Use of Dairy Manure Compost as Erosion Control Material Under Vegetated and Non Vegetated Conditions

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INTRODUCTION

Many watersheds in the USA with large and concentrated animal feeding operations (CAFOs) face the challenge of reducing manure application rates on agricultural soils that test high in phosphorous (P) by identifying alternatives for manure utilization. Water quality studies in the Bosque River watershed, home to more than one hundred dairy operations, 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, to the North Bosque River (McFarland and Hauck, 1999a, 1999b).

Studies by Persyn et al. (2004) and Risse and Faucette (2003) cite use of compost from various organic materials including animal manure for erosion control and revegetation of highway construction sites. Construction and erosion control applications of dairy manure compost (DMC) could provide an opportunity to remove large quantities of manure from the North Bosque River Watershed and help reduce the need for repeated application of manure to the same parcels of land in the watershed. However, very 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 construction.

OBJECTIVES

The objectives of this study were to:

1. Examine the efficacy of using an erosion control treatment system containing composted dairy manure for stabilization and revegetation of steep slopes.
2. Compare results of runoff volume and concentrations and loadings of physicochemical constituents from experimental plots amended with a DMC/woodchips blend (designated as erosion control compost or ECC) or inorganic fertilizer (IF) subjected to simulated intense rainfall under non-vegetated and vegetated conditions.

METHODS AND MATERIALS

Experimental plot construction and set-up, treatment installation and vegetation establishment

Eight, 3 by 6-ft (0.9 by 1.8-m) plots were established on a custom built steel bed {9.1m (30ft) × 1.8m (6ft) × 228.6mm (9in) deep} divided with metal borders and lined with a 5 mil plastic tarp (Fig. 1a). At the downslope end of each plot, a triangular tray and downspout (Fig. 1b) were constructed to convey runoff to a sampling container.

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

Soil used to fill each divided metal bed (plot) was excavated from a constructed hillside at the Riverside campus in College Station, Texas, used by the Texas Transportation Institute (TTI) for runoff studies. Three composite soil samples were collected for laboratory analysis. Soil texture was clay loam containing an average 27, 35 and 38 percent sand, silt, and clay, respectively (Table 1). Additional soil chemical analyses conducted are listed in Table 2.

Table 1. Textural analysis of soil utilized to prepare sediment bed.

Plot ID	Sand	Silt	Clay	Texture
	-------------------------%-------------------------			
Soil Sample 1	26	34	40	Clay loam
Soil Sample 2	28	34	38	Clay loam
Soil Sample 3	28	36	36	Clay loam
Std Dev	*1.2*	*1.2*	*2.0*	
Average	27	35	38	

Table 2. Chemical analysis of soil utilized to prepare sediment bed.

Plot ID	pH	EC	NO_3+NO_2	P extractable	K	Ca	Mg	SO_4-S	Na	B	OM
Soil Sample 1	7.8	2246	43	7	239	9476	426	1213	215	0.44	1.53
Soil Sample 2	7.7	2118	60	8	229	8318	413	1356	242	0.41	1.59
Soil Sample 3	7.7	2094	50	8	230	8644	414	1902	181	0.47	1.60
Std Dev	*0.1*	*81.71*	*9.0*	*1*	*5.5*	*597*	*7.2*	*364*	*30.6*	*0.03*	*0.04*
AVERAGE	7.73	2153	51	8	233	8813	418	1490	213	0.44	1.57

In each plot, soil was added to a height of 7 inches (18 cm) and tamped down to a height of 4 inches (10 cm) with a 25 lb (11.4 kg) hand tamper (Fig 2a). The two treatment systems were erosion control compost (ECC); a 1:1 (v:v) blend of dairy manure compost (DMC) and woodchips, and inorganic fertilizer (IF). For the purpose of this paper, these treatment systems will be referred to as treatments. Both treatments were replicated four times and randomly assigned to these plots (Fig. 3). For each ECC plot preparation, the bed was filled up to 2 inches below the top of the bed by adding more soil to the previously tamped layer. A 150-lb (68 Kg) hand drum roller (22 inches wide) was used to break clods and level the soil surface (Fig. 2b). A similar procedure was used for IF plot preparation, but soil was filled to the top of the bed for this treatment. The procedure used to prepare the sediment beds was consistent with that utilized by TTI for bed preparation when conducting TxDOT approved research.

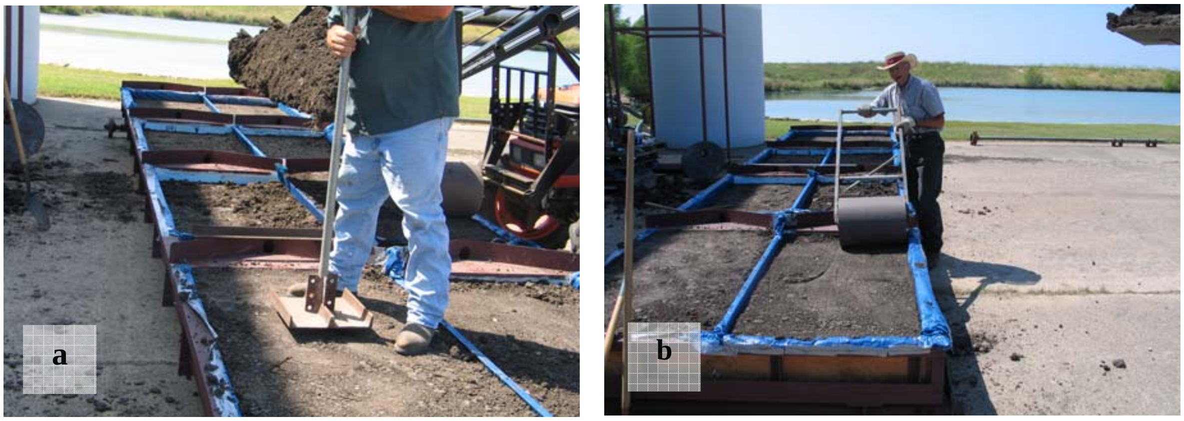

Figure 2. Soil compaction with hand tamping (a) and soil leveling with a drum roller (b).

For ECC plots, the blend of DMC and woodchips was applied on top of the soil as a 2-inch (5-cm) layer equivalent to 126 t/ac (91.1 t/ac DMC + 34.8 t/ac woodchips) or 283 mt/ha (Fig. 4). Based on chemical analysis of the DMC (Table 3a and 3b), this resulted in nutrient application rates of 1786 lb N/ac (2002 kg N/ha), 1272 lb P_2O_5/ac (1426 kg P_2O_5/ha), and 2678 lb K_2O/ac (3002 kg K_2O/ha). For the IF plots, granular fertilizer was hand broadcast and then lightly raked into the soil surface at rates of 100 lb N/ac (112 kg N/ha) as ammonium nitrate, 100 lb P_2O_5/ac (112 kg P_2O_5/ha) as triple superphosphate, and 100 lb K_2O/ac (112 kg K_2O/ha) as potassium chloride (Fig 4). These treatments were established 6 days prior to the first rainfall event. Total amounts of nutrients per plot and per acre for each treatment are presented in Table 3c. As noted in the table, due to the composition of the DMC, the ECC treatment resulted in substantially greater nutrient application rates compared to the IF treatment.

