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Impacts of Compost Blankets on Erosion Control, Revegetation, and Water Quality at Highway Construction Sites in Iowa

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Abstract

This report summarizes the results of a three-year study sponsored by the Iowa Department of Natural Resources, and the Iowa Department of Transportation. The primary objectives of the study were to evaluate the effectiveness of using composted organics on highway construction sites to control storm water runoff and erosion, and to improve the growth of roadside vegetation.

Disciplines

Bioresource and Agricultural Engineering

FINAL REPORT

IMPACTS OF COMPOST BLANKETS ON EROSION CONTROL, REVEGETATION, AND WATER QUALITY AT HIGHWAY CONSTRUCTION SITES IN IOWA

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PREFACE

This report summarizes the results of a three-year study sponsored by the Iowa Department of Natural Resources, and the Iowa Department of Transportation. The primary objectives of the study were to evaluate the effectiveness of using composted organics on highway construction sites to control storm water runoff and erosion, and to improve the growth of roadside vegetation.

To help meet the information needs and interests of a variety of readers in the composting, solid waste, environmental, and road construction industries, the report is organized into two main sections.

- The executive summary summarizes the purpose and key results of the study.
- The main body of the report describes the motivation, methods, and all findings in greater detail.

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Disclaimer

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EXECUTIVE SUMMARY

INTRODUCTION

This project was a cooperative effort sponsored by the Iowa Department of Natural Resources (IDNR) and the Iowa Department of Transportation (Iowa DOT). Since passage of the Waste Reduction and Recycling Act in 1989, one of the main goals of Iowa's solid waste management program has been to reduce the quantity of organic wastes going into landfills. This has led to the emergence of a composting industry consisting of approximately 70 facilities throughout the State that process more than 320,000 metric tons (352,740 tons) of organics per year. To support and strengthen Iowa's organic waste recycling industry, the IDNR has established programs to evaluate potential uses and markets for composted organics.

The Iowa DOT, along with municipal and county road crews throughout Iowa, maintain an 180,000 km (112,000-mile) network of city, county, and state roadways that require constant repair and expansion. Because roadway construction temporarily disturbs large land areas, effective erosion and runoff control at road construction sites is essential. Faced with increasingly stringent federal storm water management regulations for construction sites, the Iowa DOT is particularly interested in evaluating new practices which may have potential to provide runoff control and erosion protection.

The research reported here was conducted by researchers in the Agricultural and Biosystems Engineering Department at Iowa State University to help answer questions posed by IDNR and Iowa DOT regarding potential use of composted organics to control erosion and runoff on highway construction sites in Iowa.

SIGNIFICANCE

According to a recent national study by Mitchell (1997) at least 19 state departments of transportation have adopted specifications that permit or encourage the use of composted organics on highway construction projects. Despite widespread interest in compost use, however, there appears to be relatively little research data to verify the effectiveness of applying compost to highway construction sites. Furthermore, much of the work that has been reported has focused on the agronomic value of compost as a soil amendment rather than on compost's potential to reduce runoff and soil erosion. This research project was designed to provide baseline data that will help to determine if and how compost can be utilized for storm water and erosion control on construction projects in Iowa.

PROJECT OBJECTIVE

The primary objective of this research project was to compare the performance of compost-treated and conventionally-treated roadway embankments. Performance parameters include runoff quantity, runoff quality, rill and interrill erosion, and seasonal growth of planted species and weeds.

PROJECT MATERIALS AND METHODS

Three types of compost were selected for testing by the project sponsors. They included a relatively fine-textured soil-like biosolids compost, a coarse-textured mulch-like yard waste compost, and a medium-textured bio-industrial compost derived from paper mill and grain processing sludge.

These particular composts were selected for testing because the project sponsors considered them to be generally characteristic of composts that are available in substantial quantities throughout much of Iowa.

Two conventional runoff and erosion control practices that have been used by the Iowa DOT in the past provided a benchmark for evaluating the performance of the composts. These include direct seeding of erosion control vegetation into compacted roadway embankment soil or, in instances where embankment soils do not support good vegetative growth, application of a 15-cm (6-inch) blanket of imported topsoil over the embankment soil prior to seeding.

The composts were spread on the highway embankment in 5-cm (2-inch) and 10-cm (4-inch) thick blankets. The topsoil treatment was applied as a 15-cm (6-inch) blanket in accordance with long-standing Iowa DOT specifications for this practice. Neither the composts nor the topsoil were incorporated into the underlying embankment soil.

Each of the six compost treatments (3 compost types X 2 depths) and two conventional treatments was subjected to high-intensity simulated rainfall under both un-vegetated and vegetated conditions to simulate circumstances that would occur during multi-season construction projects.

Since quantity and quality of runoff are closely related to rainfall intensity, it was essential that all composts and soils be tested at the same rainfall rate. To achieve this, test plots were subjected to high intensity simulated rainfall applied using an 8-meter long (26-feet) single-sweep Norton rainfall simulator of the type used by USDA for soil erosion research. High intensity rainfall was applied at an average rate of 95 mm/hr (3.7 in/hr) for a sufficient time to cause each test plot to produce runoff for at least one hour.

During the 1st hour of runoff from each test plot, timed runoff samples were collected at 5-minute intervals. These runoff samples, or in some cases composites of these samples (see full report for further detail), were frozen and subsequently tested to determine:

- runoff rates;
- rill- and interrill erosion rates;
- total rill- and interrill erosion;
- dissolved and absorbed nutrient and metal concentrations; and
- total mass of dissolved and absorbed nutrients and metals.

