Hydrologic and Water Quality Aspects of Using a Compost/Mulch Blend for Erosion Control

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Abstract: Construction projects often expose large amounts of soil to erosive forces of wind and rain. These areas must be stabilized and vegetated before a Notice of Termination can be submitted to regulators. The objectives of this project were to compare the stabilization performance of two types of compost wood mulch blend top dressing (low and high organic matter), a wood based hydromulch, and seeded bare soil and to determine the amount of sediment and nutrients exported from each type of treatment. Ten test plots ($12.2 \times 2.4\ m^2$) were constructed at a quarry in Parker County, Texas and outfitted with runoff capture systems. Runoff quality and quantity was evaluated for 2 years after installation. Sediment discharge was reduced by 98% on the compost/mulch blend plots and about 75% with hydromulch treatment compared to bare plots. Treatments reduced nutrient loads, although runoff concentrations of nitrate and dissolved P from compost treated plots were often higher than from bare soil or hydromulch plots.

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Introduction

Areas disturbed by construction activities can generate large amounts of sediment during storms, which leads to very obvious impacts on nearby surface waters. To protect these waters, the U.S. Environmental Protection Agency (USEPA), through the Construction General Permit, requires disturbed areas to be vegetated and stabilized before a Notice of Termination can be submitted to regulators. Establishing vegetation on these disturbed areas can be time-consuming and expensive for many projects, but rainfall simulation studies have shown that compost applied to disturbed lands can substantively reduce sediment loss and enhance vegetation establishment (Bresson et al. 2001; Block 2000).

Composting is the aerobic biological degradation of waste in the solid state (Rittmann and McCarty 2001). In recent years, composting has become popular for dairy manure, poultry litter, and wastewater-treatment biosolids. The composting process consumes biodegradable organic matter (OM) and releases carbon dioxide among other products. Due to the destruction of OM and the associated reduction in volume, compost has higher nitrogen and higher phosphorus concentrations than the original waste material. The reduced volume makes the compost less costly to transport, but the higher phosphorus concentrations in the compost may leach into runoff, potentially impairing the quality of receiving waters (Easton and Petrovic 2004).

Demonstration projects from around the United States indicate that compost helps establish vegetation in resistant or difficult areas. In a Connecticut study, small amounts of compost improved turf establishment (Block 2000). Four demonstration projects in Texas showed that compost blended with wood chips could establish vegetation in areas where other methods were unsuccessful (Block 2000). A summary of three demonstration projects by Goldstein (2002) notes that seeded compost aids in establishing vegetation in sloped areas.

In addition to vegetation establishment a number of studies have also evaluated compost's benefits for erosion control. Bresson et al. (2001) compared erosion from a compost amended soil with a control soil and found that the compost amended soil delayed the onset of runoff from 2.5 to 9.2 mm of cumulative rainfall. The average TSS concentration in the incipient runoff was 11,000 mg/L for compost amended plots and 36,400 mg/L for the control soils. Total sediment load was 18.3 g or 732 kg/ha for the amended soil and 54.6 g or 2,184 kg/ha for the control soil. Another study conducted by Faucette et al. (2004) investigated runoff from several different types of composts and mulch blankets placed into a $92 \times 107\ cm^2$ frame on a 10% slope, with simulated rainfall intensities as high as 160 mm/h. Solid loss from compost plots was less than bare soil plots, ranging from 111 g for yard waste compost to 552 g for poultry litter compost, compared with 646 g for bare soil. Kirchoff et al. (2003) investigated the runoff hydrograph from a compost/soil mixture and found a delay in the onset of runoff and reduction in the peak flow rate compared to a control plot. Collectively, these studies show that compost reduces sediment loss in runoff and lowers the peak discharge.

Previous studies evaluating the effect of compost on water quality may be categorized according to the compost source ma-

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terial, whether natural or simulated rainfall was applied, and the type of test area. Test areas have included columns and trays of various sizes and a field study.

A 2-year field study by Easton and Petrovic (2004) documented the effect of nutrient source on turfgrass runoff and leachate under natural rainfall. Fertilizers were applied to $1 \times 2\ m^2$ plots situated on a 7–9% slope. Treatment plots received repeated applications of fertilizer, totaling 100 or 200 kg N/ha for the 2-year study. Three organic composts were investigated (dairy, swine, and biosolids) with results presented as the average of the three. Test plots experienced 33 precipitation events totaling 536 mm. Nitrate concentrations in runoff generally decreased with time, but appear to be influenced by repeated fertilizer application. Nitrate concentrations ranged from 13 mg/L for the unfertilized control plot in the second month to 0.1 mg/L for the compost plots in month 17. Nitrate concentrations in runoff from the treatments were lower than the control plot ($p < 0.05$). Concentrations of phosphate ($PO_4^{3-}-P$) in compost runoff fluctuated between 0.1 and 1.5 mg/L, but exceeded 2.5 mg/L on two occasions following fertilizer application. Phosphate concentrations from the control plots showed less variation and averaged 0.3 and 0.5 mg/L for years 1 and 2, respectively. The study found that nutrient concentrations and mass losses were highest in the 20-week period following turfgrass seeding, with compost treatments having greater phosphorus loss on a percent applied basis. The nutrient losses declined once turfgrass cover was established. The reduced nutrient runoff was related to overall plant growth and shoot density.

A column study by Xia et al. (2007) investigated the leaching of nitrogen and phosphorus from compost filled columns subjected to simulated rainfall. Rainfall was applied at 20.4 mm/h for 100 min. The compost for this study consisted of a 1:1 mix of biosolids and yard waste. Over the study period, nitrate concentrations dropped from 2000 to near 0 mg/L. Concentrations of total dissolved P in leachate rose from 10 to 35 mg/L before declining to around 28 mg/L. Concentrations of phosphate in leachate rose from 10 to 30 mg/L before declining to 25 mg/L. The work of Faucette et al. (2004), which was described previously in the discussion of erosion control, also analyzed nutrient levels in the runoff. Losses of nitrogen and phosphorus from most of the compost treatments were higher than those from bare soil or mulch treatments.

