

ENVIRONMENTAL EFFECTS OF APPLYING COMPOSTED ORGANICS TO NEW HIGHWAY EMBANKMENTS: PART 2. WATER QUALITY

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ABSTRACT. *An oversupply of composted organics, and imposition of new federal regulations governing stormwater discharges from construction sites, motivated the Iowa Department of Natural Resources (IDNR), and the Iowa Department of Transportation (Iowa DOT) to sponsor a study of the potential water quality impacts of using compost to control runoff and erosion on highway construction sites. Test areas treated with 5 and 10 cm deep blankets (unincorporated) of three types of compost (biosolids, yard waste, and bio-industrial byproducts) were constructed on a new highway embankment with a 3:1 sideslope and subjected to simulated rainfall intensity of approximately 100 mm h⁻¹. Concentrations and total masses of N, P, K, and nine metals in runoff from compost-treated areas were compared to those in runoff from embankment areas receiving two conventional runoff and erosion control methods typically used by the Iowa DOT (light tillage and seeding of native embankment soil, or application of 15 cm of imported topsoil followed by seeding). Simulations were replicated six times under both vegetated and unvegetated conditions, and the first hour of runoff was sampled to determine concentrations and total masses of soluble and adsorbed nutrient and metals. The applied composts generally contained much greater pollutant concentrations than either of the two soils used in the conventional treatments, and runoff from unvegetated plots treated with compost also contained significantly greater concentrations of soluble and adsorbed Zn, P, and K, and adsorbed Cr and Cu, than runoff from the two conventional treatments. In accordance with previously reported soil erosion research, runoff from all test plots was sampled periodically during the first hour of runoff. Due to their significantly greater infiltration capacity, however, compost-treated areas required significantly greater amounts of rainfall than conventionally treated areas to produce 1 h of runoff. In light of this significant difference in the amount of rain applied, the total mass of pollutants contained in runoff generated by equal amounts of rainfall was judged a more equitable basis for comparing the treatments. Runoff samples collected during the first 30 min of rainfall (equivalent to a 25-year return period storm at the applied intensity of 100 mm h⁻¹) were used for this purpose, and the resulting total masses of individual quantifiable soluble and adsorbed contaminants in runoff from conventionally treated areas were at least 5 and 33 times, respectively, those in runoff from compost-treated areas. Based on these results, blanket applications of compost can be used to reduce runoff and erosion from construction sites without increasing nutrients and metals in stormwater runoff.*

Keywords. *Compost, Construction, Erosion, Metals, Nutrients, Roads, Runoff.*

Since 1989, when the Iowa legislature mandated a 50% reduction (by year 2000) in the amount of solid waste buried in landfills, the number of publicly owned and industrial composting operations in Iowa has grown from a handful to more than 70 facilities processing

320,000 metric tons/year of yard waste, biosolids, and industrial organics annually (Iowa DNR, 1998). While successfully reducing pressure on Iowa's landfills, the rapid increase in composting operations has created a need for new markets capable of utilizing large amounts of composted materials.

The Iowa Department of Transportation (Iowa DOT) has statewide responsibility for stormwater management and erosion prevention on embankments adjoining approximately 160 km of new or reconstructed roadways that are built each year. However, the conventional practice of seeding the highly compacted subsoil used to construct highways does not always produce rapid establishment of vigorous vegetative cover needed for good erosion control. Faced with unfavorable weather conditions, temporary erosion protection is often sought through application of chopped straw or synthetic erosion control blankets, and sites with particularly poor soils are generally amended with a 15 cm layer of imported topsoil to improve vegetative growth. Because of increasingly stringent stormwater management regulations for construction sites, the Iowa DOT is interested in alternative practices that can provide runoff and erosion control prior to establishment of vegetative cover, and that can promote improved emergence and growth of vegetation as well. One of the practices being considered is application of compost to

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construction areas to control soil erosion and surface runoff. To evaluate the potential advantages and disadvantages of this practice, a two-year study was conducted to measure:

1. The concentration and total mass of nutrients and heavy metals contained in runoff.
2. The quantity of runoff and soil erosion.
3. The emergence and growth of the planted cover crop and weeds.