PERFORMANCE INDICES

Performance comparisons in the Executive Summary relating to the <u>total volume</u> of runoff, or <u>total mass</u> of individual pollutants contained in the runoff, are based on samples collected during the <u>1st 30 minutes of rainfall</u>. As explained in the full report, similar performance indices also were calculated based on samples collected during the <u>1st hour of runoff</u>. While sampling during a 1-hour runoff period is consistent with typical USDA erosion research procedures for <u>soils</u>, the duration of high-intensity rainfall needed to initiate and sustain runoff on the highly absorptive composts used in this study was much greater than for most soils, <u>and considerably longer than most naturally-occurring high-intensity storms</u> in Iowa. As a result, indices based on the 1st 30-minutes of rainfall are believed to more clearly reflect performance that is likely to occur during naturally occurring high-intensity rain storms. A more detailed discussion of performance indices is presented in the full report.

PROJECT RESULTS

VEGETATION

Since establishment of good vegetative cover is one of the most commonly used erosion control practices along highways, the ability of the test composts to grow a cover crop was measured and compared with conventional soil treatments. A cover crop consisting of oats, timothy, rye, and clover was planted and fertilized on the test plots according to Iowa DOT specifications.

Although the test composts generally had coarser textures and lower densities than soil, they produced as much of the planted cover crop species during two growing seasons as the topsoil or compacted subsoil. Equally important, areas treated with compost blankets exhibited significant suppression of weed growth. The total mass of weeds harvested from compost-treated areas at the end of two growing seasons was less than one-third of the weed growth on conventionally-treated areas.

RUNOFF QUANTITY

The volume of eroded soil and water leaving interrill test plots is a useful indicator of pollution potential. Construction sites that produce less runoff have a lower potential to discharge pollutants that are carried by the eroded soil and water.

Compost treatments demonstrated excellent capacity to control construction site runoff. During the first 30 minutes of high-intensity rainfall all un-vegetated test plots treated with compost produced less than 0.2 mm of runoff while conventionally-treated (control and topsoil) plots produced more than 15 mm of runoff.

The depth of compost applications significantly affected runoff quantities. Probably as a result of increased pore volume associated with greater compost depths, runoff from 5-cm (2-inch) applications was about 1.5 times the runoff from 10 cm applications (un-vegetated conditions). Presence or absence of vegetation did not result in significant differences in runoff.

INTERRILL EROSION

Interrill erosion is caused by raindrop impact and subsequent soil transport by a thin diffuse layer of runoff flowing over the soil surface. Sometimes called "sheet erosion," interrill erosion ultimately leads to formation of small channels or "rills" in the soil that cause concentrated water flow and accelerated soil loss through rill erosion.

Erosion results from un-vegetated tests plots showed dramatic differences between compost-treated and conventionally-treated areas. Since compost-treated test plots produced little (if any) runoff during the initial 30 minutes of rainfall, the total mass of eroded material carried by the runoff from composted plots was less than 0.02% of that in runoff from conventionally-treated areas.

Depth of application did not significantly affect interrill erosion rates. Plots treated with 5-cm of compost performed about the same as those receiving 10-cm applications.

Type of compost affected interrill erosion rates noticeably. Yard waste compost, the coarsest and most "mulch-like" of the three composts, averaged less than 1.0% of the interrill erosion produced by the more soil-like biosolids and bio-industrial composts.

It is interesting to note that, despite the additional interrill erosion protection provided by vegetation, un-vegetated compost treatments actually outperformed the vegetated conventional treatments during this study. Loss of interrill solids (30-minute storm) was less than 8-mg on un-vegetated compost treatments, while more than 7,000-mg of eroded solids were lost from the least eroded (control) vegetated conventional treatment.

RILL EROSION

Rill erosion is caused by concentration of runoff in small channels called "rills." Once rill erosion is initiated, increasing quantities of runoff can become concentrated in the rill channels, and considerable erosion damage can occur relatively quickly.

Rill runoff from conventional topsoil treatments contained solids concentrations that were 3.5 times higher than in rill runoff from compost treatments. There were no significant differences, however, in the solids concentrations measured in rill runoff from composts and compacted embankment soils (control). These results indicate that compost treatments are as vulnerable to rill erosion as compacted embankment conditions, but do represent some improvement over conventional topsoil treated applications.

Rill erosion results for the three composts were similar to the results of the interrill tests. Again, the coarsest compost (yard waste) performed the best, producing runoff with an average solids concentration that was less than half of the average concentrations in runoff from the other two composts.

Depth of compost application did not significantly affect rill erosion.

ERODIBILITY FACTORS

Soil erodibility factors characterize the inherent potential for soils and soil-like materials to erode under conditions that differ from the test conditions. Erodibility factors are valuable because they permit natural resource agencies, conservation engineers, and others to prediction erosion for various types of materials under a variety of slope, rainfall intensity, and runoff conditions.

Interrill erodibility factors were successfully developed for the composts and soils and, like the other measures of interrill erosion previously discussed, they confirm that compost treatments are considerably less susceptible to interrill erosion than topsoil or compacted subsoil. In general, interrill erodibility factors for the composts were less than 1/5th of those for compacted embankment soil or topsoil treatments.

Attempts to develop rill erodibility factors and critical shear values for the composts have not been as successful. Due in part to significant differences between the physical characteristics of compost and most soils, the mathematical relationships normally used to describe rill erosion in soil do not appear to adequately characterize the rill erosion mechanisms and rill data for composts. Additional work is under way to determine if rill erodibility factors can be calculated using modified erosion models.

WATER QUALITY

Since some types of compost contain elevated concentrations of heavy metals and/or nutrients, the chemical quality of runoff from compost-treated areas is of potential concern. Although the composts tested during this study contained higher concentrations of nutrients and selected heavy metals than the two soil treatments, none of these concentrations exceeded the maximum levels allowed by USEPA regulations for continuous land application of “high quality” biosolids.

