Annual Sediment, Nitrogen and Phosphorus Losses From Bare And Compost Amended Fill Slopes.

D.E. Rider, M.J. Curtis, V.P. Claassen
University of California, Davis

Draft Interim Report for
Model Guided Specification for Using Compost and Mulch to Promote Establishment of Vegetation of and Improvement in Stormwater Quality
RTA # 65A0182

DRAFT

Introduction:

Composted organics can be utilized for beneficial uses such as reducing eroded sediment yields, stormwater pollution prevention, and for revegetation and soil regeneration treatments. Numerous studies have shown that composts and mulches applied as soil surface blankets can reduce runoff and sediment loss from slopes as compared to bare slopes or treated slopes without a mulch cover (W&H Pacific, 1993 / Portland Metro, 1994; Demars et al., 2000; Glanville et al., 2001; Faucette et al., 2004; Grismer and Hogan, 2005). Cover treatments protect the soil surface from the kinetic impact energy of rain. This reduces the potential for sediment detachment and surface crusting, roughens the surface so that overland flow is impeded, and allows more time for percolation of rain down into the soil. In addition, compost treatments can restore disturbed soils and facilitate revegetation by increasing levels of organic matter (OM); which increases soils' water holding capacity (WHC), cation exchange capacity, and nutrients levels while decreasing soil bulk density (Munshower, 1994). Re-establishing vegetation on disturbed soils will provide long term soil erosion and stormwater buffering

protection. However, in some conditions, compost treatments have the potential to leach nutrient into stormwater runoff, creating a point source of stormwater pollution.

The type and production method of compost that is utilized (ie. maturity, curing, feedstocks) greatly affects nutrient leaching potentials. Faucette et al. (2005) presented the cumulative losses in total N and P amongst four composts added to unvegetated test plots (aged poultry litter, biosolid treated, municipal waste, and yard waste source materials). After three rainfall simulations, over a 12 month period, total N and P losses were approximately 61 and 3.4 kg ha^{-1} for the biosolid, 27.1 and 0.75 kg ha^{-1} for the municipal waste, 13.6 and 1.7 kg ha^{-1} for the aged poultry litter, and 6.8 and 1.4 kg ha^{-1} for the yard waste composts. The authors state that compost curing levels and differences in organic versus inorganic N content explain much of the N and P loss differences among the separate treatments (Faucette et al., 2005). In a similar study, nutrient levels in runoff from slopes with blanket treatments of compost slopes were higher in unvegetated plots as compared to vegetated (Glanville et al., 2004).

The method of application (blanket or incorporation), and soil preparation (tilled or non-tilled) influences the overall performance of compost treatments. Tillage treatments fracture soil crusts and soil compaction layers, thus allowing for deeper rooting depths. Incorporating compost into soil helps to stabilize soil structure by preventing reconsolidation / packing. Tillage management practices have been shown to increase surface pore size distribution (0-10 cm), increase infiltration and water holding capacities (Lipiec et al., 2006). Tillage, combined with surface roughening, decreases overland surface flow. Compost incorporation also generates soil surface roughness, which increases depression storage and causes a delay in runoff (Govers et al. 2000).

Muzzi et al. (1997) found, however, that surface amendments alone were not adequate to stop erosion and that, in most cases, tilling the ground before mulch application produced the most effective erosion control and plant growth.

The focus of this study was to evaluate the annual sediment yield and nutrient losses of different compost treatments. Many studies that evaluate erosion abatement treatments or best management practices (BMPs) heavily rely on rainfall simulators to mimic precipitation events. Rainfall simulators can be an effective research tool in such studies because it allows for the researcher to control rainfall durations and intensities that may provide useful information concerning the relative differences between erosion treatments. However, there are several major limitations to such experimental designs. Often the data from such studies only offer a "snapshot" of how erosion treatments perform over time. There are several significant variables that are not addressed by rainfall simulator studies, such as: variations in soil moisture, soil temperature, time since previous rainfall event, and distribution of rainfall intensities. These temporal variations can significantly affect observed treatment effects. Further, experimental plot sizes are restricted by the relatively small size of rainfall simulators. Thus, the inherent variability of the soil and hydrologic regime may not be adequately characterized.