In summary, nitrate concentrations in runoff from areas incorporating compost are highest immediately after the initial rain event, and decline over time to a constant level. Phosphorus concentrations in runoff did not show a consistent temporal pattern among studies but were generally greater than bare soil or mulch treatments. The density of vegetation was associated with reduced nutrient losses.

The Texas Department of Transportation (TxDOT) has used compost on construction projects since 1998 (B. Cogburn, personal communication, 2007), and currently uses two specifications (161 and Special 1001) for compost in erosion control applications. Both specifications blend equal volumes of wood chips and compost to create erosion control compost (ECC) for application to disturbed areas, but differ in OM content. Specification 161 requires compost containing 25 to 65% OM by mass, while Special Specification 1001 allows OM content as low as 10% by mass for manure compost (TxDOT 2004).

The aim of this study was to compare the vegetation establishment, runoff volume, and water quality of the two types of TxDOT approved compost/mulch blends with a common industry best management practice (BMP), wood based hydromulch, and a seeded bare soil control. Sampled rainfall events provided the basis for a comparison between treatments of runoff concentrations and the annual runoff volume and mass loss of each water quality constituent.

Materials and Methods

Installation, Sampling, and Laboratory Analyses

In May 2006, 10 test plots were constructed at a rock quarry in southwest Parker County, Texas. Plots were 12.2 m long and 2.4 m wide with slopes ranging from 11.6 to 13% along the plot length. Plots were oriented along the steepest part of the slope to encourage formation of erosive features, such as rills, that might distinguish the erosion control treatments. Earthen berms separated the plots from each other and prevented drainage from above from entering the plots. Each plot was equipped with a runoff collection system consisting of a gutter and 606-L (160-gal) galvanized tank. The tank volume corresponds to 20.7 mm of runoff from the test plot. A 15-cm polyvinylchloride pipe was cut lengthwise to function as a gutter. Metal flashing prevented water from flowing under the gutter. Flow from the gutter was collected in the water tank, which was covered to prevent direct collection of rainfall or dust between events. Prior to installation, the relationship between depth and volume for each tank was calibrated by measuring the depth associated with a known volume of water. A tipping bucket rain gauge installed at the plots recorded every time 0.25 mm of rainfall accumulated in the gauge.

Three different erosion control treatments were applied to eight of ten test plots, with only two plots left untreated for experimental control, due to budget limitations and space considerations in obtaining side-by-side plots of similar size and slope. Two treatments used a 1:1 blend of composted dairy manure and wood mulch. One of these treatments used compost with relatively low OM content (<15%), while the other used compost with higher OM content (>25%). The third treatment consisted of Biocover Daily Landfill hydromulch, manufactured by Profile Products LLC. An ideal experimental design would have at least three replicates of each treatment and the control, but only ten plots were available, so three replicates were assigned to the low OM compost/mulch and the hydromulch treatments and two replicates to the high OM compost/mulch treatment and control. Treatments were assigned sequentially to each plot rather than randomly to account for potential systematic changes in soil properties and variation in slope noted across the plot area. The test plots' soils received no preparation beyond construction of the plots. For plots receiving compost, the compost/mulch blend was blown onto the plot using a hose; then seed was applied by hand and lightly raked into the compost. For plots receiving hydromulch, seed was applied by hand and then hydromulch was blown onto the plot. The bare soil plots received seed only and were not otherwise prepared in any way. All plots were seeded with Giant Bermuda grass (Cynodon dactylon, var. aridus) at a rate of 17.6 kg/ha and Common Bermuda grass (Cynodon dactylon) at a rate of 6.4 kg/ha.

During installation, samples of the compost/mulch treatment were taken from the hose. The samples were analyzed for percent OM, total nitrogen (total N), and total phosphorus (total P) using certified Test Methods for the Examination of Composting and Compost (TMECC 2004) by a laboratory participating in the U.S. Composting Council Seal of Testing Assurance program (Table 1). Samples of the unblended compost were also taken and

Table 1. Erosion Control Treatments

Treatment	Application rate (kg/ha)	Total nitrogen[a] (kg/ha)	Total phosphorus[a] (kg/ha)	Composition: Wood fiber (%)	Composition: Other
Low OM	282,454[b]	1,375	585	50	50% composted dairy manure (8.5% OM)
High OM	282,454[b]	3,249	1,565	50	50% composted dairy manure (19% OM)
Hydromulch	2,242	18	22	67	20% corrugated carton fiber, 10% tackifier

[a]Nutrients in compost blend based on laboratory analysis. Nutrients in hydromulch based on information from the manufacturer on the addition of liquid fertilizer.

[b]Assumes compost blend applied at a rate of 141 kg/ha (126 tons/acre) based on a 2.5-cm (1-in.) compost and 2.5-cm (1-in.) wood chips.

analyzed for total Kjeldahl nitrogen (TKN), nitrate nitrogen (nitrate), total P, and Mehlich III extractable phosphorus (ext-P) in order to provide consistency with soil testing methods described below. For the purposes of quantifying nutrient application to the plots, the application rate of the compost/mulch blend was estimated as a 50-mm depth (Table 1).

Soil samples were collected annually from each plot using a standard soil probe. Any treatment material (compost/mulch or hydromulch) or vegetation was scraped aside prior to inserting the soil probe when soil samples were collected. Ten soil cores having a depth of 15 cm were taken randomly within each plot and composited for analysis. Reported soil parameters are nitrate and total P; soil classification tests were not made, though some additional information regarding soil tests is available online (Adams et al. 2008). Nitrate measurements were made using EPA method 353.2 (colorimetric, automated, cadmium reduction) (USEPA 1983). Total phosphorus was analyzed by EPA method 365.4 (colorimetric, automated, block digestion) modified to use copper sulfate as the catalyst instead of mercuric sulfate.