Despite elevated concentrations of several metals and nutrients in two of the composts, runoff from compost-treated plots did not pose an increased environmental risk. In fact, with the exception of soluble phosphorus, the total mass of individual nutrients and metals detected in runoff from compost-treated plots during a 30-minute storm were significantly lower than in runoff from conventionally-treated test plots. The low total mass of both soluble and adsorbed pollutants in compost runoff was primarily the result of significantly lower interrill erosion and runoff from compost-treated areas.

CONCLUSIONS AND RECOMMENDATIONS

Despite their differing origins, physical characteristics, and nutrient and metal content, blanket applications of all three of the composts that were tested produced excellent runoff and erosion control. As such, blanket applications of compost appears to be a potentially effective storm water and erosion management tool that can be used by engineers and planners who are responsible for storm water, erosion, and water pollution control on construction sites where large amounts of soil are temporarily disturbed.

Recognizing the added project costs of transporting and applying composts, their use is most easily justified in difficult construction situations that demand both immediate erosion and runoff control AND ability to support growth of vegetative cover. Examples include: projects that are completed too late in the growing season to establish vegetation prior to winter; projects where extremely wet or dry weather delays establishment of vegetation; areas with poor quality soils that do not support vigorous vegetative growth; or locations that are too steep or wet to reach with heavy equipment, but that can be blanketed with compost using a compost blower truck.

While the coarse yard waste compost was as resistant to rill erosion as compacted subsoil, the biosolids and bio-industrial composts showed more vulnerability to rilling. Care should be exercised when using similarly textured composts to insure that they are not placed in locations that receive concentrated flows (point discharges) of runoff. If compost blankets are placed adjacent to drainage ways or on highway foreslopes that receive concentrated runoff from traffic lanes, they should be protected with compost berms, silt fences, hay bales, or similar measures that diffuse or divert the runoff before it reaches the blanket.

On roadway embankments with standard 3 to 1 slopes, there appears to be little reason to incur the extra costs of disking or roto-tilling compost applications into the underlying soil. Prior to the first summer of rainfall simulation testing, project researchers and Iowa DOT cooperators were concerned that blanket applications of compost on 3 to 1 slopes might not remain in place when exposed to intense rainfall. Subsequent observations while applying simulated rainfall at average intensities of nearly 100 mm/hr (4 inches/hour) for periods of an hour or longer showed that the compost blankets were stable as long as they were not exposed to concentrated flow. Furthermore, the weed barrier effect of compost blankets would be substantially reduced by tilling or disking since viable weed seeds in the underlying soil would be brought to the surface where they could compete more vigorously with the desired cover crop.

In general, 5-cm (2-inch) blanket applications performed as well as 10-cm (4-inch) depths. The deeper application produced slightly less runoff, but most of the erosion, water quality, and vegetation benefits were obtained with the 5-cm (2-inch) treatments. The ability of the composts to provide these benefits with only 5-cm (2-inches) of material also provides a potential transportation cost advantage over the 15-cm (6-inch) topsoil treatments that are often used in Iowa.

Although yard waste compost performed better than the other composts in several respects, Iowa DOT representatives expressed dissatisfaction with the undesirable aesthetic aspects of the yard waste compost used in this project. Plastic bags, twine, and other visually undesirable components were the main concerns of the highway planners. In fairness to the supplier of the yard waste compost, it should be noted that this supplier can (and does) produce a screened yard waste compost of higher quality than that used in this research. The ISU researchers purposely chose to use an unscreened compost since many small composting facilities around Iowa do not have screening equipment, and the unscreened material was thought to be more representative of yard waste composts available from these smaller (but more numerous) composting operations.

Although this project was not designed to compare the economics of compost treatments with conventional site preparations, the weed suppression effect of compost blankets may provide cost benefits in situations where weed control is essential and environmental concerns dictate use of minimal herbicide applications.

PROJECT WEBSITE

Additional information and photographs for this project are available at:

http://www.abe.iastate.edu/compost/

INTRODUCTION

Responding to public concerns expressed in 1989 regarding the groundwater pollution potential and rapidly diminishing capacity of the State's landfills, the Iowa legislature mandated a 50% reduction (by year 2000) in the amount of solid waste buried in landfills, and banned land filling of all yard and garden wastes. The new solid waste policy stimulated rapid growth in the organics composting industry in Iowa during the 1990's. Today, nearly 70 composting facilities divert and process 320,000 metric tons (352,740 tons) of yard waste, biosolids, and industrial organics from Iowa landfills annually. While successfully reducing pressure on landfills, the rapid increase in composting operations also has created a need for new markets that can utilize large amounts of composted materials.

New road construction and roadway maintenance projects in Iowa offer a potentially large market for composted organics. Iowa's 180,000 km (112,000 mile) network of city, county, and state roadways require constant repair and expansion, and roadway construction projects also demand significant attention to erosion and runoff control. Rapid establishment of cover crops is one of the most widely used methods of control. During fiscal year 2000 alone, the Iowa Department of Transportation (Iowa DOT) let bids to seed and fertilize more than 1,052 hectares (2,600 acres) of land adjacent to 243 km (151 miles) of state-sponsored road construction projects. Since many city and county road projects do not utilize the Iowa DOT bidding process, statewide demand for roadside seeding and fertilization is even larger than suggested by Iowa DOT project statistics.