This study utilized natural rain events throughout the winter of 2005/2006. Northern California's Mediterranean climate is characterized as having hot dry summers and cool wet winters. The rain season in this region generally runs from early November until April (CA-DWR). This rainy season period was used to measure and model annual erosion yields. The objectives of this study were to compare compost treatments (screened and cured, unscreened and uncured), compost application methods (blanket,

DRAFT

incorporated, or a combination of a blanket over an incorporated) in terms of total runoff volume, total suspended solids, and nutrient losses (total dissolved N, NH_4-N, NO_3-N, dissolved organic N, dissolved organic C, and total P) from 2:1 tilled or planed bare slopes on disturbed earth fill materials.

Methods and Materials:

The study site was located at the University of California, Davis landfill. Research plots were installed on the west-facing slope of a constructed debris cell (~2 ha in area). The debris cell had been constructed three years earlier and had a two foot cap of soil placed over a plastic liner that covered the debris. The soil had been compacted by track walking after construction.

Research plot construction:

Table 1. Soil Characteristics.

Texture	Total C%	Total N%	NO_3^- ppm	CEC cmol kg^{-1}	pH	Bray P ppm
Clay	0.46	0.06	4.0	31.8	7.6	10.9

Table 2. Compost Characteristics

Compost Source	Bulk Density Mg m^{-3}	Total N %	NH_4^+ mg kg^{-1}	NO_3^- mg kg^{-1}	Organic C %	P mg kg^{-1}	Stability Rating† Respiration - BAC
RMC (Mature)	0.513	2.0	12	351	25.2	3097	stable - stable
BFI (Immature)	0.192	1.5	24	3.1	29.2	2367	moderately unstable - unstable

†Stability rating based on 1) Respiration rate (CO_2 evolution) under optimized moisture and temperature, 2) BAC – Biologically Available Carbon-Respiration under optimized conditions except for a carbon source. Results were interpreted and compost stability was

DRAFT

determined by Soil Control Lab, Watsonville, CA. RFC-Redding Municipal Composting Facility. BFI-Browning Ferris Inc.

Figure 1. Layout of the plots at the UCD landfill location.

Plots were constructed in October 2005, and were 1 m wide by 10 m long. Thirty two plots were placed across the base of the slope. The average slope of the plots was 2:1 (horizontal:vertical). Edging (9 cm x 2 cm) was placed around the plots so that ~6 cm of the edging was below the soil surface to prevent run-on from adjacent soil. A galvanized metal runoff collection device was placed at the base of each plot. Runoff entering the collection devise was funneled into a 17 liter bucket located below the collection devise. When runoff volumes exceeded the container capacity of the primary 17 liter bucket, one third of the overflow was diverted into a 128 liter bucket to acquire a subsample of larger flow events.

DRAFT

Table 3. Experimental treatments.

Treatment ID	Treatment description
BP	Bare, planed.
BT	Bare, tilled soil (15 cm).
AG	Established annual grass.
CMB	Mature compost applied as a blanket (3.5 cm) (180 Mg ha^{-1}) over planed bare soil.
CIB	Immature compost applied as a blanket (3.5 cm) (67 Mg ha^{-1}) over planed bare soil.
CGB	Mature compost applied as a blanket (3.5 cm) (180 Mg ha^{-1}) over planed bare soil seeded with grass.
CMT	Mature compost incorporated into the soil (15 cm) (180 Mg ha^{-1}).
MCT	A mature compost blanket application (3.5 cm) (180 Mg ha^{-1}) over a mature compost application incorporated into the soil (15 cm) (180 Mg ha^{-1}). Total mature compost application (360 Mg ha^{-1})
MT	Mature compost blanket application (unincorporated) (3.5 cm) (180 Mg ha^{-1}) over tilled soil (15 cm)