This article reports on results relevant to objective 1. Study results for project objectives 2 and 3 are described in articles by Richard et al. (2002), Persyn et al. (2004), and Glanville et al. (2001, 2003). A project website also is available at: www.abe.iastate.edu/compost.

LITERATURE REVIEW

Soil loss rates from construction sites are often reported to be 10 to 20 times those from agricultural lands (USEPA, 2000b). Control of stormwater, erosion, and sediment at construction sites was mandated by 1987 amendments to the federal Clean Water Act (CWA). Control of discharges from sites larger than 5 acres was first mandated in 1990 (USEPA, NPDES) and, as of March 2003, construction areas larger than 1 acre are now covered by these regulations (USEPA, 2000b). Guidelines and regulations specific to construction sites have been published (USEPA, 2000c, 2000d; Federal Highway Administration, 1997; USEPA, 1998).

Current literature suggests that, although many states have experimented informally with using compost and other types of soil cover to reduce erosion and water quality problems, relatively few quantitative studies on their effects have been conducted. A survey of state departments of transportation (Mitchell, 1997) indicated that 19 state DOTs had developed specifications for compost use, and that 34 reported experimental or routine use of compost on roadsides for purposes such as: improved vegetation, erosion control, filter berms, and bioremediation of contaminated soils. Highway projects where composted organics were used specifically to control erosion were reported in Maine, California, Washington, Florida, Oregon, and Arizona.

Barrett et al. (1995) noted that the most commonly cited water quality impacts associated with road construction are increased turbidity in runoff during and immediately after project completion. Their review of highway erosion research conducted since the 1960s noted that most of this work has focused on application of synthetic slope covers, natural fiber mats, mulches, sediment barriers, check dams, and sedimentation ponds. No references to utilization of composted organics for erosion control were noted.

Recent projects focusing on the benefits of using compost to improve roadside vegetation include a comparison of soils amended with compost versus soils treated with hydro mulch and fertilizer (USEPA, 1997). Work by the Texas Natural Resources Conservation Commission and the Texas Department of Transportation evaluated vegetation production and erosion on roadway embankments treated with composted cattle manure (Block, 2000; USEPA, 2000a).

Qualitative evaluation of the effects of compost on erosion include a 7-month project by the city of Portland, Oregon (Portland Solid Waste Department, 1994), and work by Ettlin and Stewart (1993) on the use of yard debris compost for erosion control on slopes up to 42%. A follow-up study

planned for 2001 by the Oregon Department of Environmental Quality and City of Portland was designed to compare the quantity and quality of runoff from an urban construction site amended with compost to that from a construction site receiving conventional stormwater control practices (Kunz, 2001).

Demars et al. (2000) reported that composted wood waste applied to a highway embankment with a 26° slope produced only about 2% of the erosion that occurred on bare plots when subjected to natural rainfall. Storey et al. (1996) used simulated rainfall to compare vegetative growth and erosion on compost-amended plots and plots treated with shredded wood and two types of synthetic chemical tackifiers. Block (2000), in a Connecticut study comparing composted yard waste, wood mulch, and straw, reported that erosion on untreated plots was more than 10 times that observed on mulched plots, and that thickness of the mulch layer did not appear to significantly affect the observed erosion rates. Agassi et al. (1998) report that 1 to 3 cm thick layers of municipal solid waste compost applied to loess soils substantially increased infiltration during simulated rainfall. Risse et al. (2002) compared runoff, total solids loss, and nutrient loss from untreated soils with that from soils blanketed with seven types of compost, aged poultry litter, and three types of wood mulch. All treatments except the aged poultry litter effectively reduced solids loss in runoff compared with the erosion from untreated soil. Total runoff from the aged poultry litter was somewhat greater than from untreated soil, and most of the compost and wood mulches produced less runoff than untreated soil, although the differences were not statistically significant. Nutrient losses from most compost treatments were greater than from bare soil or wood mulch blankets.

Recommendations regarding site characteristics and appropriate application depths of compost to reduce erosion were presented by Alexander (2001), Stewart and Pacific (1993), and Michaud (1995).