Storm water runoff and erosion control are top priorities following completion of new roadway construction projects. The compacted subsoils used in new roadway embankments, however, often lack the infiltration capacity, erosion resistance, and organic matter content needed to absorb runoff, reduce erosion, and encourage vigorous growth of cover crops. Although it is generally acknowledged that application of composted organics to erosion-prone slopes has potential to improve reduce erosion and improve growth of vegetation, few studies have been conducted to quantify these benefits. Even fewer studies have attempted to quantify the effects of compost use on the chemical quality of storm runoff. To support Iowa's solid waste management goals and simultaneously determine if compost applications are sufficiently beneficial to justify their cost in road construction projects, the Iowa Department of Natural Resources (IDNR) and Iowa Department of Transportation funded a two-year study by researchers at Iowa State University.

To investigate the potential impacts of compost on roadside erosion control and water quality, Iowa State University (ISU) researchers and representatives of the IDNR and the Iowa DOT established the following project objectives:

1. Measure and compare the quantity and quality of roadside vegetation (planted species and weed growth) grown on conventionally treated roadway foreslopes with vegetation produced on foreslopes blanketed with 5cm and 10 cm depths (2-in and 4-in) of three types of composted organics produced in Iowa,

2. Measure and compare runoff quantity and quality, and soil erosion occurring on conventionally-treated roadway foreslopes with that occurring on foreslopes treated with composted organics, and

3. Use field measurements of soil erosion to calculate soil erodibility factors that can be used with the USDA Water Erosion Prediction Program to model and predict the effects of compost.

MATERIALS AND METHODS

COMPOST SELECTION

Different feed stocks, processing technologies, and product screening techniques can produce composted organics with diverse physical, chemical, and plant growth characteristics. To obtain study results representative of the broad range compost products available throughout Iowa, the IDNR specified that the research be conducted using three types of compost that are readily available throughout the state. Composts selected were derived from: sewage biosolids and yard waste processed by the city of Davenport, IA; yard waste processed by the Metro Waste Authority of Des Moines, IA; and a mixture of source-separated bio-industrial byproducts (paper mill- and grain-processing sludges) and yard waste composted by the Bluestem Solid Waste Agency in Cedar Rapids, IA.

WATER SOURCE

Water used in the simulated rainfall studies was obtained from a 4 hectare (10-acre) lake at the Iowa State University Horticulture Farm located approximately 8 km (5 miles) from the research site. Water was hauled to the research site in a 4,500 liter (1,200 gallon) tank wagon and temporarily stored in two 9,500 L (2,510 gallon) polyethylene storage tanks. The watershed feeding the lake is used mainly for corn and soybean production.

EXPERIMENTAL DESIGN

Research was carried out using the split plot design illustrated in Appendix A. A split plot design permits testing of experimental treatments involving combinations of two or more factors. The main factors in this study include type and depth of application of the test media, and the vegetated condition of the test plots. Experimental treatments included: three different composts applied to new highway embankments as 5- and 10-cm (2- and 4-inch) blankets; and two conventional highway embankment treatments, consisting of compacted roadway embankment soil (control), and roadway embankment soil capped with 15-cm (6 inches) of imported topsoil. All treatments were tested under bare (un-vegetated) conditions to simulate runoff and erosion on a construction site immediately after completion of construction, and 6 weeks after seeding to simulate performance after erosion control vegetation is established. Each of the six compost treatments (3 composts X 2 depths) was tested 6 times under both vegetated and un-vegetated conditions. To permit side-by-side comparison of compost and conventional treatments, control and topsoil test plots were included in each of the 12 (2 compost depths X 6 replications) compost test blocks.

Table 1. Treatment names and descriptions.

Treatment	Material Description & Source	Reps[1]
Biosolids 5-cm	Biosolids compost, 5-cm depth, Davenport Composting Facility	6
Biosolids 10-cm	Biosolids compost, 10-cm depth, Davenport Composting Facility	6
Yard Waste 5-cm	Yard waste compost 5-cm depth, Des Moines Metro Waste Authority	6
Yard Waste 10-cm	Yard waste compost 10-cm depth, Des Moines Metro Waste Authority	6
Bio-industrial 5-cm	Mixed waste compost, 5-cm depth, Bluestem Solid Waste Agency	6
Bio-industrial 10-cm	Mixed waste compost, 10-cm depth, Bluestem Solid Waste Agency	6
Control	Compacted roadway embankment soil	6 (12)[2]
Topsoil 15-cm	Topsoil, 15-cm depth, from local vicinity of research site	6 (12)

[1]Number of replicated tests (reps) under both un-vegetated and vegetated conditions.
[2]Soil treatments had 6 replications (reps) for rill erosion and vegetative growth tests, and 12 replications for interrill erosion tests (see experimental design diagram in Appendix A).

SITE CONSTRUCTION

Interrill and rill plots were constructed on the two south facing embankments at a highway overpass near Ames, Iowa. Experimental units for interrill runoff and erosion tests consisted of areas measuring 1.2 m by 1.2 m (4 ft by 4 ft) that were blanketed with compost or topsoil, or similarly sized plots of untreated highway embankment soil (control). Rill test areas consisted of narrow rectangles measuring 0.9-m by 7.9-m (3-ft by 26-ft) with their long dimension running up and down the slope. All test areas were cultipacked twice, and vegetated plots were fertilized with 500 kg ha^{-1} (446 lb $acre^{-1}$) of 13-13-13 and seeded according to Iowa Department of Transportation specifications. The seed mixture included oats, annual ryegrass, red clover and timothy at rates of 108, 39, 6 and 6 kg ha^{-1} (96, 35, 5, and 5 lb $acre^{-1}$) respectively. Test areas were hand raked to remove the shallow impressions caused by cultipacking, and three-sided galvanized metal borders were driven into the centers of the test areas to delineate uniformly-sized rectangular test plots from which samples of interrill and rill runoff could be collected. Interrill test plots measured 0.50-m by 0.75-m (1.6 - by 2.5-ft), and rill test plots were 0.20-m by 5.0-m (0.67- by 16-ft). Galvanized V-shaped collector troughs were installed at the downhill edge of each test plot to facilitate runoff collection.