All treatments were kept free of vegetation using glyphosate (Roundup) herbicide unless noted. The bare plots had all their pre-existing vegetation and duff layer removed during plot construction in order to expose the bare soil. Plots with tillage had all their pre-existing vegetation and duff layer removed before tilling. The annual grass plots represent the ambient condition of the slope, on which vegetative cover was > 80 %. Compost mulch plots were constructed with a 3.5 cm deep layer of compost over the entire plot. Plot treatments testing compost tilled into the soil were constructed by applying a 3.5 cm deep layer of compost over the entire plot, which was then tilled into the soil to a depth of 15 cm. Some treatments (MCT) had another layer of compost applied over the tilled surface as a blanket. The native annual grass *Vulpia microstachys* (small fescue, Six weeks fescue) was used to seed the vegetated cured compost over bare ground. This treatment was completely vegetated within 3 months of construction.

The mature compost consisted of screened, windrowed yard waste from the Redding Municipal Composting Facility (Redding, CA). This material was produced by a 15 day, 55 °C, thermophilic process followed by 90 days of aerobic curing. The

DRAFT

material passed through a 125 x 75 mm grate during the initial tub grinding and was further screened to 19 mm (3/4 inches) after composting. The immature compost consisted of unscreened, windrowed yard waste from Browning Ferris Inc, Milpitas, CA. This material was produced by a 15 day, 55 °C, thermophilic process followed by 70-90 days of aerobic curing. Physical and chemical properties of both composts are presented in Table 2.

Runoff measurement and collection:

Precipitation events were defined as storms with more than 12 mm of cumulative precipitation that were separated by more than six hours. Figure 1 shows the cumulative precipitation over the rainy season at the landfill and the dates that samples were collected. Runoff from 19 precipitation events was collected between December 2005 and April 2006. Runoff volume from each plot was determined by measuring the depth of runoff in both the primary and secondary runoff collectors. The interior area of the container was then multiplied by the measured runoff depth to calculate the total volume. The volume of runoff in the secondary runoff collector was multiplied by three to account for the uncollected portion (2/3) of the runoff. After a precipitation event, the constituents of each runoff collector were homogenized by stirring, and a 250 ml sample was removed from the center of the collector. Runoff samples were stored at 4°C within two hours after collection until they could be analyzed.

DRAFT

Sample analysis:

Runoff samples were filtered using pre-weighed 1.5 micron glass fiber filters (Whatman 934-AH). Filters and sediment were dried at 105°C for 24 hours, placed in a desiccation chamber to cool and then weighed. The sediment concentration (mg/L) was calculated from the mass of sediment collected on the filter divided by the volume of runoff filtered. Total sediment from each plot was then calculated by multiplying the sediment concentration of the runoff sample times the total volume of runoff measured from its corresponding plot.

The filtrate of each sample was analyzed for NH_4^+, NO_3^-(Carlson et al. 1990), total dissolved nitrogen (TDN) and carbon (TDC) (Shimadzu, TOC-V and TNM-1). Dissolved organic nitrogen (DON) was calculated as the difference between TDN and mineral nitrogen ($NH_4^+$and NO_3^-). A 20 ml sample of unfiltered runoff was used to measure total phosphorous (Murphy and Riley, 1958). The mass of nutrients lost from each plot was determined by multiplying the measured concentration of each constituent by the runoff volume for each respective plot. The annual cumulative mass lost for each measured constituent was the sum of the results for all the precipitation events. During some precipitation events, the runoff volume exceeded the storage capacity of the secondary collection containers on a few plots and so the cumulative values represent a minimum. Most sediment was located in the primary collector, however, and overflow loss from the secondary collector represents a minor underestimation of total sediment loss.