After establishment of treatments, all plots were seeded on the same day with a Texas DOT recommended seed mix (tall fescue, wheat, oats) with the addition of ryegrass to ensure vegetation establishment (Fig. 5a). The mixture was broadcast (Fig. 5b) and lightly raked into the surface of each plot. All plots were monitored for seed germination, moisture and insect management.

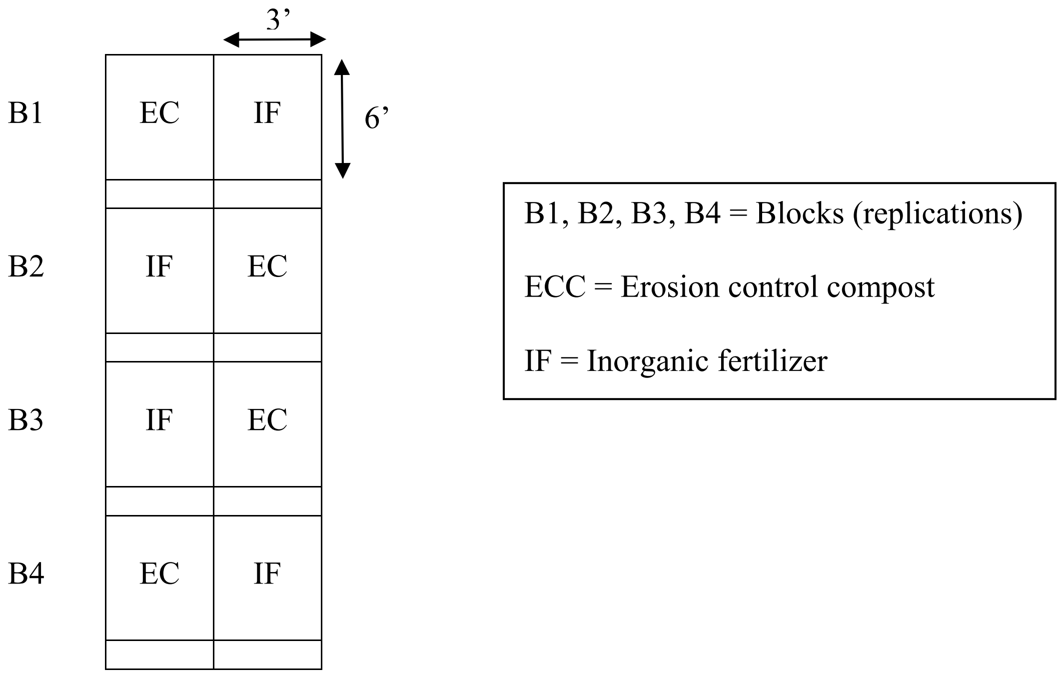

Figure 3. Experimental plots and treatment set-up (dimensions are not to scale)

Vegetation Response and Soil Sample Data Collection

Information on plant height and percent of canopy coverage is provided in Table 6. Average plant heights were measured from 10 individual plants randomly selected in each plot 47 days after planting (Fig. 6a). 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, 6 inches (15.2 cm) apart on the two 7-feet (2.1 m) diagonals crossing each plot were ranked (Fig. 6b). Measurements were made starting 6 inches away from plot borders to eliminate edge effects.

In addition to the initial composite soil samples collected and analyzed (Table 1 and 2), composite soil samples were collected from each plot at three stages of the study. Samples were collected (1) following the first rainfall simulation event; (2) after vegetation establishment, but prior to second rainfall simulation event; and (3) following the second rainfall simulation event. Each composite sample was collected by thoroughly mixing 10 subsamples collected at a 6 inch depth in each plot. Soil samples were submitted to TCE Soil, Water and Forage Testing Laboratory and analyzed according to the approved Marketing Composted Manure to Public Entities Quality Assurance Project Plan.

Table 3a. Laboratory analysis of dairy manure compost utilized in the rainfall simulation study. Parameters listed were determined on a wet weight basis.

Parameter	Units	Wet Weight Basis
Total N	%	0.98
Ammonia	mg/kg	584
Nitrate	mg/kg	8
Organic Nitrogen	%	0.92
Phosphorus as P2O5	%	0.69
Phosphorus	mg/kg	3048
Potassium as K2O	%	1.5
Potassium	mg/kg	12250
Calcium	%	9.1
Magnesium	%	0.52
Sulfate (SO4)	mg/kg	449
Copper	mg/kg	29
Zinc	mg/kg	90
Iron	mg/kg	5855
Manganese	mg/kg	153
Boron	mg/kg	19
Sodium	%	0.27
Chloride	%	0.17
pH	units	9.06
EC	mmhos/cm	4.165
Bulk Density	lb/cu ft	47
Carbonates as CaCO3	lb/ton	67
Organic matter	%	20.7
Organic Carbon	%	14.2
Ash	%	58.8
C:N Ratio	ratio	14
Moisture	%	20.5

Table 3b. Laboratory analysis of dairy manure compost utilized in the rainfall simulation study. Parameters listed were determined on a dry weight basis

Parameter	Units	Dry Weight Basis
Arsenic	mg/kg dw	3
Cadmium	mg/kg dw	less than 1
Chromium	mg/kg dw	6
Copper	mg/kg dw	36
Lead	mg/kg dw	2
Mercury	mg/kg dw	less than 1
Molybdenum	mg/kg dw	1
Nickel	mg/kg dw	5
Selenium	mg/kg dw	less than 1
Zinc	mg/kg dw	114
Cobalt	mg/kg dw	2
Total Solids	%	79.5
Fecal Coliform	mpn/g dw	17
Salmonella	mpn/4 g dw	less than 3
Respiration	mg CO2-C/g OM/day	7
Biological Avail. Carbon	mg CO2-C/g OM/day	7.2
Emergence	%	100
Relative Seedling Vigor	%	100
Description of plants	NA	Healthy
0.25" to 0.38"	% by weight	0
	% by volume	0
	Bulk Density (g/cc)	0
0.16" to 0.25"	% by weight	1.8
	% by volume	1.6
	Bulk Density (g/cc)	0.7
0.08" to 0.16"	% by weight	18.8
	% by volume	21.3
	Bulk Density (g/cc)	0.56
<0.08"	% by weight	79.4
	% by volume	77.1
	Bulk Density (g/cc)	0.65

Table 3c. Application rates of nitrogen (in the form of N), phosphorus (in the form of P_2O_5), and K (in the form of K_2O) per plot and per acre for each treatment, ECC and IF.