RAINFALL SIMULATION

To insure that all test plot were exposed to comparable rainfall conditions (intensity, uniformity of application, and raindrop size) rainfall was applied using an 8-m (26 ft) long single-sweep Norton rainfall simulator of the type developed and used for soil erosion studies by the USDA National Soil Erosion Research Laboratory. Rainfall application and runoff sampling methods were similar to those used by USDA researchers during field erosion studies conducted as part of the Water Erosion Prediction Project (WEPP) as described in detail by Liebenow et al. (1990) and King et al. (1995). One important difference between the USDA procedures and those used in this particular study is that the standard rainfall intensity of 63 mm/hr (2.5 inches/hr) used on soil had to be increased to 80 –110 mm/hr (3.1 – 4.3 inches/hr) to initiate runoff from the highly absorbent compost-treated plots within 30-60 minutes. Rain gages positioned at the top of each experimental plot were used to measure the total amount of rainfall applied.

SAMPLING & DETERMINATION OF RUNOFF & EROSION

Data collection procedures for interrill erosion were adopted from those described by Liebenow et al. (1990) and were performed on bare plots immediately after construction, and on vegetated plots 6 weeks after seeding. Once runoff began on a test plot, samples were collected at five-minute intervals for a total of one hour.

Runoff rates were calculated using the weight and collection time of each runoff sample. These were subsequently converted into runoff depth per unit time by assuming a runoff density of 1000 kg/m^3 (62 lb/ft^3) and using the plot area of 0.375-m^2 (4 ft^2).

Total erosion, and steady state erosion rates, from each test plot were determined by analyzing runoff samples for total suspended solids. This was accomplished by: extracting thoroughly mixed triplicate sub samples from each runoff sample; centrifuging the sub samples to settle all solids; extracting a portion of supernatant for <u>dissolved</u> solids analysis; drying the sub samples at 104^oC (219^oF); and weighing the dry solids to determine <u>total</u> solids. The mass of <u>suspended</u> solids (erosion products) was determined by subtracting the mass of dissolved solids from the total solids values. This value of total suspended solids was used in all calculations of interrill detachment rates.

A preliminary review of the data showed that both runoff and erosion <u>rates</u> were quite variable during the initial 30-40 minutes of runoff, but that these values generally stabilized during the last 20 minutes of the 1-hour sampling period. Based on this observation, steady state runoff and interrill erosion rates were estimated by averaging the values from the final four samples during each of the 1-hour runoff sampling periods.

Rill erosion data were collected using techniques adapted from those described in King et al. (1995). First, rainfall was applied to the test areas until interrill erosion was initiated. Brief periods of inflow were then directed onto the top of each rill test plot to simulate natural rilling that is typically caused by concentrated runoff from adjacent land areas. Five or six different inflow rates were applied to each test plot for brief periods of time to permit collection of representative rill erosion samples caused by a typical range of rill flow velocities. The rill flow velocity associated with each flow rate was determined by measuring the time necessary for fluorescent dye to traverse 1.2- or 2.4-m (4- or 8-ft) of rill length.

During application of each distinct inflow rate, two timed runoff samples (30 sec or less) were collected and weighed to determine the discharge rate of the rill. Two 1-L rill erosion samples also were collected for determination of the mass of solids detached by rill erosion processes at each flow rate. Suspended solids concentrations in these samples were determined using laboratory procedures similar to those used on the interrill erosion samples. Care was taken to insure that all inflow tests conducted on compost or topsoil blankets were completed before rill erosion cut into the underlying soil material. Rill erosion detachment rates were calculated using procedures described by King et al. (1995).

COVER CROP SAMPLING & QUANTIFICATION

After six weeks of growth, above ground vegetation was harvested from randomly selected sampling areas located within each test area. In year-one, sample areas were randomly selected by tossing a metal ring (0.07-m^2 area) into the test area. Due to the relatively small size of the sampling ring and spatial variability of vegetative growth, there was some potential for bias in the sampling procedure. This bias was reduced in year-two by increasing the size of the sampling area to a 0.50-m by 0.75-m (20- by 40-inches) rectangle. Harvested biomass samples were dried at 90˚C (194˚F), separated into sub-samples consisting of planted species and weed species, and weighed.

SAMPLING & MEASUREMENT OF SOIL & COMPOST QUALITY

For each of the composts, the topsoil, and the compacted embankment soil (control) a composite sample derived from five sub-samples was collected prior to plot construction each year. The samples were packaged in Ziploc bags, and stored at -4^{o}C (24.8˚F) prior to drying, grinding, digestion, and analysis.

Bulk density and moisture content of all composts and soils used in the study were measured as described in Milford (1991) and in the Test Methods for the Examination of Composting and Compost (TMECC) (USCC, 1997). The Iowa State University (ISU) Agronomy Textural Laboratory conducted textural class identification of the two soils using standard procedures, and aggregate size analysis of the composts was conducted following procedures outlined in the TMECC. Compost carbon-to-nitrogen ratios (C:N) were determined by analysis of carbon and nitrogen on a CHN-2000 Analyzer.

Nutrient and heavy metal concentrations were determined using the sample preparation and analytical methods described in the *Chemical Analysis* section of this report.