DRAFT

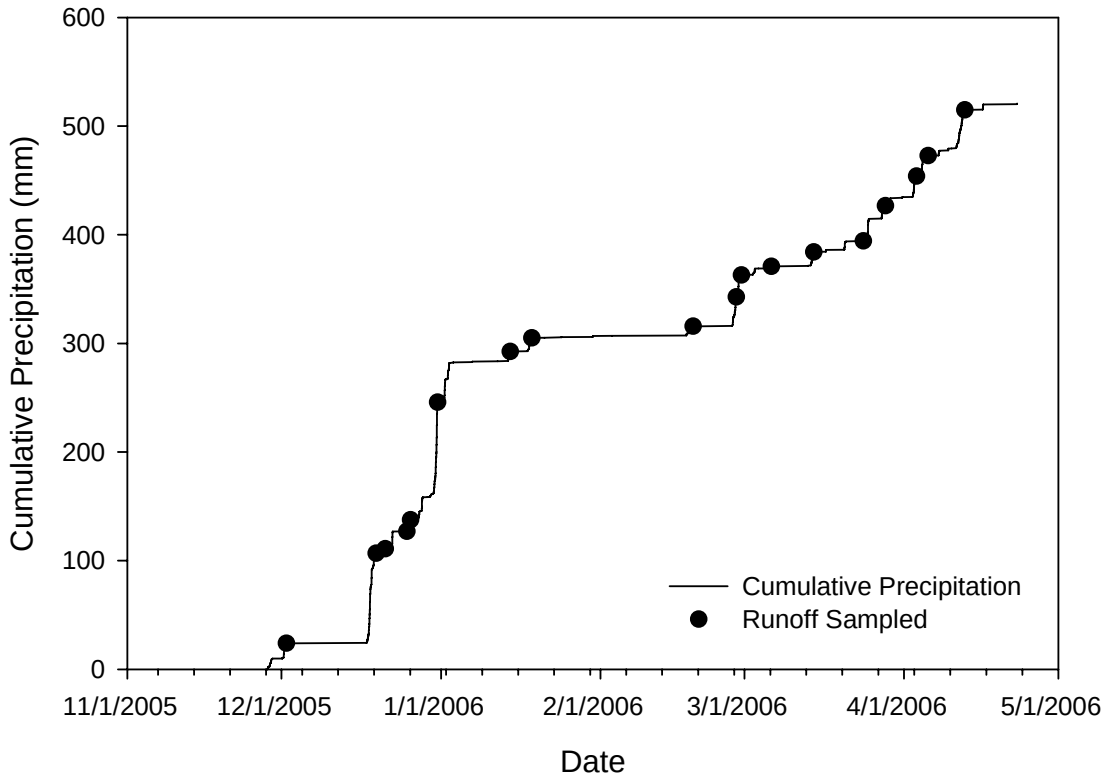

Figure 2. Cumulative precipitation for Davis, CA from 12/1/05 through 05/01/06.

Statistical Analysis

Statistical analysis was performed using JMP® statistical software (JMP, version 6, SAS Institute, Inc., 1989-2005). Inspection of the annual runoff data revealed a nuisance variable with a significant spatial influence upon runoff response, expressed laterally across the experimental slope. Multiple linear regression (JMP "Fit Model" platform, ordinary least-squares) of total runoff volume vs. plot treatment and plot spatial position (modeled as a continuous effect) identified a significant ($F=13.47$, $p=0.001209$) linear relationship between plot position (i.e. the nuisance variable) and runoff volume, independent of treatment effects. No interaction was detected between plot position and

plot treatment, however, suggesting that while a significant spatial effect on runoff existed across the experimental slope, this effect did not vary between treatments. Not surprisingly, this nuisance variable was found to show a similar effect with regard to the other response variables, all of which depend upon runoff volume.

To control for the effect of this nuisance variable, single-factor analysis of covariance (ANCOVA, using JMP "Fit Model" platform) was employed for factor level mean comparisons, with the nuisance variable (spatial position) included as the model covariate. Multiple-pairwise comparisons of the ANCOVA least-squares means (or *marginal* means) were conducted using the Tukey-Kramer HSD test. The ANCOVA assumptions of homoscedacity and residual normality were tested according to the Levene (Levene, 1960) and Shapiro-Wilk (Shapiro and Wilk, 1965) tests, respectively. The assumption of homogeneity of slope was verified by detection of a non-significant interaction between the plot position and treatment effects. For all tests, statistical significance was determined at the alpha = 0.10 confidence level.