MATERIALS AND METHODS

EXPERIMENTAL DESIGN

This project was designed to compare the concentration and total mass of nutrients and metals contained in runoff from compost-treated and conventionally treated highway embankments having typical 3:1 sideslopes. Each test setup consisted of five adjacent test plots measuring 120 × 180 cm that were simultaneously exposed to simulated rainfall. Three of the five plots were blanketed (surface applied without incorporation) with a 5 or 10 cm deep layer of one of three composts. To permit direct comparison with conventional embankment preparations, the two remaining test plots were constructed using two methods commonly employed by the Iowa Department of Transportation. These included light disking of the embankment soil followed by fertilization and seeding (control treatment), and application of a 15 cm blanket of imported topsoil prior to fertilization and seeding (topsoil treatment).

All test plots were constructed in late May or early June. Half of the plots were tested in an unvegetated condition by subjecting them to high-intensity rainfall as soon as possible following construction. The remaining plots were fertilized (500 kg/ha of 13-13-13), seeded with a mixture of oats, annual rye, timothy, and red clover (at 108, 39, 6, and 6 kg/ha

respectively), and cultipacked as typically specified by Iowa DOT. These plots were subjected to simulated rainfall 6 to 8 weeks after planting to evaluate their performance after vegetative cover was established. All test runs were replicated six times (three times during each of two summers), but each test plot was subjected to high-intensity rainfall only once. Runoff samples from each test plot were subsampled in the lab and used to quantify runoff and erosion (project objective 2) as well as nutrient and metal export.

COMPOST SELECTION

Different feedstocks, processing technologies, and product screening techniques can produce composted organics with diverse physical, chemical, and plant growth characteristics. To help ensure that results would be representative of composts typically available throughout Iowa, the Iowa Department of Natural Resources (primary project sponsor) specified that the research be conducted using three specific materials. These included: a sewage biosolids and yard waste compost from the city of Davenport, Iowa; a yard waste compost from the Metro Waste Authority of Des Moines, Iowa; and a bio-industrial (paper mill and grain processing sludge) and yard waste compost from the Bluestem Solid Waste Agency in Cedar Rapids, Iowa.

RESEARCH SITE

The research was conducted on the sideslopes of a reconstructed interstate highway overpass located approximately 16 km north of Ames, Iowa. Embankment slopes were 3:1, the maximum typically allowed by state construction standards, and slope lengths were approximately 15 m.

WATER SOURCE AND APPLICATION

To ensure comparability of results, all test areas were subjected to identical high-intensity rainfall applied with an 8 m long single-sweep Norton rainfall simulator with operating characteristics similar to the one developed by Meyer and Harmon (1979). Unvegetated plots were tested each year during mid to late June (as soon after construction as physically possible). Vegetated plots were tested in mid to late July (approximately six weeks after seeding). Rainfall application and runoff sampling methods were similar to those of Liebenow et al. (1990) and King et al. (1995). To initiate runoff from the compost-treated plots within 30 to 60 min, however, it was necessary to increase rainfall intensity from the 63 mm h⁻¹ typically used by USDA to quantify erosion on natural soils to nearly 100 mm h⁻¹. Although this application rate is about 50% greater than the USDA rate, rainfall of this intensity lasting 30 min (the storm duration used to estimate the total mass of nutrients and metals contained in plot runoff) is only a 25-year return period storm in central Iowa. Rain gauges positioned at the top of each experimental plot were used to measure the total amount of rainfall applied.

Water used in the simulated rainfall studies was obtained from a 4 ha lake at the Iowa State University Horticulture Farm, located approximately 8 km from the research site. The watershed feeding the lake is used mainly for corn and soybean production. Samples of the lake water were collected for nutrient and metal analyses each time a load was hauled (N = 45).

RUNOFF SAMPLING

To quantify the concentration and total mass of nutrients and metals in runoff from each treatment, runoff was collected in 50 × 75 cm test areas similar to those used by Liebenow et al. (1990) during interrill erosion studies conducted by the USDA in the western U.S. Test areas were bordered on three sides with 20 cm high steel border, and runoff originating within the border was captured in a V-shaped galvanized steel trough installed at the downhill edge of each test area (fig. 1).