Water samples from selected storms were collected over 23 months (June 2006–April 2008). Storms were selected for sampling based on when they occurred and how many plots responded so that the sampling budget would last through the study. In the first 3 months all storms were sampled; in the next 2 months only storms where all plots responded were sampled; subsequently, samples were taken for only one storm every 2 months where all plots responded. The storm selection criteria of requiring all plots to respond may introduce bias into the regression model and load analysis because only larger storms get sampled. Most of the mass loss occurred in these larger storms so actually sampling them improves the estimate of the total loss. However, the hydrology estimates suffer because the precise amount of rainfall needed to generate runoff is less certain.

Upon completion of a storm selected for sampling, the rainfall depth and runoff volume were noted and a water sample was collected from each responding plot. A representative sample was obtained from collection tanks using one person to thoroughly mix the contents using a canoe paddle with particular emphasis on resuspending all deposited sediments on the bottom of the tank using a vigorous circular stirring action and then a second person obtained the sample by submerging a 1-L container in the tank while contents were still thoroughly agitated and mixed. Samples were analyzed for TSS (USEPA method 160.2, gravimetric, dried at 103–105°C), nitrate, TKN, dissolved P, and total P (USEPA 1983). Methods were the same as those used for soils outlined above including modifications for TKN and total P. Samples were generally analyzed for all parameters except for some early events where only TSS was measured.

In addition to storm sampling, periodic site visits were made to document changes in vegetative cover and rill development, and to control encroaching vegetation between plots. Ideally, the amount of vegetation on the plots would have been quantified using a counting grid to measure the shoot density; instead the fraction of each plot covered by vegetation was estimated visually. Plots were deemed to have complete coverage when an observer standing at the bottom of the plot could not see bare soil within the plot. Vegetation observations were made monthly until compost treated plots achieved 70% coverage and every other month thereafter. Encroachment of vegetation between plots was managed manually by installation of metal edging and use of a gas powered string trimmer. The trimmer was used to remove vegetation that had clearly encroached from an adjacent plot rather than grown from within the plot itself. The use of a trimmer was favored over manually removing the runners to avoid dislodging the soil or using an herbicide such as glyphosate. Changes in the test plots over the study period were described in detailed field notes and photographs, which are available online (Adams et al. 2008).

Data Analysis and Application

The analysis of storm runoff data focused on four areas: (1) use of regression to develop a rainfall-runoff relationship for each treatment; (2) evaluation of changes in constituent concentrations over time; (3) comparison of event concentrations between treatments using Wilcoxon signed-rank test; and (4) estimation of the mass loss of nutrients and sediment from each treatment over the study period.

The runoff volume from each treatment was used to determine the depth of rainfall required to initiate runoff and the amount of rainfall retained by the treatment once runoff began. This information was used to estimate runoff volumes for unmonitored events. Estimation of runoff volume for storms not monitored was important for evaluating overall runoff volumes and mass losses. Multiple linear regression was used to develop a relationship for runoff volume for each treatment based on rainfall depth, time since the first event (to account for changes in vegetation coverage over time), and peak rainfall intensity by event. Rainfall intensity was computed on a 15-min basis, with the peak intensity being the maximum value for a given storm event. In some cases, runoff overflowed the tank used for volume measurement. These overflow events were excluded from the regression analysis. Confidence intervals ($\alpha = 0.05$) were used to compare regression coefficients between treatments. The regression analysis was performed using the R Environment for Statistical Computing version 2.9.1 (R Development Core Team 2009).

Measured concentrations were plotted over time to visually observe changes between and within treatments, particularly with the establishment of vegetation. Concentrations for each event were averaged for plots within the same treatment. Treatments

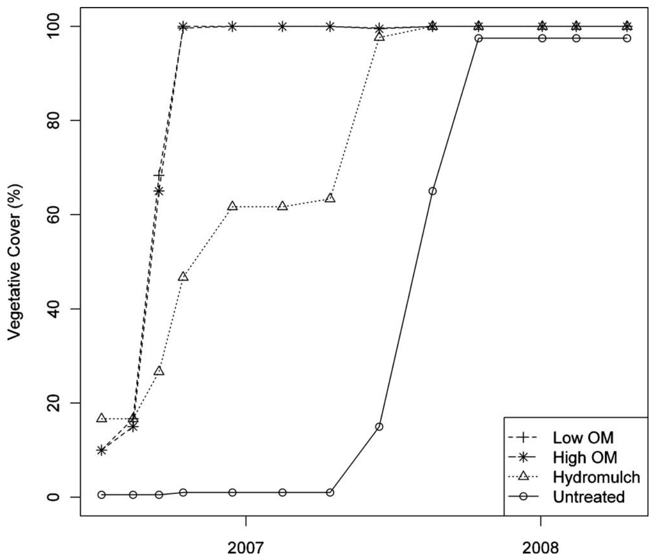

Fig. 1. Vegetative cover (average of replicate plots) over time

were compared based on the event mean concentration of plots representing each treatment using a Wilcoxon signed-rank test because the differences between the treatments were not normally distributed. A p value from a Wilcoxon signed-rank test was calculated for each pair of treatments, so that each water quality parameter had six p values. Treatment comparisons with a p value less than 0.05 were considered statistically different. Wilcoxon signed-rank tests were conducted using the R Environment for Statistical Computing.

Measured and estimated nutrient and sediment loadings were calculated for the study period (June 2006–May 2008) for measured and unmeasured rainfall events. For measured events, the concentration was multiplied by the volume, except when overflow was indicated. For unmeasured and most overflow events, the runoff volume was estimated using the multiple regression model based on rainfall depth, intensity, and time since the first event of the study period. Concentrations were linearly interpolated between sampled events based on the date of the unmeasured event. Total loadings were calculated as the sum of measured and unmeasured events.

Results and Discussion

Several types of measurements were made as part of this project including nutrient concentrations in compost, vegetation density, rainfall depth and runoff volume, and nutrient and suspended solid concentrations in runoff. The following subsections present each type of data independently and then combine the information to estimate the mass loss of each constituent. Export coefficients (kg/ha/yr) are derived from these estimates to quantify the impact of nutrient losses on receiving waters.

