishment of vegetation, simulated rainfall produced significantly higher TDS in the first flush from ECC plots than IF plots, while TS and TSS in the first flush from ECC plots were statistically similar to those from IF plots (table 6). The remaining runoff from vegetated ECC plots had significantly higher TS and TDS than those in the runoff from vegetated IF plots. This trend was due to significantly higher runoff rate and total runoff volume from vegetated ECC plots than those from the vegetated IF plots. However, TSS in the remaining runoff from vegetated IF plots again were significantly higher than those from vegetated ECC plots. As in the non-vegetated rainfall event, solids in the runoff from vegetated ECC plots were primarily in the form of dissolved solids, while solids in the runoff from vegetated IF plots were dominantly in the form of suspended solids.

Lower overall total solids (sediment) in the remaining runoff from IF plots under vegetated conditions as compared to non-vegetated conditions were due to reduced overland flow (runoff rate and total volume of runoff, table 5) and soil erosion (table 6). In contrast, vegetated ECC plots had greater overall total solids in the remaining runoff compared to non-vegetated conditions, most of which were in the form of dissolved solids.

Nitrogen, Phosphorous, and Potassium

Due to the nutrient composition of the dairy manure compost used in the study, very high rates of N, P, and K were applied to the ECC plots as compared to the IF plots. The TKN in the first flush and remaining runoff from non-vegetated and vegetated ECC plots was significantly greater than that in corresponding IF plots (table 6). The TKN in first flush and remaining runoff from the vegetated ECC and IF plots decreased as compared to corresponding first flush and remaining runoff from non-vegetated ECC and IF plots. The percentage decrease was greater for the ECC treatment compared to the IF treatment.

The nitrate and nitrite (NNN) in the first flush and remaining runoff from non-vegetated ECC plots was statistically similar to that in corresponding non-vegetated IF plots (table 6). In contrast, NNN in the first flush and remaining runoff from vegetated ECC plots was significantly lower than that from vegetated IF plots.

Soluble P (ortho P) concentrations in the first flush from non-vegetated ECC plots tended to be greater, but were statistically similar to those in corresponding non-vegetated IF plots (table 6). However, ortho P concentrations in the remaining runoff from non-vegetated ECC plots and from both first flush and remaining runoff of the vegetated ECC plots were significantly greater than those in corresponding IF plots. Concentrations of ortho P from vegetated plots remained fairly consistent in both first flush and remaining runoff for ECC and IF treatments. Viator et al. (2004) found no significant differences in P losses in the first runoff solution from plots that received similar P rates of inorganic fertilizer and composted dairy manure. However, P losses were significantly greater in runoff from composted dairy manure plots compared to inorganic fertilizer plots for subsequent runoff events.

Total P concentrations in the remaining runoff from non-vegetated ECC plots were significantly greater than those in the remaining runoff from the non-vegetated IF plots (table 6). A similar trend was observed for total P in first flush samples, although differences were not significant. For vegetated conditions, total P concentrations in the first flush and remaining runoff from ECC plots were significantly greater than those from corresponding IF plots. Total P concentrations in the first flush and remaining runoff from both ECC and IF plots were considerably lower once vegetation was established.

Potassium (K) concentrations in the first flush and remaining runoff from the non-vegetated and vegetated ECC plots were significantly greater than those in corresponding IF plots (table 6). Concentrations of K in the first flush and remaining runoff from the vegetated ECC plots were about one-half of those in the first flush and remaining runoff from the non-vegetated ECC plots. Conversely, K concentrations remained effectively unchanged in the first flush and remaining runoff from the vegetated IF plots.

Total masses of primary nutrients (N, P, and K) were determined by summing weights calculated using runoff volume and nutrient concentrations for first flush and remaining runoff for each treatment under non-vegetated and vegetated conditions (table 7). The ECC plots substantially delayed runoff and therefore received more rainfall than the IF plots. In addition, due to higher nutrient levels in the compost, the ECC plots received substantially greater nutrient applications than the IF plots. Both factors contributed to the greater total nutrient mass losses of nitrogen, phosphorus, and potassium. Total masses of TKN lost were significantly greater for ECC under both non-vegetated (4 fold) and vegetated (7 fold) conditions compared to IF.