After runoff began, 10 to 12 samples were collected at 5 min intervals for up to 1 h. A flow-weighted composite sample was obtained by combining approximately 2 min of runoff during each sample collection interval. Composite samples were stored at -4°C prior to filtration and analysis for soluble and adsorbed metals and nutrients.

SOIL AND COMPOST SAMPLING

A batch of each type of compost (and the imported topsoil) was delivered by truck at the beginning of each summer, and all replications tested each summer were constructed from the same batch. To evaluate the concentrations of nutrients and metals present in the compost, topsoil, and native embankment soil, five samples of each material were collected before plot construction each summer. These were combined, packaged in Ziploc bags, and stored at -4°C prior to drying, grinding, digestion, and analysis.

LABORATORY ANALYSES

Soil and compost samples were prepared and digested in triplicate according to EPA Method 3051, a strong HNO₃ acid microwave digestion procedure designed to release acid labile As, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Se, Zn, P, and K. After digestion, samples were analyzed using an inductively coupled argon plasma (ICP) instrument (detection limit 0.010 mg L⁻¹). Total nitrogen in the soils and composts was evaluated in triplicate using a CHN-2000 analyzer (detection limit 0.001%, Leco Corporation, St. Joseph, Mich.).

Concentration and total mass of sediment-attached nutrients and metals contained in runoff were quantified by passing runoff samples through a 0.45 μm MicronSep cellulose filter (Osmonics, Inc., Minnetonka, Minn.). Filters and their associated solids were digested together and analyzed for metals and nutrients using the same methods and equipment used for the composts and soils. The portion of the samples that passed through the 0.45 μm filter were diluted with aqua regia and analyzed for soluble metals, P, and K using ICP. Nitrate and ammonium nitrogen in solution was determined colorimetrically using a Lachat Instrument (detection limit 0.20 mg L⁻¹).

Laboratory quality control and quality assurance procedures included acid washing of laboratory vessels and equipment prior to use. Acids used in washing and sample processing were trace metal free, and a sewage biosolids sample certified by the National Institute of Standards and Technology (NIST) was included with each batch of samples to quantify metal recovery. Standards and laboratory blanks were evaluated after every 10 samples processed via ICP, and samples were rerun if metals concentrations were not within 5% of NIST-certified values. Standards were evaluated after every 20 samples processed through the CHN-2000 analyzer and the Lachat instrument, and samples were rerun if results were not within 5% to 10% of known values.



Figure 1. Rainfall simulator and test plot setup during interrill runoff sampling.

STATISTICAL ANALYSES

Statistical analyses were performed using SAS version 8.0 (SAS, 1999). Parametric tests (ANOVA using PROC GLM) were used to identify significant treatment-related differences in the mean concentrations and total masses of soluble and adsorbed pollutants. Since residual plots indicated that variance of the soluble and adsorbed mass data was not constant, these data were log-transformed, and the treatment-by-treatment comparisons were evaluated using contrast statements.

Varying proportions of the samples collected from each treatment contained soluble or adsorbed concentrations of certain pollutants that were below the detection limit. Treatment means were computed, and tests for significant differences were conducted as follows:

- If all treatment samples contained detectable concentrations of a certain pollutant, then log-transformed values were used to compare treatments. The back-transformed mean (i.e., the geometric mean) of the observations is used to summarize the data.
- If less than 25% of samples tested for a particular pollutant were below the detection limit, then these samples were assigned a value equal to 1/2 of the detection limit (as recommended by USEPA in Gibbons, 1994), and the log-transformed values were used to compare treatments. The back-transformed mean (i.e., the geometric mean) of the observations is used to summarize the data.
- If more than 25% of samples tested for a particular pollutant were below the detection limit, then a statistically reliable value of the population mean and standard deviation could not be calculated. In these cases, the maximum sample value is reported in the data tables. Although maximum values cannot be used to identify significant differences among treatments, maximum concentrations are representative of

worst-case conditions and are potentially valuable if regulatory ceiling limits have been published.

- If all samples tested for a particular pollutant were below the detection limit, then the representative value for the treatment is reported as “BDL.”