CHEMICAL ANALYSIS OF SOIL, COMPOST, & RUNOFF QUALITY

Soil and compost samples were thawed, sub sampled, and air dried to constant weight. They were then ground with a mortar and pestle and digested in triplicate according to EPA Method 3051, a strong nitric acid (HNO_3) microwave digestion procedure designed to release acid labile forms of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se), zinc (Zn), phosphorus (P), and potassium (K). After digestion, samples were diluted with 5 mL of deionized water and analyzed using an Inductively Coupled Argon Plasma (ICP) instrument with a charged injection device manufactured by Thermo Jarrell-Ash. Concentrations were corrected for moisture content by drying additional samples in the oven at 104^{o}C (219˚F) until constant weight was achieved and determining the moisture content. Total nitrogen was evaluated in triplicate using a CHN-2000 analyzer manufactured by LECO Corporation.

Eroded sediment was separated from runoff samples by passing them through a 0.45-μm filter. Filters and their associated sediment were digested together and analyzed for adsorbed metals and nutrients using the same methods and equipment described for the composts and soils.

The portions of the runoff samples that passed through the 0.45-μm filter were diluted with 1 mL of aqua regia (HNO_3 and HCl acid solution) and analyzed for soluble metals, P, and K using ICP. Nitrate and ammonium nitrogen in solution were determined colorimetrically using a Lachat Instrument. Samples from two of the biosolids compost plots were discolored and were filtered through activated carbon and reanalyzed to reduce analytical interference.

Laboratory quality control and assurance procedures included acid washing of laboratory vessels and equipment prior to use. Acids used in 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 during digestion. Standards and laboratory blanks were evaluated after every 10 samples processed via ICP, and samples were rerun if metals concentrations were not within 5 percent of NIST-certified values. Standards were evaluated after every 20 samples processed through the CHN-2000 analyzer and the Lachat instrument. Samples were rerun if results were not within 10 percent of known values.

Differences in laboratory detection limits for soil/compost, eroded sediment, and liquid samples analyzed via ICP were caused primarily by differences in their physical characteristics. The base detection limit for liquid samples processed through ICP is 0.010 mg/L, but for solid samples (soil/compost materials) which require digestion prior to analysis, the detection limit was increased to 1.200 mg/kg by dilution during digestion, and by further dilution to match the pH of samples to that of standard matrices. Similarly, the detection limit for the liquid fraction of runoff samples was increased to 0.012 mg/L due to dilutions needed to match pH of samples and standard matrices. The detection limit for sediment samples also varied because the filtered samples were not ground prior to testing (to avoid sample contamination). This caused variable sample masses and subsequent differences in dilution during sample digestion.

RUNOFF, EROSION, & WATER QUALITY PERFORMANCE INDICES

Several performance indices were used to help identify differences in the quantity and quality of erosion and runoff produced by areas treated with compost and those that received conventional soil treatments. Key performance indices (under both un-vegetated and vegetated test conditions) included:

Runoff Quantity

- steady state runoff rate,
- time to initiate runoff;
- total volume of runoff produced during the 1st hour of runoff;
- total volume of runoff produced during a 30-minutes storm;

Runoff Quality

- soluble nutrient and metal concentration,
- adsorbed nutrient and metal concentrations (attached to eroded soil in runoff),
- total mass of soluble nutrients and heavy metals in 1st hour of runoff,
- total mass of soluble nutrients and heavy metals in runoff produced by 30-minute of rainfall,
- total mass of adsorbed nutrients and heavy metals in 1st hour of runoff,
- total mass of adsorbed nutrients and heavy metals in runoff produced by 30-minute of rainfall;

Interrill Erosion

- interrill erosion rate,
- interrill erodibility factor,
- total mass of interrill erosion in 1st hour of runoff;
- total mass of interrill erosion produced by 30-minute of rainfall; and

Rill Erosion

- concentration of eroded solids in rill runoff.

Readers will note that performance indices for the total volume of runoff and total mass of individual pollutants (eroded solids, nutrients, heavy metals) are based on samples collected during two different time periods (1st hour of runoff, and 1st 30-minutes of rainfall).

Runoff and erosion sampling during the first hour of runoff is typically used by USDA to quantify the erodibility of different soil types. This procedure requires application of sufficient high-intensity rainfall to initiate and sustain runoff for one hour.

Following initial analysis of the "1st hour" field data collected during this study, it became obvious that the soil and topsoil treatments responded much more quickly to high intensity rainfall than areas treated with compost. While conventional soil treatments began producing runoff within 5 to 7 minutes after rainfall was first applied, test plots treated with the much more absorptive composts often took 25 to 30 minutes (or longer) to produce runoff.

Because of their ability to delay runoff, compost-treated plots had to be exposed to much longer periods (abnormally long when compared to naturally occurring storms) of high intensity rainfall than conventionally-treated areas in order to initiate and sustain runoff for a one hour sampling period. As a result, total mass and total volume performance comparisons based on 1st hour data tend to reflect differences caused by unequal exposure to rainfall energy as well as those attributable to differing physical and chemical characteristics. While such comparisons are not necessarily incorrect, they do tend to obscure the potentially beneficial runoff retention capacity of the compost treated areas.

To compare compost- and conventionally-treated areas under equal exposure to rainfall energy, a new performance index was calculated based on runoff and erosion samples collected during the 1^{st} 30 minutes of rainfall. Comparisons based in these "30-minute" indices are believed to more accurately reflect performance that is likely to occur during naturally occurring high-intensity storms of normal duration. Selection of a 30-minute duration storm is substantiated by National Oceanic & Atmospheric Administration (NOAA) 15-minute rainfall data for Ames, Iowa for the period from 1984 through 2002. During this period, more than 8,200 15-minute intervals were recorded in which rainfall intensity averaged more than 1 mm/hr (0.04 inches/hour). Only 0.12% of these intervals, however, exhibited average rainfall intensities equal to or greater than the nearly 100 mm/hr (4-inches/hr) applications used during this study.