Total masses of nitrate and nitrite (NNN) were not different for ECC compared to IF under non-vegetated or vegetated conditions. Total masses of ortho P and total P were not different for ECC compared to IF for non-vegetated conditions; however, ECC produced significantly greater masses (more than 10 fold) of both ortho P and total P compared to IF under vegetated conditions. Total masses of K were significantly greater (more than 10 fold) for ECC than IF under both vegetated and non-vegetated conditions.

Table 7. Total mass of nitrogen, phosphorus, and potassium parameters in first flush and remaining runoff under non-vegetated and vegetated conditions (presented as treatment means).^[a]

Parameters	Non-Vegetated		Vegetated	
	ECC	IF	ECC	IF
Total water (L)	24.8 a ±7.68	48.6 b ±5.31	48.4 a ±5.69	21 b ±3.27
TKN (mg)	1349 a ±647	288 b ±31.1	834 a ±55.9	105 b ±28.6
NNN (mg)	38.7 a ±33.6	21.4 a ±4.91	44.3 a ±14.9	32.7 a ±5.38
Ortho P (mg)	36.8 a ±6.02	45.9 a ±11.43	112 a ±11.16	8.2 b ±2.35
Total P (mg)	276 a ±38.7	262 a ±74.3	109 a ±10	8.26 b ±1.10
K (mg)	5829 a ±2303	326 b ±43.5	5582 a ±1405	167 b ±21.2

^[a] Means and standard deviations. Non-vegetated or vegetated ECC and IF treatment means within a row followed by different letters are significantly different at the 5% level.

A comparison of nutrient ratios for ECC and IF treatments indicates that despite more rainfall exposure time, lower total runoff volume and greater water retention under non-vegetated conditions, and greater rainfall exposure time, total runoff volume and water retention under vegetated conditions, the ECC plots yielded much greater nutrient losses as compared to the IF plots. These greater nutrient losses were most likely due to the fact that when compared to the IF treatment, ECC resulted in 18.5, 13.25, and 27.75 times greater rates of application of N, P₂O₅, and K₂O, respectively (table 2).

SUMMARY AND CONCLUSIONS

The objective of this study was to compare two TxDOT-specified methods for stabilization and revegetation of steep slopes: a dairy manure compost/woodchips blend designated as erosion control compost (ECC), and inorganic fertilizer (IF). These two methods were evaluated with simulated rainfall on small plots under non-vegetated and vegetated conditions and compared based on runoff, erosion control, and constituent losses.

Under non-vegetated conditions, ECC nearly doubled the average time to initiate runoff by allowing 22 mm of rainfall to infiltrate, as compared to about 13 mm for the IF treatment. Under vegetated conditions, ECC increased the average time to initiate runoff from 5 min for the IF treatment to 27 min, which allowed 39 mm to infiltrate, as compared to 7 mm for IF.

Total suspended solids and total solids concentrations in first flush and remaining runoff were significantly greater for IF than ECC under non-vegetated conditions due to substantially greater soil loss. In contrast, the total solids concentrations in remaining runoff from the vegetated ECC plots were significantly greater than those in IF plots but were predominantly in the form of total dissolved solids.

Nutrient concentrations were higher for ECC due to higher nutrient application rates than for IF; therefore in extreme events, the potential for very high nutrient losses exists for the ECC treatment. Observed increases in concentrations and total masses of nutrients in runoff from the ECC plots compared to IF were most likely due to substantially greater total nutrient loadings as a result of the chemical composition of the manure-based compost utilized in the ECC treatment (ECC treatment contained 18.5, 13.3, and 27.8 times more N, P₂O₅, and K₂O, respectively).

This study supports previous work that has shown the benefits of organic soil amendments for reducing soil erosion, particularly from highly erodible surfaces. In the absence of vegetation, the ECC treatment significantly reduced the loss of solids during runoff events. In addition, the use of ECC delayed runoff for a substantially longer time period than IF when vegetated. Under both non-vegetated and vegetated conditions, the ECC treatment retained greater amounts of rainfall than the IF treatment. Although ECC reduced erosion, it also contributed elevated levels of nutrients in the runoff, which can represent an adverse impact on water resources and thus counteract erosion control benefits. Conclusive evaluation of the use of composted manure as an erosion control material as it affects water quality, i.e., comparing its average life-cycle rate of release of nutrients in particular applications with that of control treatments,

will require either an extended outdoor field trial or sequential testing with multiple simulated rainfall events on the same set of plots until the soil nutrient concentrations in the compost-treated plots fall within agronomic levels.

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