	N		**P_2O_5**		**K_2O**	
	lbs/plot	**lbs/A**	**lbs/plot**	**lbs/A**	**lbs/plot**	**lbs/A**
ECC	0.74	1786	0.53	1272	1.11	2678
IF	0.04	100	0.04	100	0.04	100
	lbs/plot		**lbs/plot**		**lbs/plot**	
Ratio of ECC:IF	18.5		13.25		27.75	

Figure 4. Metal bed plots with the IF treatment incorporated into soil and the ECC treatment applied on the soil surface.

Figure 5. Grass seed (left) being braodcast on IF treatment (right).

Figure 6. Plant height (a) and percent of canopy coverage (b) measurement .

Rainfall simulation and surface runoff sampling

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

An oscillating rain rack (Fig. 7), suspended 14 feet (4.3 m) above the test surface (ECC and IF plots) is equipped with drip emitters that produce 0.12 to 0.16 inch (3mm to 4mm) droplets to mimic a rainfall intensity of 3.5in/hr (88.9 mm/hr), which corresponds to a 25-yr return frequency of a 1-hr storm at the experimental site. Oscillation of the rack provides a randomized raindrop pattern for uniform coverage of treatment plots. The 25-yr 1-hr storm event is the typical rate used in highway roadside erosion control material testing in the TTI rainfall simulation facility (Li et al. 2003).

The steel bed with established treatements was hoisted under the rain rack (Fig. 7 and 8 for non-vegetated and vegetated conditions, respectively) at a 3:1 side slope to mimic road right-of-way.

Tap water was used for both rainfall simulation events. Chemical analysis of tap water samples collected at the time of each rainfall simulation event are presented in Table 8.

At the downstream end of each plot, a reinforced 2-inch diameter plastic hose was connected to the downspout of each plot to collect the first flush (first litre of runoff) and the subsequent total runoff for a period of 30 minutes following runoff initiation.

For both rainfall events, time to initiate runoff (time difference between start of simulated rainfall and beginning of overland flow) for each plot was recorded. Runoff was collected for a total of 30 minutes. The first liter of runoff (first flush) was collected directly in a plastic bottle (Fig. 9a) and subsequent runoff from each plot was collected into individual clean 30-gallon (113 L) plastic containers (Fig. 9b) and weighed for total runoff mass (Fig 10a). After weighing, contents of each container were thoroughly agitated to re-suspend solids, and a representative sub-sample was collected in a plastic bottle (Figs. 10a-c). This procedure of weighing and sampling was repeated for all plots during both rainfall events.

Because the sediment beds were to be placed outdoors between rainfall events, 3 small incisions (approximately 3 cm in length) were placed in the plastic lining under each plot. The cuts aided water flow through the plots so rainfall and irrigation applied to the bed would not pool in each plot. Prior to the second rainfall event, each incision was sealed with caulking to avoid leaks during rainfall simulation.

Figure 7. Oscillating rain rack with emitters (left) and non-vegetated treatment plots (right) hoisted under the rack at a 3:1 sideslope.

Figure 8. Rainfall simulation on vegetated ECC and IF treatment plots.

Analysis of soil, compost and runoff

Soil, compost and runoff water sample collection and laboratory analyses followed approved procedures and methodologies described in the Marketing Composted Manure to Public Entities Quality Assurance Project Plan. Table 4 lists analytes determined for soil and runoff water samples and the corresponding procedure for the analysis of each parameter. Three composite samples of dairy manure compost were collected prior to treatment installation and analyzed by Soil Control Laboratories. Parameters and laboratory methodology as defined by the Test Methods for the Examination of Compost and Composting are listed in Table 5.

Figure 9. Samples of first flush (a) and subsequent runoff (b) being collected during rainfall simulation event.

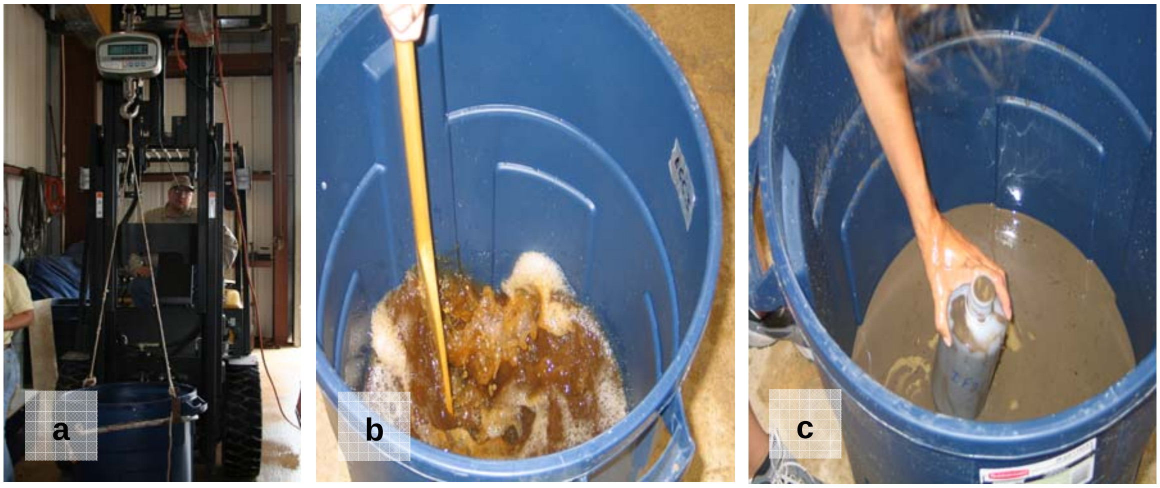

Figure 10. Weighing (a), mixing (b) and sub-sampling (c) of total runoff mass.

Table 4. Soil and runoff water sample parameters analyzed and the corresponding methodology as defined by the Soil, Water and Forage Testing Laboratory.

Parameter	SWFTL[a] Method
Soil	
pH	0015
Electrical Conductivity	0015
NO_3–N + NO_2–N (NNN)	0014
Extractable Phosphorus	00079 & 00081
Water Soluble P (CaCl)	0064
Potassium	00079 & 00081
Calcium	00079 & 00081
Magnesium	00079 & 00081
Sodium	00079 & 00081
Sulfate-Sulfur	00079 & 00081
Boron	0022 & 00081
Moisture	NA
Organic Matter	NA
Water	
pH	0041
Electrical Conductivity	0040
NO_3–N + NO_2–N (NNN)	0038
Total Phosphorus	0037
Ortho-phosphate	0061 & 0062
Potassium	0037
Calcium	0037
Magnesium	0037
Sodium	0037
Sulfate-Sulfur	0037
Total Solids	0057[b]
Total Suspended Solids	0057

[a] SWFTL = Soil, Water and Forage Testing Laboratory SOP code

[b] Standard Operating Procedure 0057 based on Standard Method 2540 (Franson 1989)

Table 5. Dairy manure compost sample parameters analyzed and corresponding methodology utilized by Soil Control Laboratories.