RESULTS AND DISCUSSION

COMPOST AND SOIL QUALITY

Metals

All soils and composts contained detectible amounts of one or more heavy metals (table 1). However, mean concentrations

Table 1. Metal and nutrient concentrations in compost, topsoil, and roadway embankment soil (control).^[a]

Element	Biosolids Mean (mg kg ⁻¹)	Yard Waste Mean (mg kg ⁻¹)	Bio-industrial Mean (mg kg ⁻¹)	Control Mean (mg kg ⁻¹)	Topsoil Mean (mg kg ⁻¹)
As	BDL ^[b]	4.62	1.97	4.82	3.82
Cd	1.63	BDL	BDL	BDL	BDL
Cr	61.7	9.12	16.0	9.78	8.25
Cu	194	21.3	69.5	6.95	8.73
Hg	2.37	1.61	BDL	BDL	BDL
Mo	7.49	0.88	1.63	BDL	BDL
Ni	18.7	9.90	14.7	11.9	8.64
Pb	70.4	26.1	59.1	19.7	13.7
Se	BDL	BDL	BDL	BDL	BDL
Zn	1,000	139	308	42.7	45.7
N	25,600	19,000	11,800	1,070	1,390
P	15,700	2,580	2,890	333	439
K	5,950	10,900	3,270	858	746

^[a] Two composite samples were collected from each material.

^[b] BDL = all samples analyzed were below the analytical detection limit.

were below current USEPA maximum concentrations (USEPA, 1999) for heavy metals in “high quality” biosolids, which are considered safe for bulk application to sensitive areas such as lawns or home gardens.

As shown in table 1, mean concentrations of Cd, Cr, Cu, Mo, Ni, Pb, and Zn were greater in the biosolids compost than in the other test materials. The lowest mean concentrations of most metals generally occurred in the topsoil, control soil, and yard waste compost. One notable exception was for arsenic concentrations, which were greater in the two soils and the yard waste compost.

Nutrients

Mean N, P, and K concentrations in the composts were greater than those in the two test soils. The highest mean N and P concentrations occurred in the biosolids compost, while the mean K concentration was highest in the yard waste compost.

RAIN WATER QUALITY

The quality of the water applied to the test plots through the rainfall simulator was tested periodically to determine its potential to affect runoff quality. Throughout the two-year study, 45 samples of the applied water were subjected to the same tests as the runoff samples.

Metals

Mean rainwater concentrations of all metals were at or below the detection level of 0.01 mg L⁻¹. Based on these results, metal concentrations in runoff from the test plots were assumed not to be significantly affected by metals in the applied rainfall.

Nutrients

The mean total P concentration in lake water applied to the test plots as simulated rainfall during the two-year study was 0.03 mg L⁻¹ (as P). This is quite low compared to the many lakes in Iowa having total P exceeding 0.10 mg L⁻¹. Mean potassium concentrations during the same period averaged about 0.9 mg L⁻¹ (as K). Mean soluble P and K concentrations in runoff from the control soil and topsoil were only 3 to 4 times greater than in the rainfall and so may have been affected slightly by the rainfall values. However, mean soluble P and K concentrations in runoff from the composts were at least 12 to 50 times greater than those in the rainfall and are not believed to have been significantly affected by the quality of the rainfall.

With the exception of one sample taken during the second summer of the study, NH₄-N concentrations in water applied to the runoff plots were below detection, as might be expected in water taken from a well aerated body of surface water.

Mean NO₃-N concentrations showed distinct differences between the two years of the study. In the first year, NO₃-N concentrations in all samples were below the detection limit of 0.2 mg L⁻¹. In the second year, however, NO₃-N concentrations in rainwater averaged 0.73 mg L⁻¹ with a maximum detection of 2.11 mg L⁻¹. Since more than 25% of the runoff samples tested during the two years of the project were below the detection limit for NO₃-N, a reliable mean value could not be calculated. Consequently, treatment-related differences in NO₃-N could not be tested statistically, making the yearly differences in mean concentrations of NO₃-N in the applied water irrelevant.

RUNOFF QUALITY

Discussion of runoff quality is limited to results for trials conducted on unvegetated test plots. The concentrations and total masses of soluble and adsorbed pollutants exported in runoff from vegetated plots were typically lower (Glanville et al., 2003), but the treatment-related rankings were essentially the same as for the unvegetated test plots.