STATISTICAL ANALYSES

Statistical analyses were performed using SAS version 8.0 (SAS, 1999). Analysis of variance (ANOVA) using PROC GLM was used to identify significant differences in runoff, erosion, vegetation, and water quality produced by the various treatments. Additional researchable questions were answered using contrast statements and pair wise techniques.

The metal and nutrient concentrations in the composts and soils were compared using non-parametric statistical analysis. The project statistical consultant recommended use of non-parametric techniques for these data because they are not normally distributed, and their variance is not constant.

Nutrient and heavy metal analyses of runoff and erosion samples showed that varying proportions of the samples analyzed for certain pollutants contained concentrations that were below the detection limit of the analytical instrument or procedure. Based on the recommendations of the project statistical consultant, samples for which analytical results were below the detection limit were handled as follows:

1. If all samples tested for a particular pollutant had detectible concentrations, the geometric mean of the detectible values was calculated and used to determine statistical significance among the treatments.
2. If less than 25% of the samples tested for a particular pollutant were below the detection limit, the non-detects were assigned a value equal to ½ of the detection limit (a typical statistical approach that recognizes that non-detects do not necessarily mean that zero pollutant was present). The geometric mean of all the detectible and assigned values was calculated and used to determine statistical significance among the treatments.
3. If more than 25% of the samples tested for a particular pollutant were below the detection limit, a statistically reliable value of the population mean and standard deviation could not be calculated. In these cases, the maximum value is reported. Although the maximum values cannot be used to determine if statistically significant differences exist among treatments, maximum pollutant concentrations can be compared to regulatory values such as those given in table 14.
4. If all samples tested for a particular pollutant were below the detection limit (BDL), the treatment was assigned a designation of BDL.

In some cases, statistical analyses of data in this report are based on the geometric mean, rather than the more common arithmetic mean. Use of the geometric mean is a common statistical technique that is used when data sets contain a small number of extreme values that can seriously bias the arithmetic mean, or when data sets are non-normally distributed or exhibit non-constant variance.

All statistically significant differences among treatments identified in this study were declared at a probability of 0.05 or less (i.e. there is less than a 5% chance that the treatment means are not truly different).

RESULTS AND DISCUSSION

Performance comparisons in this section that involve total volume of runoff, or total mass of individual pollutants contained in the runoff, are based on samples collected during the 1st 30 minutes of rainfall. As noted in the earlier discussion of performance indices, the 30-minute rainfall data are believed to more clearly reflect the performance that is likely to occur during high-intensity rain storms of normal duration. In the interests of complete reporting of all results, performance indices based on the 1st hour of runoff are tabulated and compared in Appendix B. Although the "30-minute rainfall" and "1st hour runoff" data differ on some minor points, both indices substantiate the same major trends and conclusions.

COMPOST AND SOIL PHYSICAL CHARACTERISTICS

As shown in tables 2 and 3, bulk densities for the three composts were less than half of those for the two soils. Among the composts, the bio-industrial compost was the densest, the yard waste compost had the lowest density, and values for these two materials were consistent from year 1 to year 2. Bulk density for the biosolids compost showed more variability. It was denser than the yard waste compost in year 1, but an increase in the wood chip content in year 2 reduced its bulk density below that of the yard waste compost. This density change was also reflected in the particle size distribution for the biosolids compost (Table 2) which shows a decrease of 22 percentage points in year 2 for the sample fraction containing particle sizes smaller than 6.35 mm.

Table 2. Physical and chemical characteristics of composts.

Year	Compost Type	Moisture Content (%)	C:N Ratio	Bulk Density (kg/m^3)	Size Aggregate (%<22.2 mm)	Size Aggregate (%<11 mm)	Size Aggregate (%<6.35 mm)
1	Biosolids	29	11	514	100	100	96
2	Biosolids	27	11	387	100	97	74
1	Yard waste	39	13	411	94	88	86
2	Yard waste	32	13	414	94	85	85
1	Bio-industrial	29	17	557	100	99	94
2	Bio-industrial	28	19	635	100	100	95

Table 3. Physical and chemical characteristics of soils.

Year	Media	Moisture Content (%)	%C	Bulk Density (kg/m^3)	% Sand (0.05-2.00 mm)	% Silt (0.002-0.05 mm)	% Clay (<0.002 mm)
1	Control	5	3.38	1,326	58.1	28.0	13.9
2	Control	6	1.03	1,301	72.5	16.7	10.8
1	Topsoil	10	2.50	1,302	61.5	23.9	14.6
2	Topsoil	6	1.47	1,657	71.8	17.2	11.0