Parameter	**CL[a] Method (TMECC[b] Method)**
Chemical Properties	
Electrical Conductivity	04.10-A
PH	04.11-A
Organic Properties	
Organic Matter	05.07-A
Fecal Coliform	07.01-B
Metals	
Magnesium	04.12-B/04.14-A
Sodium	04.12-B/04.14-A
Manganese	04.12-B/04.14-A
Copper	04.12-B/04.14-A
Calcium	04.12-B/04.14-A
Zinc	04.12-B/04.14-A
Iron	04.12-B/04.14-A
Arsenic	04.12-B/04.14-A
Chromium	04.12-B/04.14-A
Cadmium	04.12-B/04.14-A
Lead	04.12-B/04.14-A
Mercury	04.12-B/04.14-A
Molybdenum	04.12-B/04.14-A
Nickel	04.12-B/04.14-A
Selenium	04.12-B/04.14-A
Nutrients	
Total Nitrogen	04.02-D
Total Phosphorus	04.12-B/04.14-A
Total Potassium	04.12-B/04.14-A
Physical Properties	
Particle Size	02.02-B
Maturity	05.05-A
Stability	05.08-B
Moisture	03.09-A

[a] CL = Control Laboratories

[b] TMECC = Test Methods for the Examination of Composting and Compost

Statistical analysis

Data were analyzed using the ANOVA procedure for a randomized complete block design in Stat View (SAS Inc.), and means were separated using Fisher's least significant difference (LSD) method.

RESULTS AND DISCUSSION

Vegetation response

Vegetation response data are presented in Table 6. Average plant height for the ECC plots (15.6 inches) was significantly greater than that for the IF (11.7 inches) 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 6. Plant height and canopy coverage data.

Treatment	Rep 1	Rep 2	Rep 3	Rep 4	Statistics
	Plant heights (in)				
ECC	14.5* ±1.53**	15.0 ±1.59	16.3 ±1.42	16.4 ±1.31	15.6 ±1.63
IF	13.2 ±1.74	11.7 ±1.98	12.2 ±1.95	9.7 ±1.18	11.7 ±2.12
	Canopy coverage (%)				
ECC	98%*	96%	97%	99%	
IF	97%	98%	98%	98%	

* Average; ** SD

Soil Characteristics

Soil sample results from the three sampling events are presented in Tables 7a, 7b and 7c. Application of the ECC treatment significantly increased percent organic matter in ECC plots compared to soil sample results prior to treatment. The application of ECC and IF treatments had no effect on soil pH levels and minimal effect on EC levels. Compost used in this study had a pH of 9.06 (Table 3a), which is above the TxDOT compost specification (pH must be between 5.5 and 8.5). Data presented here warrants further investigation of the pH specification as vegetation response and soil sample results indicated no harmful effects from utilizing a high pH dairy compost based material.

The drain holes did preclude development of a mass balance of soil nutrients for the plots. However, soil sample data as listed in Tables 7a, 7b and 7c provide information about the effects of compost and inorganic fertilizer on soil characteristics.

Table 7a. Composite soil sample characteristics of individual plots following first rainfall simulation event. Samples were collected and submitted to laboratory on September 28, 2005.

Plot ID	pH	EC	NO_3+NO_2	P^a	P^b	K	Ca	Mg	SO_4-S	Na	B	OM
		umho/cm				ppm						%
ECC Rep 1	7.7	1801	39	430	10.51	994	7424	680	2542	510	2.26	7.60
ECC Rep 2	7.7	1904	38	412	4.96	758	7897	668	2812	403	1.87	6.34
ECC Rep 3	7.7	2131	61	188	3.93	646	7954	516	3812	366	1.62	4.27
ECC Rep 4	7.7	1765	32	367	6.60	709	8004	646	2794	406	1.63	5.62
Std Dev	*0.0*	*164.7*	*13*	*111*	*2.89*	*152*	*267*	*75.7*	*562*	*61.9*	*0.30*	*1.39*
AVERAGE	7.7	1900	43	349	6.50	777	7820	628	2990	421	1.85	5.96
IF Rep 1	7.5	1986	89	36	<1	230	8481	419	5019	224	0.93	1.82
IF Rep 2	7.5	1998	102	19	<1	289	8730	410	5237	240	0.82	1.84
IF Rep 3	7.4	1969	99	21	<1	262	9436	436	6543	208	0.86	1.81
IF Rep 4	7.1	1306	111	17	8.25	251	7518	377	3767	234	0.95	1.93
Std Dev	0.19	339.4	9.1	8.7	-	24.6	793	24.8	1137	14.0	0.06	0.19
AVERAGE	7.38	1815	100	23	-	258	8541	411	5141	227	0.89	7.38

Table 7b. Composite soil sample characteristics of individual plots prior to second rainfall simulation event. Samples were collected and submitted to laboratory on November 11, 2005.

Plot ID	pH	EC	NO_3+NO_2	P^a	P^b	K	Ca	Mg	SO_4-S	Na	B	OM
		umho/cm				ppm						%
ECC Rep 1	7.5	1892	3	505	9.28	1210	7220	702	2132	655	2.556	2.6
ECC Rep 2	7.8	1498	3	403	4.34	766	7652	644	2521	547	1.87	6.78
ECC Rep 3	7.5	1669	46	368	2.28	687	8169	652	2770	526	1.711	5.44
ECC Rep 4	7.6	802	7	398	1.87	866	7278	632	2192	505	1.676	6.37
Std Dev	*0.14*	*471*	*21*	*59.9*	*3.40*	*230*	*437*	*30.8*	*298*	*66.7*	*0.41*	*1.88*
AVERAGE	7.6	1465	15	418	4.44	882	7580	658	2404	558	1.95	5.30
IF Rep 1	7.5	1574	15	22	<1	202	7148	310	2812	290	na	1.83
IF Rep 2	7.7	1805	3	28	1.67	229	8208	367	4297	312	0.823	1.73
IF Rep 3	7.4	2066	41	24	<1	229	8668	348	4405	312	0.975	1.78
IF Rep 4	7.6	1717	51	25	<1	248	8730	402	4722	342	0.987	2.17
Std Dev	*0.13*	*206.9*	*22*	*2.4*	-	*19.0*	*732*	*38.2*	*851*	*21.4*	*0.09*	*0.20*
AVERAGE	7.55	1791	27	25	-	227	8189	357	4059	314	0.93	1.88

Table 7c. Composite soil sample characteristics of individual plots following second rainfall simulation event. Samples were collected and submitted to laboratory on November 22, 2005.