Since statistical tests indicated no significant differences in runoff quality attributable to the depth of the compost applications, the treatment differences discussed below are based on aggregated data for the 5 and 10 cm compost applications.

Soluble Metal and Nutrient Concentrations

Soluble metal concentrations in runoff from unvegetated plots are summarized in table 2. Statistically reliable mean values and tests of significance could be calculated only for Zn, P, and K, as more than 25% of samples for one or more treatments contained concentrations of other nutrients or metals that were below the detection limit.

Soluble Zn and P concentrations in runoff from the biosolids and yard waste composts were significantly greater (6 to 12 times greater for Zn, and 9 to 24 times greater for P) than in runoff from the control and topsoil plots. Soluble K concentrations in runoff from all three composts were significantly greater (2 to 15 times) than in runoff from the two soils.

Adsorbed Metal and Nutrient Concentrations

Metal concentrations in the solids eroded from the tests plots are summarized in table 2. In all cases but one, the tabulated concentrations are below EPA Part 503 standards for “high quality” biosolids. The exception is the adsorbed concentration reported for mercury exported from the biosolids plots. This value is approximately twice the EPA standard, but due to a high proportion of sample results that were below the detection limit for mercury, it is a maximum value (rather than the mean) for the samples from the biosolids plots.

Sufficient numbers of sample values were above the detection limit to calculate and compare sample means for eight elements (Cr, Cu, Ni, Pb, Zn, N, P, and K). Statistically comparable means could not be computed for As, Cd, Hg, Mo, and Se because more than 25% of sample values for one or more treatments were below the detection limit.

Eroded materials from one or more of the compost-treated plots contained significantly ($p < 0.05$) greater concentrations of several elements than were found in solids eroded from the control and topsoil plots. Notable examples include: chromium concentrations from biosolids plots that were 3 times those in either of the two soils; copper from all three composts (1.5 to 11 times); zinc from all composts (3 to 6 times); phosphorus from all three composts (3 to 24 times); and potassium from the biosolids and yard waste composts (1.8 to 3.5 times).

Mean concentrations of three pollutants in eroded solids from two or more of the compost-treated plots were less than or equal to those in eroded products from either or both of the control or topsoil plots. These included: nickel concentrations, which were significantly ($p < 0.05$) greater (1.6 to 2.6 times) in sediments from the two soils; lead, which was statistically similar in sediments from the control, biosolids, and bio-industrial plots; and total nitrogen, which did not differ significantly among any of the treatments.

Table 2. Geometric mean^[a] or maximum^[b] concentrations of soluble and adsorbed elements in runoff from unvegetated plots.^[c]

Parameter	Soluble Concentration (mg L ⁻¹)					Adsorbed Concentrations (mg kg ⁻¹)				
	Biosolids	Yard Waste	Bio-industrial	Control	Topsoil	Biosolids	Yard Waste	Bio-industrial	Control	Topsoil
As	BDL ^[d]	BDL	BDL	BDL	BDL	[33.7]	BDL	[17.4]	5.74	4.00
Cd	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	[3.45]	BDL
Cr	[0.02]	BDL	BDL	BDL	BDL	67.5 c	24.9 b	21.4 a,b	21.6 a,b	18.9 a
Cu	0.03	0.03	0.03	[0.03]	[0.03]	184 e	36.0 c	75.3 d	24.0 b	16.6 a
Hg	BDL	BDL	BDL	BDL	BDL	[36.3]	[15.0]	BDL	[5.14]	[3.84]
Mo	[0.54]	[0.03]	BDL	BDL	BDL	[64.2]	[41.8]	[4.85]	BDL	BDL
Ni	[0.04]	BDL	BDL	BDL	BDL	15.8 b	8.61 a	10.7 a	22.4 c	16.7 b,c
Pb	BDL	BDL	BDL	BDL	BDL	44.6 c	16.9 a	43.7 c	42.6 c	23.7 b
Se	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zn	0.17 b	0.18 b	0.02 a	0.02 a	0.03 a	1,620 d	562 c	521 c	153 b	99.6 a
NO ₃ -N	1.08	[30.4]	[8.57]	[1.71]	[2.07]					
NH ₄ -N	5.91	[2.07]	[90.1]	[0.72]	[1.74]					
Total N						13,400 a	11,600 a	6,300 a	6,240 a	5,290 a
P	3.10 b	1.26 b	0.36 a	0.14 a	0.13 a	17,300 d	4,300 c	2,900 b	854 a	726 a
K	20.0 c	47.3 d	10.9 b	5.05 a	3.09 a	4,300 b	6,400 c	2,350 a	2,430 a	1,790 a

[a] If <25% of samples were below the detection limit, then the geometric mean was tabulated using half of the detection limit as the assigned value for those samples below the detection limit.