Vegetation

Vegetative cover was monitored throughout the study to see how quickly the different treatments established vegetation. The fraction of vegetative cover was estimated on 13 occasions (Fig. 1). All plots may have established vegetation more slowly than usual due to drought conditions during the first summer of the study (June 2006–August 2006). To mitigate the drought effect, all test plots received supplemental watering during the first summer. Compost/mulch blend plots established vegetation faster than other treatments, appearing to have complete cover in about 4 months. The low and high OM compost/mulch plots established vegetation at approximately the same rate. The hydromulch plots took almost three times longer than the compost plots, establishing complete coverage after 1 year. Even after 1 year, the seeded bare soil plots had little vegetation. The order in which the treatments established vegetation (compost/mulch plots first, then hydromulch, then seeded bare soil) is consistent with the nutrient levels of the treatments and agrees with the observations of Bresson et al. (2001). Efforts to control encroachment of vegetation between plots were only partially successful. Encroachment, especially onto the seeded bare soil plots, contributed to the rate at which vegetation was established.

Runoff Volume

The volume of runoff produced by each test plot was measured to determine the amount of rainfall retained by each treatment, facilitate the computation of mass losses during monitored events, and provide a basis for estimating runoff volumes for events where only rainfall depth was recorded. During this project, the field site had 136 rain days with 1,651 mm of total rainfall. Complete volume and water quality observations, nonzero data for each of the 10 plots, were collected from 16 storm events throughout the project. Partial data, usually runoff volume, were measured for seven additional events. Rainfall from events with complete data totaled 502 mm or 30% of the total rainfall. Relatively large storms (>48 mm) in September, October, and November 2006, effectively ending the very dry summer, caused the runoff collection tanks to overflow, preventing determination of runoff volume.

For each treatment, the relationship between runoff and rainfall, time since the first event, and peak rainfall intensity was explored using multiple regressions. The regression analysis excluded overflow events, but included data from the seven additional storms where only some but not all ten plots responded. The regression equations have the form

$$\text{Runoff} = A + B \times \text{Rainfall} + C \times \text{Day Number} + D \times \text{Peak Intensity} \quad (1)$$

where Runoff=depth of runoff in mm; Rainfall=depth of rainfall in mm; Day Number=number of days since the first event; Peak Intensity=peak rainfall intensity for a 15-min period in mm/h; and A, B, C, and D=coefficients determined by the regression.

Details of the regression analysis are shown in Table 2. All of the regression coefficients were statistically significant ($p<0.05$) except for day number (coefficient C) on the hydromulch ($p=0.06$) and untreated plots ($p=0.21$). The p value for hydromulch is very close to the cutoff value of 0.05, suggesting that the treatment probably does produce less runoff as time passes and vegetation grows. The p value for untreated plots is further from the cutoff making any inferences difficult. Residual standard errors—a measure of how well the regression reproduces the measured values—ranged from 1.5 mm for the low OM plots to 3.3 mm for the hydromulch plots. Adjusted R^2 values—the fraction of variability in the data accounted for by the model—ranged from 0.731 for the high OM plots to 0.909 for the untreated plots.

While the other variables were important in characterizing the amount of runoff, rainfall depth was the primary variable driving

Table 2. Multiple Regression Parameter Estimates and Model Statistics for Estimating Runoff Depth from Rainfall, Day Number, and Peak Intensity by Treatment

	Treatment			
Parameter	Low OM	High OM	Hydromulch	Untreated
A, intercept (mm)	−1.70	−2.04	−2.82	−3.91
B, rainfall slope (no units)	0.215	0.207	0.341	0.500
C, day number slope (mm)	−0.00922	−0.00831	−0.00419[a]	−0.0023[a]
D, peak intensity slope (h)	0.0610	0.0739	0.189	0.187
Standard error (mm)	1.46	1.97	3.30	2.26
Adjusted R^2	0.823	0.731	0.733	0.909
Number of observations	55	37	54	36

[a]Parameter estimate for the regression coefficient was not statistically significant at level 0.05.

the regression equation. Hypothesis testing (t-tests) on the differences in rainfall slope (parameter B) showed that compost/mulch treatments offer similar runoff performance ($p=0.06$), and that the industry BMP (hydromulch) generates more runoff than the compost/mulch treatments ($p<0.00$), but less than the untreated plots ($p<0.00$).

The regression coefficients shown in Table 2 were used to project runoff volumes for unmeasured events and those events during which the tanks overflowed. In some cases the runoff volume measured for an overflow event (i.e., the volume of the tank) exceeded the volume predicted by the regression equation, suggesting that the overflow was small. The volume of the collection tank was used in these cases. The compost plots were projected to produce much less runoff than hydromulch or untreated plots (Table 4). This result is consistent with the work of Bresson et al. (2001), Kirchoff et al. (2003), and Easton and Petrovic (2004). The availability of nutrients and the ability of the compost/mulch blend to hold water on the plots greatly aided the speed with which vegetation was able to establish compared to the hydromulch and untreated plots. Even when all ten plots were totally vegetated, the compost treated plots continued to have much less runoff.

A SCS curve number was estimated for each treatment to facilitate a broader application of this study's results. The average runoff volume for each event by treatment was used to estimate the curve numbers. A curve number was calculated for each year of the study by minimizing the residual sum of squares for each treatment (Table 3).