Plot ID	pH	EC	NO_3+NO_2	P^a	P^b	K	Ca	Mg	SO_4-S	Na	B	OM
		umho/cm				ppm						%
ECC Rep 1	7.8	1889	4	792	8.45	1327	8598	916	2752	816	2.01	10.09
ECC Rep 2	7.7	2210	4	252	1.14	625	8800	578	4357	534	1.28	4.52
ECC Rep 3	7.7	2340	6	318	1.92	576	8969	645	4057	593	1.37	4.92
ECC Rep 4	7.6	2390	7	288	1.5	651	9453	628	4713	518	1.16	4.36
Std Dev	*0.1*	*225.3*	*2*	*254*	*3.48*	*356*	*365*	*152*	*855*	*138*	*0.38*	*2.76*
AVERAGE	7.7	2207	5	413	3.25	795	8955	692	3970	615	1.46	5.97
IF Rep 1	7.5	2320	13	38	0.15	304	9551	408	5303	383	0.91	1.74
IF Rep 2	7.5	2530	14	19	0.1	280	9749	442	5647	393	0.68	1.81
IF Rep 3	7.5	2920	16	21	0.26	280	10334	411	7522	364	0.77	1.89
IF Rep 4	7.6	2740	17	34	0.26	306	10354	427	6336	417	0.78	1.7
Std Dev	*0.0*	*259.7*	*1.8*	*9.4*	*0.08*	*14.5*	*409*	*15.7*	*979*	*22.1*	*0.09*	*0.08*
AVERAGE	7.53	2628	15	28	0.19	293	9997	422	6202	389	0.79	1.79

[a] extractable; [b] water soluble

Runoff volume characteristics of non-vegetated and vegetated ECC and IF treatments

Time to initiate runoff, total amount of rainfall, total mass of runoff water and runoff rate from ECC and IF treatment plots resulting from simulated rainfall under non-vegetated and vegetated conditions are presented in Table 8.

Both systems (IF and ECC) received the same intensity of rainfall (3.5 in/hr). However, due to the inherent hydrophilic property of organic matter and prevention of soil surface sealing by the 5-cm thick erosion control blanket in the ECC system, considerably more time was required to initiate runoff from ECC plots compared to IF plots. Therefore, the ECC plots received rain for longer duration than the IF plots. Thus, ECC received a greater amount of 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. 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 mass from IF was significantly greater ($P \leq 0.05$) than that from ECC indicating more water infiltrated into the ECC plots than IF plots.

Runoff rates (cm/h) from ECC and IF plots were calculated from total runoff water mass (converted to volume using density of water), surface area (18 ft^2 or 1.67 m^2) and the time (30 min.) for runoff collection from each plot. During the non-vegetated rainfall event, average runoff rate for ECC was significantly lower than IF. Surface sealing due to raindrop impact on the bare soil surface of IF treatment plots reduced infiltration and rain water and initiated quicker overland flow as compared to ECC where the woodchips and compost protected the soil surface. Figure 11 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%±1.68 for ECC vs. 1.85% ±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 water mass from ECC plots as compared to the IF plots.

Vegetated conditions: Similar to results observed for non-vegetated conditions, simulated rainfall on vegetated plots resulted in greater average time to initiate runoff from ECC compared to IF plots, but differences were statistically significant in this case (Table 8). 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 (less than 20 minutes) as compared to exposed soil (IF treatment).

Considerably more time (>20 minutes longer) was required to initiate runoff from vegetated ECC plots compared to vegetated IF plots. Thus, ECC plots received a much greater amount of rainfall, which resulted in increased runoff rate and mass. As a result, the total mass of runoff water and runoff rate from vegetated ECC plots were significantly greater than from vegetated IF plots despite the fact that ECC plots absorbed and retained more of the rainfall applied than the

IF plots. As noted in Table 8, the ECC plots absorbed more water than the IF plots during the entire vegetated rainfall simulation event.

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 mass of runoff water as compared to the non-vegetated IF plots. Surface sealing caused by raindrop impact on the exposed soil of the non-vegetated IF plots likely explain this result. Established vegetation on the IF plots slowed runoff rate and improved water infiltration.

Vegetated ECC plots took much longer to initiate runoff and had twice the runoff rate and total runoff mass compared to the non-vegetated ECC plots. The ECC treatment coupled with vegetation improved infiltration and substantially delayed runoff for vegetated ECC plots compared to non-vegetated ECC plots (~15 minutes to runoff under non-vegetated conditions versus ~26 minutes to runoff for vegetated conditions). This delay in runoff led to increased rainfall exposure time for vegetated ECC plots (~45 minutes rainfall exposure for non vegetated conditions versus ~56 minutes rainfall exposure for vegetated conditions). 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 the plots reached a saturation point prior to producing runoff, thereby suggesting that once runoff was initiated, the amount of runoff collected was directly proportional to the amount of rainfall applied contributing to greater runoff volume and mass.

In comparing IF and ECC treatments, ECC retained greater amounts of rainfall than IF under both vegetated and non-vegetated conditions. This indicates that the ECC treatment in contrast to the IF treatment would prevent runoff from equal intensity, relatively short duration rainfall events, especially under vegetated conditions. This is further corroborated by greater water retention within ECC plots and thus, significantly greater delay in initiation of runoff under vegetated conditions from ECC plots compared to IF plots.

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. When the incisions were made, water immediately drained from the plots indicating thorough infiltration. In deeper profiles, it is possible that more water would have saturated the soils and produced less runoff. The plots in the constructed sediment bed, however, mimic those possible on road right-of-ways with profile limiting conditions, such as shallow soils (e.g. depth to bedrock) or compacted subsoils.

Table 8. Time to initiate runoff, total runoff mass, and runoff rate from non-vegetated and vegetated ECC and IF treatment plots.

	Non-Vegetated		Vegetated	
Parameters	**ECC**	**IF**	**ECC**	**IF**
Time to Runoff[3] (min.)	15.11[1] (±11.03)[2]	8.84 (±1.28)	26.49[a] (±1.34)	4.82[b] (±1.57)
Total Rain Water (kg or L[4]) ***applied to plot***	112.36 (±27.40)	96.81 (±3.19)	140.36[a] (±3.10)	86.81[b] (±3.65)
Total Runoff Water (kg) ***received from plot***	24.84[a] (±7.68)	48.62[b] (±5.30)	48.38[a] (±5.69)	20.98[b] (±3.26)
Runoff Rate (cm/hr)	2.97[a] (±0.92)	5.81[b] (±0.64)	5.79[a] (±0.68)	2.51[b] (±0.39)

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

[2] Standard deviation.

[3] 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. Rainfall simulation system was fully charged within 1 min 45 sec and 1 min 15 sec of first drop during the first and second rainfall simulation events, respectively.

[4] Liters of water converted to kg water assuming density of water is 1 kg/L

Figure 11. Post rainfall IF and ECC treatment plot surface conditions from non-vegetated simulation event.

Runoff Quality of non-vegetated and vegetated ECC and IF treatments

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 9. All analytes for ECC and IF except solids, pH and ECC in Table 9 are concentrations (mg/L) determined from either the first flush (1-L) or remaining runoff from non-vegetated or vegetated rainfall simulation events. All solids are total quantities determined from either the first flush or the total mass of remaining runoff from ECC and IF treatments. Analysis of the tap water revealed alkaline (pH: 8.1) water with trace amounts of TKN, nitrite + nitrate (NNN), P, K, Ca, and S. Tap water TS was mostly dissolved solids and Na was a major constituent of the tap water 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 9). Greater sodium and elevated total salt 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, sodium and total salt 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 nitrogen concentrations in the ECC plots, as evidenced by elevated runoff TKN concentrations, likely resulted in lower pH levels due to nitrification of ammonium.