[b] If >25% of samples were below the analytical detection limit, then statistically reliable values of the mean and standard deviation could not be calculated. In these cases, the maximum value [indicated in brackets] is reported and can be compared with regulatory values.

[c] Means (for comparable data, i.e., soluble or adsorbed concentrations) followed by different letters within the same row are significantly different ($p < 0.05$). N = 12 for all parameters tested.

[d] BDL = all samples analyzed were below the analytical detection limit.

Among the three composts, eroded solids from areas treated with biosolids compost contained significantly ($p < 0.05$) greater concentrations of five (Cr, Cu, Ni, Zn, and P) of the eight pollutants for which reliable mean values could be calculated.

TOTAL MASS OF POLLUTANTS IN RUNOFF

Selection of Performance Indicator

In a departure from the experimental design (and from traditional soil erosion study procedures) in which runoff samples were collected periodically throughout the first hour of runoff, the total mass of each pollutant contained in the runoff was calculated based only on those samples collected during the first 30 min of rainfall.

The decision to compare treatments on the basis of samples collected during a fixed period of exposure to high-intensity rainfall (rather than during a fixed period of runoff) resulted from preliminary data analyses showing a significant disparity in the duration of rainfall needed to initiate and sustain runoff for 1 h. Conventional soil treatments typically began producing runoff within 5 to 7 min and, as a result, were subjected to less than 70 min of rainfall in order to produce runoff for 1 h. Test plots treated with the highly absorptive composts, however, required 25 to 60 min of rainfall to initiate runoff, and consequently were exposed to as much as 2 h of rainfall in order to permit 1 h of runoff sampling.

The decision to calculate and compare pollutant masses produced during a 30 min storm was based on rainfall intensity-duration-frequency maps for Iowa, which show that a 100 mm h⁻¹ storm lasting 30 min has a return period of approximately 25 years. This is the same return period as a 63 mm h⁻¹ storm lasting 60 min (test conditions typically used by USDA researchers when conducting soil erosion studies), and a storm of this magnitude, though fairly severe, can realistically be expected to occur naturally. By contrast, rainfall applications of 100 mm h⁻¹ for periods exceeding 1 h (the conditions necessary to sustain runoff on the compost-

treated areas for 1 h) are equivalent to rare natural storms having return periods well in excess of 100 years.

Soluble Metals and Nutrients

Due to the relatively high incidence of samples with concentrations below the detection limit, Zn, P, and K were the only soluble species for which reliable mean total mass values could be determined for all treatments. As shown in table 3, the mean total mass values of soluble Zn and K were significantly ($p < 0.05$) greater (>15 times and >18 times) in runoff from the conventional treatments. Total phosphorus in runoff from the conventional treatments was also significantly ($p < 0.05$) greater than in runoff from the yard waste and bio-industrial composts, and the mass of P in runoff from the biosolids was

Table 3. Mass of soluble and adsorbed pollutants in runoff during initial 30 min of rainfall on unvegetated test plots.^[a]

Parameter	Biosolids	Yard	Bio-	Control	Topsoil
	GM ^[b] (mg)	Waste GM (mg)	industrial GM (mg)	GM (mg)	GM (mg)
Soluble					
Zn	<0.01 a	<0.01 a	<0.01 a	0.15 b	0.16 b
P	0.17 b,c	<0.01 a	0.01 a,b	1.38 c	0.76 c
K	1.08 a	0.09 a	0.29 a	49.6 b	18.0 b
Adsorbed					
Cr	0.01 b	<0.01 a	<0.01 b	0.92 c	0.76 c
Cu	0.02 b	<0.01 a	0.01 b	1.03 c	0.66 c
Ni	<0.01 b	<0.01 a	<0.01 b	0.96 c	0.67 c
Pb	0.01 b	<0.01 a	<0.01 b	1.82 c	0.95 c
Zn	0.10 b	<0.01 a	0.03 b	6.55 c	3.99 c
N	0.47 b	<0.01 a	0.09 a,b	267 c	212 c
P	0.45 b	<0.01 a	0.09 a,b	36.5 c	29.1 c
K	0.17 b	<0.01 a	0.09 a,b	104 c	71.6 c