If a significant departure from normality or homoscedacity was detected, a data transformation was attempted in order to meet these assumptions. Selection of an appropriate power transform, $Y' = Y^{\lambda}$, was aided by inspection of a Box-Cox plot of the residual sum of squares (RSS) as a function of λ, from which a convenient transformation (e.g. Log[Y] or $\sqrt{Y}$) was selected based on the location of the RSS minimum. Treatment means presented in tables are the back-transformed means. Possible outliers were identified by analysis of their deleted studentized residuals, with significance determined using a Bonferroni critical *t*-value of $t(0.10/(2 \cdot n_T); n_T - r - 1)$, where n_T and r are the total number of observations and factor levels, respectively. Observations meeting this

criterion were considered for removal if their associated Cook's D statistic (a measure of the influence of the observation upon the estimated parameters) exceeded the critical value F (0.5, p, n-p).

Data are presented with each treatment value corrected as if it were spatially positioned at the center of the field plot (plot #18). Thus, the absolute values reported in Table 4 are relative to the runoff levels from plot #18 and are presented here for relative comparison purposes. This was done to normalize the nuisance variable of runoff as it relates to plot position (Figure 1).

Results:

Table 4. Annual Data. All values indicate kg ha^{-1}.

Treatment		Sediment		NO_3^-		NH_4^+		P	
AG	annual grass	737.4	b	3.8	c	3.5	d	5.9	c
BP	bare planed soil	3554.2	ab	12.1	abc	25.9	abc	12.4	abc
BT	bare tilled soil	4216.1	ab	10.2	bc	22.6	abcd	7.8	bc
CIB	immat comp blkt over bare soil	1740.9	ab	35.8	a	11.9	bcd	33.5	a
CMB	mature comp blkt over bare soil	1346.0	ab	41.3	ab	55.0	ab	32.9	a
CGB	comp grass planed over bare soil	614.2	b	4.0	c	6.6	cd	22.1	abc
CMT	mature comp tilled into soil	6516.8	a	14.9	abc	24.1	abcd	21.8	ab
MCT	comp blkt over comp till into soil	656.2	b	8.1	c	24.5	abcd	18.1	abc
MT	comp blkt over tilled soil without comp	1772.6	ab	37.9	a	108.3	a	27.5	a

The nutrient loss data, normalized for the ambient hydrologic gradient on site, are presented in Table 4. The highest sediment losses occurred from the bare planed soil, the bare tilled soil and the compost mulch tilled into soil. These were treatments that were either bare or had only fine (< 3/4 inch) compost fibers that did not hold the soil well

DRAFT

after tillage. The incorporation of compost into the soil may have increased sediment loss due to mechanical fracturing. No other treatments differed statistically in this experiment, but the lowest sediment losses were from grass covered slopes or those with tillage and a mulch cover. The rainfall during this year (50 % above normal) and site conditions (subsurface flow) created excessive experimental variability, although the best treatments produced only 10 to 20 % of the sediment coming from the worst treatments.

The treatments that produced the lowest NO_3^- runoff are those with no compost added, or those with a compost blanket over compost tilled into the soil. These treatments grouped together because either they 1) did not have NO_3^- available for losses or 2) if they had NO_3^- from compost, the infiltration was evidently great enough to infiltrate it rather than lose it to overland flow. The highest losses of NO_3^- came from compost applications to plots with reduced infiltration (lack of tillage, or no compost incorporated to maintain pores). These extreme cases statistically differed from each other, but intermediate treatments did not.