Soil texture data were not collected for this project, but for comparative purposes the site is expected to belong to Hydrologic Soil Group C or D. In the first year, untreated plots discharged a volume of runoff equivalent to a site with a curve number of 95, which is slightly lower than the reported value of 98 for paved parking lots, roofs, and driveways. The hydromulch plots had a curve number of 93, which corresponds to a commercial or industrial district having between 72 and 85% impervious cover. Both compost treatments had a curve number of 83, which is similar to open spaces (lawns, parks, etc.) in fair condition (CN=84). In the second year, curve numbers for all treatments fell as vegetative cover improved. Untreated plots had a curve number of 92, similar to a gravel road or industrial district. Hydromulch plots had a curve number of 87, consistent with pasture or range land in poor condition. For compost/mulch treatments the curve number fell to 64, which is lower than tabulated values for the expected soil group (Table 5.5.2, Chow et al. 1988). The curve numbers presented here offer similar conclusions as the multiple regression analysis: Compost/mulch plots generate less runoff than the hydromulch or untreated plots, and the condition of all plots improves as vegetation becomes established.

Table 3. SCS Curve Numbers

	Curve number (Group II AMC)	
Treatment	Year 1	Year 2
Low OM		
High OM	83	64
Hydromulch	93	87
Untreated	95	92

Nutrient and Sediment Concentrations in Runoff

Concentrations of the water quality parameters were measured to detect differences between treatments and estimate mass losses. Fig. 2 shows the concentration time series graphs and Table 5 reports p values of the Wilcoxon signed-rank test between the treatments. In Table 5, the plus sign (+) indicates which of the two different treatments had significantly higher concentrations.

Average TSS concentrations from all treatments decreased with time [Fig. 2(a)]. Concentrations for untreated plots reached a maximum of 80,000 mg/L early in the study. The second highest

Table 4. Total Runoff Volume from Each Treatment after 1,651 mm of Rainfall over 23 Months

	Total runoff depth (mm)			
	Low OM	High OM	Hydromulch	Untreated
Runoff from monitored events that did not overflow	32.7	33.2	144	197
Runoff from unmonitored events estimated using regression	97.8	99.3	312	438
Estimated runoff from monitored events where the collection tank overflowed	57.1	57.3	77.4	102
Total	188	190	533	737

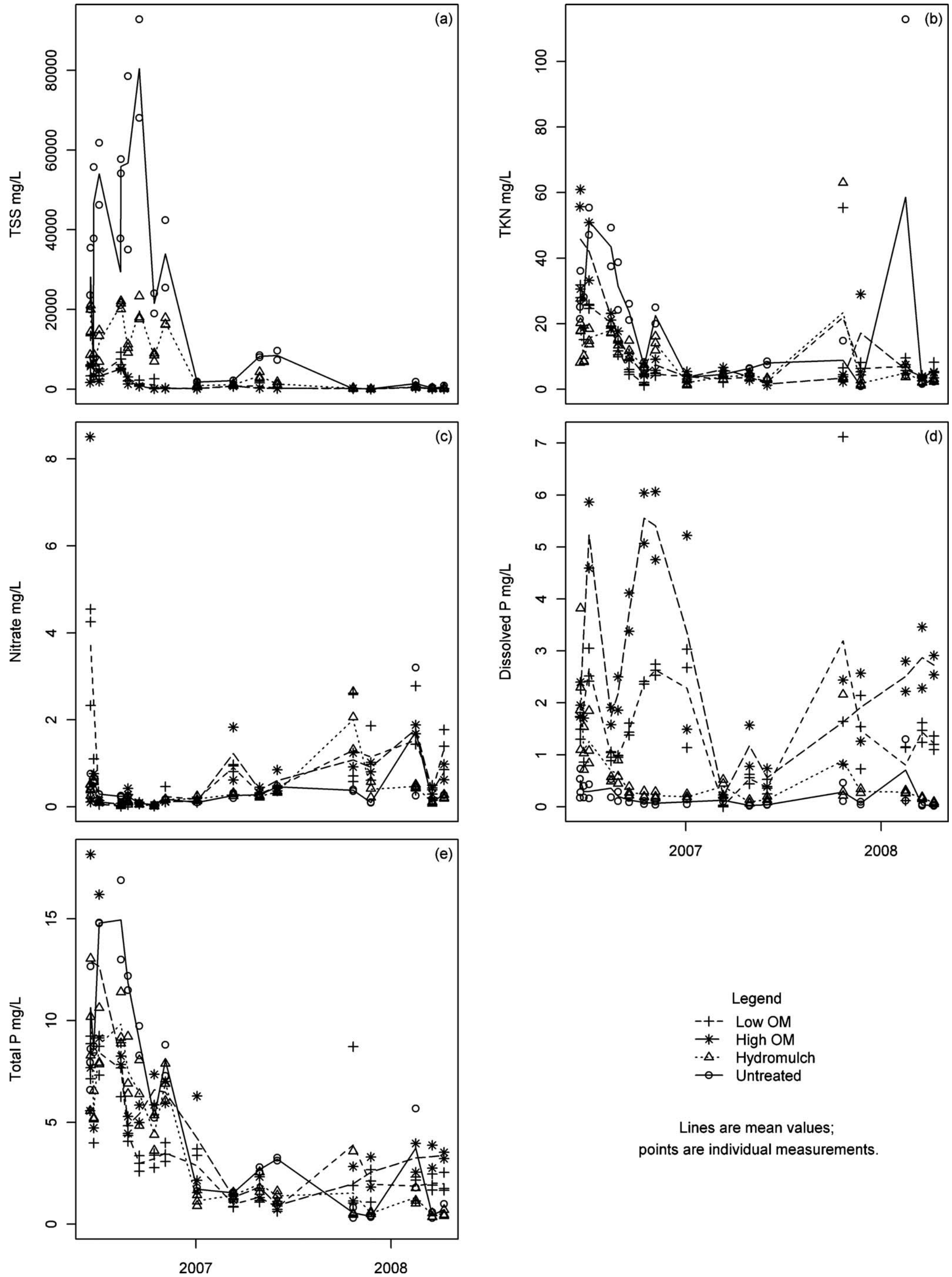

Fig. 2. Time series plots of runoff concentrations

TSS concentrations occurred from the hydromulch treated plots. As shown in Table 5, each treatment was different from the others with respect to TSS concentrations across events. The fact that the low OM plots had significantly higher TSS concentrations than the high OM plots suggests that the high OM plots had more vegetation, though this difference was not detected visually. In the first 2 months of the study, compost and hydromulch plots had approximately the same vegetative cover (10–20%; Fig. 1), but compost plots had lower TSS concentrations [Fig. 2(a)]. This result suggests that the compost/mulch treatment reduces erosion by another means in addition to establishing vegetation. An explanation suggested by Adams (1966) is that a surface cover such as the compost/mulch blanket protects soil from the energy of rainfall. Rainfall energy was not measured in this study, but the TSS concentrations are consistent with this effect.