[a] Means followed by different letters within the same row are significantly different ($p < 0.05$). N = 12 for all parameters tested.

[b] GM = geometric mean.

statistically similar to that produced by the conventional treatments. The significantly greater total mass of soluble pollutants exported from the conventionally treated test plots is due mainly to the significantly ($p < 0.05$) greater (>120 times) runoff produced by the control and topsoil plots (table 4).

Among the three composts, there were no statistically significant differences in the mass of soluble Zn and K contained in runoff from any of the composts. Soluble P from the biosolids compost was significantly ($p < 0.05$) greater than for yard waste compost.

Adsorbed Metals and Nutrients

Statistically reliable means for adsorbed Cr, Cu, Ni, Pb, Zn, N, P, and K were calculated for all treatments. In every case, the mass of adsorbed pollutants exported in eroded sediment from the conventionally treated plots was significantly ($p < 0.05$) greater than from any of the compost treatments. For the various adsorbed metals, the masses exported from conventional soil treatments were at least 30 to 95 times greater than from the compost-treated plots. Nutrient ratios were even greater, with mean total masses of N and K from the conventional treatments at least 400 times those produced by any of the composts. Like the soluble total mass values, the significantly greater values for the conventional treatments are due mainly to a significantly ($p < 0.05$) greater (>5000 times) total mass of carrier (eroded sediment in this case) produced by the control soil and topsoil (table 4).

Among the composts, the biosolids compost produced significantly ($p < 0.05$) greater masses of all metals and nutrients than the yard waste compost. The bio-industrial compost produced intermediate masses of material that did not differ significantly from one or both of the other composts.

CONCLUSIONS

Chemical analysis of three types of composted organics, topsoil, and a compacted roadway embankment soil showed greater concentrations of Cd, Cr, Cu, Hg, Mo, Ni, Se, Zn, N, P, and K in the composts than in the soils. Composted biosolids had greater concentrations of most metals and nutrients than the other composts.

Soluble concentrations of P, K, and Zn were significantly ($p < 0.05$) greater in runoff from one or more of the composts than from the control and topsoil plots. Tests for nine other metals and two forms of nitrogen produced a sufficiently high proportion of samples below the detection limit (typically for several treatments) that statistically reliable means could not be calculated or compared.

Material eroded from the test plots contained quantifiable concentrations of five adsorbed metals and three adsorbed nutrients. In nearly all cases, the mean adsorbed concentra-

tions of nutrients and metals contained in erosion products from the composts were equal to or significantly greater than those in eroded materials flushed from the two soils. The highest adsorbed concentrations generally occurred in eroded solids from the biosolids compost.

Although pollutant concentrations were generally significantly greater in runoff from compost-treated areas, the total mass of most pollutants measured in runoff produced during the first 30 min of rainfall was significantly lower for plots blanketed with compost than for conventionally treated plots. The much greater total masses of pollutants contained in runoff from the control and topsoil plots was caused by significantly greater runoff and erosion from these materials than from any of the composts.

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Table 4. Total runoff and erosion during initial 30 min of rainfall on unvegetated test plots.^[a]

Parameter (units)	Biosolids GM ^[b]	Yard Waste GM	Bio- industrial GM	Control GM	Topsoil GM
Runoff (mm)	0.13 b	<0.01 a	0.08 a,b	26.2 c	15.5 c
Eroded solids (mg)	7.84 b	0.02 a	2.52 b	43,000 c	40,000 c

^[a] Means followed by the different letters within the same row are significantly different ($p < 0.05$). N = 12 for all parameters tested.

^[b] GM = geometric mean.

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