Total Solids, Total Dissolved Solids and Total Suspended Solids

As noted above, due to the physical characteristics of the manure and woodchips mixture in the ECC system, considerably more time was required to initiate runoff from ECC plots compared to IF plots. Therefore, the ECC plots received rain for longer duration than the IF plots. Thus, ECC received a greater amount of rainfall under both vegetated and non-vegetated conditions.

Non-vegetated conditions: 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 9). Total dissolved solids in ECC runoff tended to be slightly higher but were statistically similar to IF runoff. Differences between concentration of solids within ECC treatments could have resulted from the preferential flow or channeling along the plot border, which resulted in quicker runoff from 2 of the 4 replications. Most 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 and transported out of the IF plots by the overland flow. Overall, lower sediment yield in the first flush and remaining runoff from ECC followed a trend similar to the runoff rate and total mass of runoff water (Table 7) from these non-vegetated plots. All ECC plots had less soil disturbance from raindrop impact than IF plots. This effect is visually illustrated by plot photographs in Figure 11 which show the more eroded surface conditions for IF compared to ECC plots post simulated rainfall under non-vegetated conditions.

Vegetated conditions: 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 9). 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.

Comparison of non-vegetated and vegetated conditions: Lower overall total solids (sediment) in the runoff from IF plots under vegetated conditions as compared to non-vegetated conditions were due to the vegetative cover that reduced overland flow (runoff rate and total mass of runoff water, Table 8) and reduced soil erosion from these plots as compared to the non-vegetated IF plots (Table 9). In contrast, vegetated ECC plots had greater overall total solids in the runoff under vegetated conditions compared to non-vegetated conditions but most of the vegetated ECC plot runoff solids were in the form of dissolved solids. Greater total mass of runoff as a result of higher runoff rate from vegetated ECC (Table 8) plots versus non-vegetated ECC plots resulted in higher TS from the vegetated ECC. Greater time to initiate runoff for vegetated ECC plots as compared to the non-vegetated ECC plots (Table 8) also provided more interaction time between compost and rainwater enhancing the dissolution of soluble compost constituents and their transport in overland flow.

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 IF plots. In addition, due to the inherent property of the ECC system, considerably more time was required to initiate runoff from ECC plots compared to IF plots. Thus, ECC received more rainfall under both vegetated and non-vegetated conditions.

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. 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 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 9). 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. However, ortho P concentrations in the remaining runoff from non-vegetated ECC plots were significantly greater than those in corresponding IF plots. Similarly, for the vegetated plots, ortho P concentrations in the first flush and remaining runoff of 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.

Total P concentrations in the first flush remaining runoff from non-vegetated ECC plots were significantly greater than those in the remaining runoff from the non-vegetated IF plots. 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. 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 10). 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 (Table 3c) than the IF plots. Both factors contributed to the greater total nutrient mass losses of nitrogen, phosphorus and potassium. Total masses of TKN 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. For comparison, Table 11 provides the concentration of primary nutrients (N, P and K) on a mass per acre or hectare basis.

Due to differences in rainfall exposure time on ECC and IF plots under vegetated conditions, ratios of total mass of TKN, total P and K losses in the runoff from these treatments were compared to ratios of rainfall exposure time, runoff mass and total water retained (difference between average total rainfall applied to a plot and average total runoff collected from a plot).

Results of these calculations are presented in table 12. In addition, the ratio of total N, P_2O_5 and K_2O applied in the ECC and IF systems were compared and presented in table 3c.

While the ratio of rainfall exposure time was similar for non-vegetated conditions, runoff mass was only half for ECC compared to IF. Nevertheless, TKN and total K losses from ECC plots were nearly 4.7 and 17.9 times greater than IF plots, respectively. Total P losses were similar from both treatment systems.

Under vegetated conditions, ECC had a total rainfall exposure time 1.6 times and total runoff mass 2.3 times greater than IF. But, ECC nutrient losses were 8, 13, and 33 times greater than IF for TKN, total P, and total K, respectively.

Under both non-vegetated and vegetated conditions, ECC plots received 1.16 and 1.62 times more rainfall than IF plots, yet retained 1.82 and 1.40 times more water than IF plots, respectively. ECC yielded greater nutrient losses under both conditions.

A comparison of nutrient ratios for ECC and IF treatments indicates that despite more rainfall exposure time, lower total runoff mass and greater water retention under non vegetated conditions and greater rainfall exposure time, total runoff mass and water retention under vegetated conditions, the ECC plots yielded much greater nutrient losses as compared to IF plots. These greater nutrient losses from ECC plots were most likely due to the fact that when compared to the IF treatment, the ECC treatment resulted in 18.5, 13.25 and 27.75 times greater rates of application of N, P_2O_5 and K_2O, respectively (Table 3c). Chastain et. al. (2006) determined that a 5 cm application of an erosion control blanket (a mixture of composted cow manure with wood waste) resulted in application rates of P_2O_5 and K_2O that were in excess of agronomic rates for the crop.

Sulfur, Calcium, Magnesium

Sulfur and sulfate concentrations in the first flush of non-vegetated IF plots were greater than those in ECC plots; however, concentrations were not different in remaining runoff. Under vegetated conditions, both sulfur and sulfate concentrations were significantly greater in the first flush and remaining runoff of ECC plots compared to corresponding IF plots. Calcium concentrations in the first flush collected from the ECC plots during the non-vegetated rainfall event were significantly lower than the first flush collected from the IF plots. All other calcium concentrations under non-vegetated conditions tended to be consistent in runoff; however, Ca concentrations in both first flush and remaining runoff of vegetated plots were significantly greater from ECC treatments. This may have been due to Ca additions from the compost application and/or Na substitution for Ca in ECC plots, which had greater Na levels. A similar response was observed for Mg under vegetated conditions.

Table 9. Total mass or concentration of physicochemical constituents in first flush, remaining runoff and tap water.