Ammonium losses were lowest from plots with grasses actively growing. The NH_4^+ losses were highest from plots having a compost blanket application over soil with reduced infiltration, either from lack of tillage, or tillage without organics incorporated into the soil, or from bare soils with no composts added at all. The immature compost had about 20 % of the ammonium loss as the mature compost in a paired set of treatments. The presence of grass cover or improved infiltration were associated with reduced ammonium losses.

DRAFT

Phosphorus losses were also lowest with grass cover or improved infiltration although statistical differences were not detected in this location and rain year. The highest losses occurred with compost blankets over bare soil or reduced infiltration.

Because a site cannot be managed for only one of the tested impacts (sediment, nitrate, ammonium or phosphorus), the cumulative ranked score of the performance of each treatment was calculated, such that treatments with lower sediment or nutrient losses were assigned lower scores. The three treatments with the lowest overall score (lowest sediment or nutrient losses) were the treatments that had grass growth or that had enhanced infiltration (compost mulch over compost incorporated into the soil (MCT)). Given that the nutrient addition to the MCT treatment was double that of any other compost amendment and that it the nearly the lowest overall losses, this treatment stands out as being effective in field conditions. The ability of a grass cover to take up nutrients, as in the other low ranking treatments, is also noteworthy. The poorest performing treatments (highest overall scores and greatest losses of sediment and nutrients) were those treatments that had a missing treatment component, such as no tillage or no mulch cover, or tillage without compost incorporation to maintain open pore structure, allowing the soil to recompact and lose infiltration.

Conclusions:

Treatments that support a grass cover, have a mulch protection for the surface and a organic amendment tilled into the soil provided the greatest reduction in sediment, nitrate, ammonium and phosphorus losses when measured in a very wet year, using annual cumulative loss data.

DRAFT

References:

Demars, K., R. Long, and J. Ives. 2000. Use of wood waste materials for erosion control. Technical Report prepared for The New England Transportation Consortium, April, 2000. NETCR 20. Project #97-3, The University of Connecticut, Storrs, Connecticut.

Faucette L, Risse L, Nearing M, Gaskin J, and West L. 2004. Runoff, erosion, and nutrient losses from compost and mulch blankets under simulated rainfall. Journal of Soil and Water Conservation 59.4: p154(7)

Glanville T, Persyn R, Richard T, Laflen J, and Dixon P. 2004. Environmental effects of applying composted organics to new highway embankments: part 2. water quality. Transactions of the ASAE Vol. 47(2): 471-478

Govers G, Takken I, and Helming K. 2000. Soil roughness and overland flow. AGRONOMIE 20 (2): 131-146

Grismer M and Hogan M. 2005. Simulated rainfall evaluation of revegataion/mulch erosion control in the Lake Tahoe basin - 3: Soil treatment effects. Land degradation & development 16: 489–501

Kramer, C.Y. (1956), "Extension of multiple range tests to group means with unequal numbers of replications," Biometrics, 12, 309–310.

Levene, H. (1960), "Robust tests for the equality of variances" In I. Olkin (ed), Contributions to probability and statistics, Stanford Univ. Press.

Lipiec J, Kus J, Slowinska-Jurkiewicz A, Nosalewicz A. 2006. Soil porosity and water infiltration as influenced by tillage methods. Soil & Tillage Research 89 (2): 210-220

Munshower, F 1994. Practical Handbook of Disturbed Land Revegetation. Lewis Publishers. Boca Raton, Fl.

Muzzi E, Roffi F, Sirotti M, Bagnaresi U. 1997. Revegetation techniques on clay soil slopes in northern Italy. Land Degradation & Developement 8 (2): 127-137

Shapiro, S.S., Wilk, M.B. (1965). "An analysis of variance test for normality (complete samples)", Biometrika, 52, 3 and 4, pages 591-611.

Tukey, J. (1953), "A problem of multiple comparisons," Dittoed manuscript of 396 pages, Princeton University.

W&H Pacific, 1993. Demonstration project using yard debris compost for erosion control. Final report for Metropolitan Service District, Portland. 29 pg.

DRAFT