TKN concentrations were highest from the untreated plots [Fig. 2(b)], although all values generally decreased over time. Because fertilizer or nutrients were not applied to the untreated plots, the TKN in runoff from these plots appeared to have come from the organic content of the soil. High concentrations of TKN were associated with high TSS concentrations in runoff, particularly for the untreated plots. Significant differences in TKN concentrations were observed between the untreated control and both the low OM compost/mulch and hydromulch

Table 5. *p* Values from Wilcoxon Signed-Rank Test

Treatment pair	Low OM	High OM	Low OM	Hydromulch	Low OM	Untreated	High OM	Hydromulch	High OM	Untreated	Hydromulch	Untreated
TSS	+			+		+		+		+		+
	0.004		0.000		0.000		0.000		0.000		0.000	
						+						+
TKN	0.074		0.597		0.034		0.231		0.105		0.006	
Nitrate			+									
	0.980		0.029		0.144		0.074		0.144		0.243	
Dissolved-P		+	+		+		+		+		+	
	0.002		0.002		0.000		0.000		0.000		0.001	
Total P		+				+						+
	0.002		0.375		0.034		0.117		0.821		0.001	

treatments (Table 4). While not significant across all events early in the study, the high OM compost plots had higher TKN concentrations than the low OM compost plots, which was consistent with the higher TKN concentrations in the high OM compost blend (11,476 mg/kg) compared with the low OM compost blend (4,863 mg/kg). A few high TKN concentrations from individual plots were noted for events monitored in October and November 2007 (63-mg/L hydromulch 23 October 2007, 55-mg/L low OM compost 23 October 2007, and 29-mg/L high OM compost 26 November 2007). These concentrations may have been related to rodent activity noted within the plots and tanks when samples were collected. An inexplicably high TKN concentration (113 mg/L) was reported for an untreated plot in February 2008.

The variation in nitrate concentrations over time showed a different pattern than TKN or TSS. After an initial decline, nitrate concentrations tended to increase over time, particularly for the compost blend treatments [Fig. 2(c)]. One possible explanation for this increase is the nitrogen demand associated with mulch decomposition. Bacteria that breakdown the woody mulch initially mixed with the compost exert a substantial nitrogen demand (Battaglia et al. 2009), but as this process slows more nitrogen becomes available, which allows additional leaching from the compost/mulch blend into the runoff. The very high nitrate concentration associated with the low OM compost treatment during the first runoff event (mean 3.7 mg/L) was most likely related to the high amount of extractable nitrogen measured in the compost and initial soil values. The low OM treatment—having less microbial activity than the high OM—contained more extractable nitrate (7.34 mg/kg) than the high OM treatment (3.02 mg/kg). Initial soil values of nitrate on two of the low OM plots (15.1 and 19.5 mg/kg) were also well above the average across all plots (11.8 mg/kg). The higher soil and compost nitrate concentrations most likely explain the early spike in nitrate in runoff from the low OM treatment. High nitrate concentrations (1.3–2.6 mg/L) for the hydromulch treatment were noted along with rodent activity in October 2007. As with TKN, an inexplicably high nitrate concentration was reported for an untreated plot in February 2008 (3.2 mg/L).

Compost blend plots produced much higher dissolved-P concentrations than hydromulch or untreated plots. Both compost treatments exhibited two peaks in dissolved-P concentration in the first 6 months of monitoring, while the other treatments showed a general decline [Fig. 2(d)]. Later in the monitoring period, dissolved-P concentrations in runoff showed a generally increasing trend from the compost treatments, while concentrations from the untreated and hydromulch plots were more consistent over time. High dissolved-P concentrations occurred only in October 2007 (2.2-mg/L hydromulch and 7.1-mg/L low OM compost) and were associated with rodent activity. All of the treatments had different dissolved-P concentrations (Table 5). The concentration of dissolved P in runoff appeared to correspond to the relative amount of total phosphorus applied to each treatment, either as compost or fertilizer (Table 1).

Total-P concentrations demonstrated the combined effect of TSS and dissolved-P losses. Like TSS, total-P concentrations generally declined through the study period [Fig. 2(e)]. Early in the study untreated plots often had the highest total-P concentration, but compost plots were higher near the end of the study. The increase in total P from the compost plots was driven by the dissolved P and not sediment losses. The results of paired testing were mixed. Concentrations of total P were similar between high OM compost and untreated plots, but untreated plots had higher concentrations than low OM or hydromulch plots (Table 5). The high OM treatment also had significantly higher total-P concentrations than the low OM treatment. The fact that untreated plots were not significantly different from high OM but were different from the low OM compost blend plots for total P was related to higher concentrations of dissolved P observed from the high OM plots. On average across events, the concentration of dissolved P represented over 50% of the total P in runoff from the high OM plots and only about 3% of total P from untreated plots. While runoff from the low OM treatment had higher TSS concentrations than the high OM treatment derived runoff, the low OM plots had significantly lower concentrations of total P than high OM plots because dissolved-P concentrations were lower.

One might expect total-P concentrations in the runoff to reflect the concentration in the surface matrix. While initial soil concentrations for total P ranged from 211 to 328 mg/kg across all plots, total P in the compost applied measured 2,100 mg/kg for the low OM compost to 5,500 mg/kg for the high OM compost after blending. Despite the higher total P in the surface matrix of the compost plots, total-P concentrations in runoff from the compost treatments were similar to or less than the hydromulch or untreated plots (Table 4) because the P had different sources. For the untreated plots, most P was in a particulate form and thus associated with TSSs. Due to the erosion control provided by the compost treatments, compost plots lost much less sediment and slightly less total P. Of the P exported from the compost plots, most was in dissolved form, suggesting that some P leaches from the compost into the runoff.