	Non-Vegetated				**Vegetated**				**Tap Water**
Sample ID	**First Flush**		**Remaining Runoff**		**First Flush**		**Remaining Runoff**		**1-L n=2**$^{\#}$
Parameters	**ECC**	**IF**	**ECC**	**IF**	**ECC**	**IF**	**ECC**	**IF**	
pH	8.6*^{a} (±.0001)**	7.9 ^{b} (±.096)	8.4^{a} (±.29)	7.9 ^{b} (±.0001)	8.2^{a} (±.082)	8.6 ^{b} (±.082)	8.0 ^{a} (±.0001)	8.4 ^{b} (±.082)	8.1
EC µmohs/cm	1742 (±387)	1343 (±48)	2183 (±623)	1248 (±65)	2365 ^{a} (±525)	907 ^{b} (±38)	2885 ^{a} (±176)	903 ^{b} (±76)	843
TS (Kg)	0.003^{a} (±.0001)**	0.019^{b} (±.01)	0.084^{a} (±0.03)	0.671^{b} (±0.147)	0.0024 (±0.0004)	0.0027 (±0.003)	0.132^{a} (±0.003)	0.034^{b} (±0.004)	0.0005 (±0.0001)
TDS (Kg)	0.002 (±0.0006)	0.001 (±0.0001)	0.061 (±0.036)	0.048 (±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 (±0.0002)	0.0025 (±0.002)	0.011^{a} (±0.003)	0.027^{b} (±0.006)	--
TKN (mg/L)	48.7^{a} (±19.92)	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} (±0.88)	2.7 (±0.42)
NNN (mg/L)	0.63 (±0.68)	1.52 (±0.24)	1.36 (±0.99)	0.42 (±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)	1.59 (±0.27)	0.84 (±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)	13.25 (±3.39)	5.49 (±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)
S (mg/L)	31.26^{a} (±14.11)	132.3^{b} (±52.56)	121.2 (±110.07)	100 (±16.63)	256.4^{a} (±75.02)	15.73^{b} (±4.57)	384.8^{a} (±23.06)	16.20^{b} (±14.84)	3.47 (±0.48)
SO4-S (mg/L)	93.6^{a} (±42.24)	396.2^{b} (±157.39)	362.9 (±329.60)	299.1 (±49.81)	767.6^{a} (±224.65)	47.1^{b} (±13.69)	1152^{a} (±69.04)	48.5^{b} (±44.44)	10.4 (±1.43)
K (mg/L)	219.3^{a} (±95.65)	8.11^{b} (±2.16)	229^{a} (±26.64)	6.70^{b} (±0.89)	104.42^{a} (±43.27)	10.29^{b} (±1.32)	117.3^{a} (±33.55)	7.98^{b} (±1.41)	3.2 (±0.87)
Ca (mg/L)	11.68 (±2.76)	172 (±54.74)	124 (±135.88)	125.6 (±20.02)	277.6^{a} (±78.94)	34.04^{b} (±8.37)	411^{a} (±64.98)	30.05^{b} (±12.84)	3.15 (±0.28)
Mg (mg/L)	3.80^{a} (±1.052)	10.40^{b} (±2.51)	14.12 (±12.45)	7.33 (±0.96)	27.72^{a} (±9.25)	2.05^{b} (±0.51)	39.1^{a} (±4.96)	1.81^{b} (±0.75)	0.53 (±0.007)
Na (mg/L)	285.2^{a} (±28.91)	223.2^{b} (±3.58)	283.23^{a} (±18.60)	224^{b} (±2.25)	303^{a} (±56.84)	201.5^{b} (±4.18)	299^{a} (±37.75)	200^{b} (±2.82)	219 (±22)

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

[**] Standard deviation

[#] For tap water**,** n= 1 for pH and EC

Table 10. Total mass of nitrogen, phosphorus and potassium parameters in first flush and remaining runoff under non-vegetated and vegetated conditions.

	Non-Vegetated		Vegetated	
Parameters	**ECC**	**IF**	**ECC**	**IF**
TOTAL WATER [Kg]	24.84^{a*} (±7.68)**	48.62^{b} (±5.31)	48.38^{a} (±5.69)	20.98^{b} (±3.27)
TKN [mg]	1349^{a} (±647)	287.6^{b} (±31.05)	834^{a} (±55.85)	104.8^{b} (±28.60)
NNN [mg]	38.72 (±33.64)	21.43 (±4.91)	44.30 (±14.94)	32.7 (±5.38)
Ortho P [mg]	36.76 (±6.02)	45.90 (±11.43)	112.3^{a} (±11.16)	8.20^{b} (±2.35)
Total P [mg]	275.6 (±38.66)	262.2 (±74.32)	109.4^{a} (±9.97)	8.26^{b} (±1.10)
K [mg]	5829a (±2303)	325.9b (±43.51)	5582a (±1405)	167.4b (±21.18)

* Non-vegetated or vegetated ECC and IF treatment means within a row followed by different letters are significantly different at the 5% level.

** Standard deviation.

Table 11. Rate of nutrient loss (lbs/ac or kg/ha) contained in runoff from non-vegetated and vegetated ECC and IF plots. (Calculations based on total mass presented in Table 7).

	Non-Vegetated		Vegetated	
Parameters	**ECC**	**IF**	**ECC**	**IF**
	lb/A			
TKN	7.20^{a} (±3.45)	1.53^{b} (±0.17)	4.45^{a} (±0.30)	0.56^{b} (±0.15)
NNN	0.21 (±0.18)	0.11 (±0.03)	0.24 (±0.08)	0.17 (±0.03)
Ortho P	0.20 (±0.03)	0.24 (±0.06)	0.60^{a} (±0.06)	0.04^{b} (±0.01)
Total P	1.47 (±0.21)	1.40 (±0.40)	0.58^{a} (±0.05)	0.04^{b} (±0.01)
K	31.10^{a} (±12.29)	1.74^{b} (±0.23)	29.79^{a} (±7.50)	0.89^{b} (±0.11)
	kg/ha			
TKN	8.07^{a} (±3.86)	1.72^{b} (±0.19)	4.99^{a} (±0.33)	0.63^{b} (±0.17)
NNN	0.23 (±0.20)	0.13 (±0.03)	0.26 (±0.09)	0.20 (±0.03)
Ortho P	0.22 (±0.04)	0.27 (±0.07)	0.67^{a} (±0.07)	0.05^{b} (±0.01)
Total P	1.65 (±0.23)	1.57 (±0.44)	0.65^{a} (±0.06)	0.05^{b} (±0.01)
K	34.84^{a} (±13.76)	1.95^{b} (±0.26)	33.37^{a} (±8.40)	1.00^{b} (±0.13)

* Non-vegetated or vegetated ECC and IF treatment means within a row followed by different letters are significantly different at the 5% level.

** Standard deviation.

Table 12. Comparison of ratios of rainfall exposure time, runoff mass and nutrient losses for ECC and IF treatments under non-vegetated and vegetated conditions.

	Ratio of ECC:IF							
Parameter	-------------**non–vegetated**--------------				----------------**vegetated**-----------------			
		TKN	**Total P**	**K**		**TKN**	**Total P**	**K**
Ratio of rainfall exposure time[*]	**1.16**	4.69	1.05	17.89	**1.62**	7.96	13.24	33.35
Ratio of runoff mass	**0.51**	4.69	1.05	17.89	**2.31**	7.96	13.24	33.35
Ratio of total Water Retained[**]	**1.82**	4.69	1.05	17.89	**1.40**	7.96	13.24	33.35

[*] A measurement of total rain water applied

[**] The difference between total rainfall volume and the runoff volume

SUMMARY

Simulated rainfall was applied to constructed plots set on a 3:1 slope that received an application of either erosion control compost (dairy manure compost/woodchips; 1:1 volume mixture) or inorganic fertilizer under non-vegetated and vegetated conditions. Time to initiate runoff was greater for ECC than IF under non-vegetated and vegetated conditions. Runoff rate and total runoff were greater for IF under non-vegetated conditions, but the reverse was true under vegetated conditions. Because considerably more time (>20 minutes longer) was required to initiate runoff from vegetated ECC plots compared to vegetated IF plots, the ECC plots received greater amounts of rainfall which resulted in increased runoff rate and mass.