Nutrient and Sediment Loads

Runoff volume and concentration data were combined to estimate the mass loss—or load—of each constituent for monitored events.

Table 6. Comparison of Total Load for All Events, June 2006–May 2008

	Total load (kg/ha)			
	Low OM	High OM	Hydromulch	Untreated
TSS	2,590	1,910	30,100	136,000
TKN	14.6	19.3	43.4	109
Nitrate	1.08	0.875	1.98	2.64
Dissolved P	2.64	5.06	2.12	1.02
Total P	5.76	8.75	17.8	34.3

The mass loss for sampled and unsampled events was summed to estimate the total load exported during the study (Table 6) on a per hectare basis. In terms of total performance, the high OM treatment had the lowest sediment loss. The high OM treatment exported less TSS than the low OM treatment, suggesting that the low OM plot had slightly less vegetation. The difference in vegetation is likely related to the level of OM and nutrients provided by the treatments (Table 1). The difference in sediment loss between compost treatments was very small relative to sediment losses from the hydromulch and untreated plots. Sediment export from the hydromulch plots was about 15 times more than the compost plots, and the untreated plots exported about 61 times more TSS than the compost plots. The hydromulch treatment provided better erosion control than no treatment (four times), but compost was much more effective.

Losses in TKN were highest for the untreated plots and associated with the highest TSS losses. The low OM treatment exported the least TKN. The untreated plots had much higher losses of nitrate (two times) than the hydromulch or compost plots. Dissolved-P losses from all treatments were higher than from the untreated plots, indicating that phosphorus associated with the compost and hydromulch enters the runoff in dissolved form. However, due to phosphorus associated with sediment losses, untreated plots had the highest losses of total phosphorus, while the low OM plots exported the least total phosphorus (Table 5).

Dissolved P is the only constituent for which losses were higher from compost and hydromulch plots than the untreated control plots. Three events in the fall of 2006 comprise about 75% of the measured losses of dissolved P for the compost treatments. Except for these three events, dissolved-P losses from the compost are very similar to those from hydromulch and untreated plots. Even though concentrations of dissolved P from compost plots rose late in the study, small runoff volumes lead to mass losses that are similar to the other treatments.

The compost/mulch plots received far more nutrients than the hydromulch plots, but exported less total nitrogen and total phosphorus (Table 7). The compost plots exported about 1% of the total nitrogen mass applied compared with 250% for the hydromulch plots, which suggests that nitrogen associated with sediment losses comprised the difference between nitrogen applied and nitrogen lost. In terms of total mass, the compost plots exported the least nitrogen. The untreated plots exported the most nitrogen, reflecting the high sediment losses. The relatively small nitrogen loss from the compost plots suggests that these treatments pose less risk of nitrogen pollution than hydromulch or bare soil. The results for total phosphorus were similar. The low OM compost plots exported 1% of the mass applied, and the least total mass of the four treatments. Losses of total phosphorus from high OM plots were about 50% more than that of low OM plots. This ratio reflects the difference in the amount of total phosphorus applied in the compost treatments.

Table 7. Applied and Exported Nutrients

	Low OM	High OM	Hydromulch	Untreated
Nitrogen applied (kg/ha)				
Total N	1,380	3,250	18.0	—
Total nitrogen exported (kg/ha)				
First year	11.6	17.9	27.7	70.6
Second year	4.11	2.33	17.7	40.7
Total	15.7	20.2	45.4	111
Fraction of total N exported	1.14%	0.622%	—	—
Phosphorus applied (kg/ha)				
Total P	585	1,570	22.0	—
Total phosphorus exported (kg/ha)				
First year	4.8	7.8	14.6	26.0
Second year	0.939	1.00	3.21	8.34
Total	5.74	8.80	17.8	34.4
Fraction of total P exported	0.981%	0.561%	—	—

Note: Nutrient application rates assume compost blend applied at a rate of 126 tons/acre.

Concentrations of nutrients continue to be higher off the compost plots than the untreated or hydromulch plots, indicating a continuing release of nutrients from the compost. This release should be expected as the compost material slowly breaks down. The concentration of soluble nutrients in runoff from the compost plots will increase as nutrients are converted from relatively insoluble to more soluble forms.

Impacts on Receiving Waters

This study found that compost and hydromulch treatments greatly decrease runoff volume and sediment loading, but may involve a water quality trade-off. The additional nutrients in these treatments, which benefit the establishment of vegetation, may negatively affect water quality if discharged into nutrient sensitive waterbodies. To put these nutrient loadings into perspective, export coefficients for years 1 and 2 by treatment were compared to export coefficients derived for common land uses noted in literature (Table 8). Because year 2 represented only 10 months, loadings were extrapolated to 12 months assuming similar loading rate during the remaining 2 months of the year.

The range of nutrient export coefficients for each land use is large, because of variations in management practices, such as fertilizer application rates, and weather conditions under which data were collected to derive export values. The range of coefficient values and their relative ranking in magnitude by land use does, however, allow a general characterization of different land uses by their relative nutrient contributions (e.g., row crop will typically deliver more nutrients than forest). With regard to the study plots, nutrient export from year 1 was comparable to row crop agriculture or fields fertilized using animal waste. By year 2, export from the compost plots had decreased to a level more similar to land associated with pasture nonrow crop agriculture or forested land even with similar total rainfall conditions as in year 1. Nutrient export from the hydromulch and untreated plots also

Table 8. Export Coefficients in Literature and from the Present Work

Land use/treatment	TN (kg/ha/yr)	TP (kg/ha/yr)	Literature sources
Animal waste applied fields	4.0–100	0.8–12	B, C, D
Row crops	2.1–80	0.3–19	E
Pasture/nonrow crop	1.0–14	0.1–2.9	B, E, C
Forest	1.0–6.3	<0.1–0.9	B, A
Range/idle land	0.5–6.0	0.1–0.3	B, C
Urban	1.9–14	0.1–7.6	B, C
Year 1			
Low OM	11.6	4.8	
High OM	17.9	7.8	
Hydromulch	27.7	14.6	
Untreated	70.6	26.0	
Year 2			
Low OM	4.93	1.13	
High OM	2.79	1.20	
Hydromulch	21.2	3.85	
Untreated	48.8	10.0	

Note: Literature sources: A: Clesceri et al. (1986); B: Loehr et al. (1989); C: McFarland and Hauck (2001); D: Overcash et al. (1983); and E: Reckhow et al. (1980).

decreased, but continued to be more similar to nutrient export from intensive agricultural practices than less intensive practices.