Water pH values fluctuated somewhat for ECC and IF treatments for the non-vegetated and vegetated rainfall simulations, with values being higher for ECC under non-vegetated conditions and higher for IF under vegetated conditions. Higher initial Na and total salt levels in runoff from ECC plots during unvegetated rainfall simulation likely were offset by release of organic acids and nitrification, reducing pH values at the vegetated rainfall simulation. Total salt levels remained high in runoff from the vegetated ECC plots and were significantly greater than those in IF plots, which were similar to tap water.

Total suspended solids and TS in first flush and remaining runoff were significantly greater for IF plots than ECC plots under non-vegetated conditions due to substantially greater soil loss. In contrast, TS in remaining runoff of vegetated ECC plots were significantly greater than those in IF plots, but the bulk of the TS was in the form of TDS. Higher nutrient and salt levels in the compost likely contributed to this result.

Concentrations of TKN in the first flush and remaining runoff from both non-vegetated and vegetated ECC plots were significantly greater than those in corresponding IF plots. In addition, ortho P and total P concentrations in the remaining runoff from non-vegetated plots and both the first flush and remaining runoff of vegetated plots were significantly greater for ECC plots compared to IF. Likewise, K concentrations in the first flush and remaining runoff from non-vegetated plots were significantly greater for ECC than IF treatments, with similar results for vegetated plots although concentrations in ECC plots decreased by about 50%. Increased nutrient concentrations 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 application contained 18.5, 13.25 and 27.75 times greater rates of N, P_2O_5 and K_2O, respectively).

Total masses of TKN and K were significantly greater for ECC compared to IF under both non-vegetated and vegetated conditions. Total masses of both ortho P and total P were not different for ECC compared to IF under non-vegetated conditions, but were significantly greater for ECC than IF under vegetated conditions. Here again, the substantially greater total nutrient loadings resulting from use of manure compost in the ECC treatment likely explain these results. Numerous studies have reported a direct correlation between phosphorus losses, both in the dissolved and suspended solids fractions, as soil test phosphorus levels increase (Schwartz and Dao, 2005; Vietor, et al. 2003; Vietor, et al. 2002). Vietor et al, (2004) found no significant differences in P losses in the first runoff solution from plots which received similar P rates of inorganic fertilizer and composted dairy manure. However, P levels were significantly greater in runoff from the composted dairy manure plots compared to inorganic fertilizer plots for subsequent runoff events.

Due to the significant differences in rainfall exposure time on ECC and IF plots under vegetated conditions, ratios of total mass of TKN, total P and K losses in the runoff from these treatments were compared to ratios of rainfall exposure time, runoff mass and total water retained (difference between average total rainfall applied to a plot and average total runoff collected from a plot). This comparison of nutrient ratios for ECC and IF treatments indicates that due to greater rainfall exposure time, total runoff mass and water retention under vegetated conditions, and due to a greater application rate of N, P_2O_5 and K_2O, the ECC plots yielded greater nutrient losses as compared to IF plots.

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 a runoff event. In addition, when vegetated, the use of an ECC material delayed runoff for a substantially longer time period than IF. Under both non-vegetated and vegetated conditions, the ECC treatment retained greater amounts of rainfall than the IF treatment.

However, when runoff events of equal duration, but disparate rainfall exposure time, under vegetated conditions were compared, the ECC plots produced more runoff than the IF plots. In addition, losses of N, P and K were greater for the compost amended plots (ECC) compared to IF. The continued mineralization of nutrients from compost over time may result in considerably greater nutrient loadings in runoff over the life of the treatment. Thus, reduced rates of compost and/or the use of compost materials with lower nutrient levels may be warranted where significant runoff is anticipated.

Data and nutrient balance calculations performed by Chastain et. al. (2006) clearly demonstrate that amendment application recommendations based on a prescribed volume (blanket depth) are not useful. Rather, application rates of nutrient rich materials, such as compost, should be determined based on the analysis of: (1) plant nutrients in the product, (2) nutrient requirements of the intended vegetation, and (3) soil-test results. Findings of this study support the recommendation made by Chastain et. al. (2006). A total nutrient analysis of proposed compost/organic soil amendments should be utilized in the selection of the material and in determination of proper loading rates for erosion control and the enhancement of vegetative cover. Total N and P rates within an erosion control system should be based on projected nutrient release to provide available N and P to maximize erosion control, yet reduce nutrient loss under runoff events. This more conservative approach, such as increasing the wood chip to compost ratio, will minimize offsite losses of N and P during initial establishment, but more importantly, will limit long-term losses of these nutrients as organically bound fractions are released through mineralization.

Finally, additional data should be collected to further evaluate DMC as an erosion control treatment. To compensate for the delay in runoff from the ECC treatment under vegetated conditions, the study methodology should be modified to expose the sediment bed to a fixed duration of rainfall, collect runoff for the duration of the rainfall and in addition, collect runoff sub-samples at set time intervals during the event. This modification will determine changes, if any, in the loss of sediment and/or nutrients over time and allow for the comparison of runoff constituents from the entire rainfall event.

LIMITATIONS OF THE STUDY DESIGN

(Information below provided by reviewers at the Texas Commission on Environmental Quality)

“The design of this study provided for the experimental plots to be subjected to rainfall of uniform intensity but varying duration. The average duration of rainfall exposure for the compost treatments was substantially greater than for the control treatments. This study does not provide a basis for predicting the relative performance of the two treatments in any single, defined rainfall event or in any representative set of rainfall events.

The results of this study raise concerns about the potential release of nutrients from erosion control compost (ECC) containing 50% composted manure in extended, high-intensity storms. However, the substantial difference in average duration of rain exposure experienced by the treatments limits the use of the study results in evaluating the probable effects of using this treatment as an alternative to the control treatment – either in regard to erosion control or in regard to nutrient loadings in runoff. Neither does it provide a basis for recommending modifications of the ECC treatment. Such evaluation will require, at a minimum, the testing of the recommended modifications of the ECC treatment alongside treatments using the current ECC specifications. Because of these design limitations, the Texas Commission on Environmental Quality cannot apply the information and conclusions described in this study about the performance of the two treatments to water quality management practices.

Conclusive evaluation of the use of composted manure as a water quality management tool – 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 in a representative set of rain events until the soil nutrient concentrations in the compost-treated plots fall within agronomic levels."

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