While loadings of total N and total P from compost treatments were less than nutrient loadings from hydromulch and untreated areas, there is one area of concern. Loadings of dissolved P from compost treatments were higher than from hydromulch or untreated plots. Because 40–60% of total-P loadings from compost treatments were measured as dissolved P, a form readily available for algae growth, this could be a potential water quality problem if the runoff goes directly into a nutrient sensitive waterbody. In widely applying these treatments within a watershed, nutrient loadings should be considered with regard to the sensitivity of the receiving water. Of note, plots used in this study had a 12% slope. As the slope decreases, it is anticipated that the volume of runoff and, thus, nutrient and TSS loadings should also decrease.

On a watershed level, the impact of these erosion control treatments will depend on the amount of land area involved, the slope of the reclaimed area, what other land area is contributing, the nearness of the treated area to the receiving waterbody, the type of receiving waterbody (stream or reservoir), and the sensitivity of that waterbody to the addition of nutrients, particularly soluble P. While these erosion control treatments, particularly the compost, greatly decrease the amount of sediment transported off these highly erodible reclamation sites, the trade-off in potential nutrient loadings needs to be considered before implementing these practices.

Conclusions

This study was initiated, in part, to address large sediment loads exported from quarry sites. The compost/mulch blends address this concern very well, providing a 98% reduction compared to untreated plots and 78% compared to hydromulch plots. The compost treatments achieve this reduction by establishing vegetative cover much faster than hydromulch (three times) or no treatment (four times), by retaining more rainfall, and by protecting soil from the energy of precipitation.

The benefits of using these compost/mulch treatments include their ability to promote rapid vegetation establishment and to protect the soil from erosive forces such as the impacts of rain drops before and during the establishment of vegetation. Establishing vegetation by seed requires favorable conditions for germination (including adequate moisture, appropriate temperature, and a good matrix for root growth) as well as adequate nutrients for plant growth. The compost/mulch treatments provided a favorable and protective environment for establishment of the Bermuda grass cover beginning with the fall rains following the intense heat and drought of the first summer. The other treatments, in contrast, experienced an extended delay in vegetation establishment, and were significantly assisted by the spread of grass runners from the compost plots.

Based on TSS losses, this study detected only a small difference between the low OM and high OM treatments in the ability to establish vegetation. This difference may be due to application rates of nutrients or OM, or both. The higher nutrient treatment (high OM) reduced losses of sediment, but provided more nitrogen, phosphorus, and OM. Since differences in establishing vegetation were small, the compost/mulch blend recipe does not appear to be an important factor affecting vegetation establishment.

A major benefit of the compost blend was its ability to hold water on the plots. The compost/mulch plots retained about 90% of the rainfall over the study period, compared with 68 and 55% retentions for the hydromulch and bare plots, respectively. This difference represented an additional 343 mm of water for the compost/mulch plots compared to hydromulch, which was likely a substantial factor in promoting vegetation establishment.

The compost/mulch treatments were found to export less total mass of nitrogen and phosphorus than hydromulch or bare soil. In comparison to hydromulch, the compost/mulch treatments reduced the discharge of total phosphorus by 50% (high OM treatment) to 68% (low OM treatment), and reduced the discharge of total nitrogen by 65% for the low OM treatment and 56% for the high OM blend. The loads of total phosphorus and total nitrogen exported from the compost treated test plots were also substantially less than those from the bare soil plots. Remarkably, the compost treated plots exported only 1% or less of the nutrients applied in the initial treatment during the 2 years of this study, with annual loads similar to those produced by row crop agriculture.

On the other hand, the compost/mulch blend treatments exported more P in dissolved form than either the control or hydromulch treated plots. Dissolved P can contribute to eutrophication in streams and lakes because algae growth is usually limited by P availability in freshwater systems. Particulate P, not being in dissolved form, is less available to algae. The calcareous nature of the soils in the current study should tightly bind most P making it unavailable without large enough changes in pH to allow P to desorb. In other systems where P is bound by Al or Fe rather than Ca, reducing or anaerobic conditions, such as those often found in deep waters or wetlands, may release particulate sorbed P (Reddy et al. 1999). Therefore the bound fraction of total P poses less direct risk of eutrophication than the dissolved fraction. This increased export of dissolved phosphorus means that using one of the compost/mulch blend treatments to control erosion increases the potential for an algae bloom in the receiving waters. Compost treatments pose less risk when applied at a greater distance from the waterbody, when covering a relatively small portion of the watershed, on relatively gentle slopes, and outside of areas where concentrated runoff flows occur.

The compost blends showed similar performance with regard to runoff volume and vegetation establishment. For this reason, a blend with lower phosphorus levels (i.e., lower compost to mulch ratio and/or use of compost with lower P content) but with similar physical characteristics such as water-holding capacity would be expected to perform like the treatments studied here. Further research should confirm this hypothesis and recommend a recipe for ECC that balances nutrient and organic content with vegetation establishment. In sum, the potential risk that compost treatments pose to surface waters by exporting bioavailable phosphorus may be reduced by developing a lower nutrient formulation that would still provide the many benefits documented in this study.

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