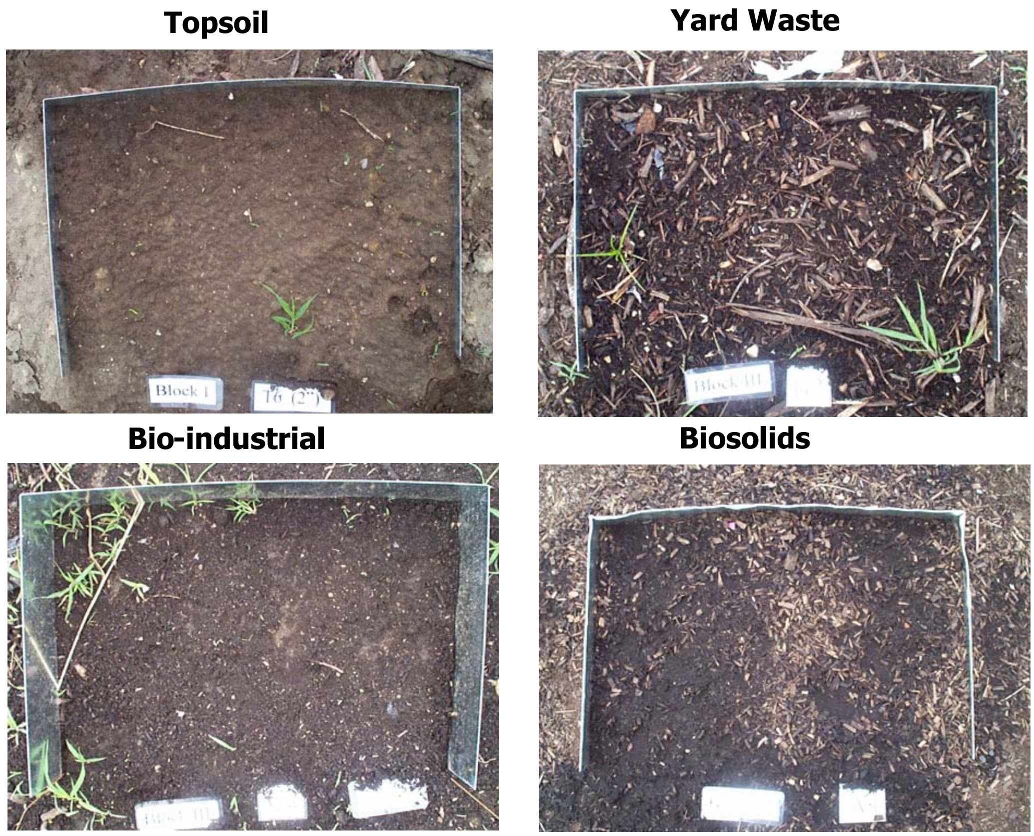

Figure 1. Visual appearance of topsoil and three compost types used in the project.

PERFORMANCE STATISTICS

The remaining portions of this section address key questions regarding the field performance of compost-treated and conventionally treated highway embankments. In most cases, these questions are answered by comparing the mean value of performance indices for each treatment. A variety of statistical tests were used to identify situations in which mean values differ sufficiently to be declared "significantly different." The presence or absence of statistically significant differences is indicated in by superscript letters shown in the summary data tables. Mean values that differ significantly are assigned different letters, while means with the same letter are considered to be statistically equivalent.

Since values that are statistically "significantly different" do not always differ greatly in a practical sense, the ratio of values that have been declared to be significantly different is also reported in the narrative to give readers a general indication of the magnitude of these differences without having to constantly consult the tabulated values.

VEGETATION

> ***Major Findings***
>
> *Test areas blanketed with any of the three composts produced amounts of planted cover crop that were statistically equivalent to cover vegetation grown on the topsoil or control plots.*
>
> *Compost depth did not significantly affect cover crop growth.*
>
> *Compost-treated areas produced less than 1/3 of the weed growth produced on control or topsoil-treated areas.*

Key performance questions and statistically significant differences (unless otherwise noted) regarding vegetation are as follows.

PLANTED GROWTH

1. How does the planted cover crop growth compare between compost and soil treatments?

- Planted cover crop growth was statistically equivalent among all treatments (table 4).

2. Is the depth of compost application a significant factor affecting cover crop growth of the planted species?

- Compost depth was not a significant factor.

WEED GROWTH

3. How does the weed growth compare between compost and soil treatments?

- All compost types had significantly less weed growth (36% or less of weed growth from topsoil or control plots, table 5).

4. Is the depth of compost application a significant factor affecting weed growth?

- Compost depth was not a significant factor.

TOTAL (PLANTED + WEED) GROWTH

5. How does the total (planted + weed) cover crop growth compare between compost and soil treatments?

- There were no significant differences in total cover crop growth between the subsoil, topsoil, and bio-industrial compost treatments (table 6).

- Biosolids and yard waste composts had significantly less total cover crop growth than the control (58% or less of total cover crop growth from control plots). This higher quantity of total vegetative growth may indicate that soil treatments would provide superior erosion protection on vegetated plots; however, results in the next two sections (runoff and erosion) indicate that composts are still better erosion control materials.

6. Is the depth of compost application a significant factor affecting total cover crop growth?

- Compost depth was not a significant factor.

Table 4. Above ground dry mass of planted species (combined depths, both years).

Treatment	N	Mean Mass of Planted Species (g/m^2)	Standard Deviation
Biosolids	12	229.61[a]	266.89
Yard Waste	12	338.90[a]	372.46
Bio-industrial	12	366.44[a]	411.01
Control	6	353.97[a]	409.23
Topsoil	6	293.66[a]	258.47

Means with different letter designations are significantly different ($p<0.05$).

Table 5. Above ground dry mass of weeds (combined depths, both years).

Treatment	N	Mean Weed Mass (g/m^2)	Standard Deviation
Biosolids	12	33.90[a]	79.30
Yard Waste	12	74.62[a]	117.46
Bio-industrial	12	93.70[a]	178.33
Control	6	353.14[b]	307.87
Topsoil	6	260.45[b]	287.02

Means with different letter designations are significantly different ($p<0.05$).

Table 6. Above ground total (planted + weed) dry biomass (combined depths, both years).

Treatment	N	Mean Total Mass (g/m^2)	Standard Deviation
Biosolids	12	263.51[a]	293.72
Yard Waste	12	413.52[a,b]	360.69
Bio-industrial	12	460.14[b,c]	360.01
Control	6	707.10[c]	646.02
Topsoil	6	554.11[b,c]	372.96

Means with different letter designations are significantly different ($p<0.05$).

INTERRILL RUNOFF

Major Findings

Compost-treated areas subjected to high intensity rainfall took significantly longer time to produce runoff than conventionally-treated areas.

Under both un-vegetated and vegetated conditions, compost-treated areas produced significantly less total interrill runoff than conventionally treated areas.

Total interrill runoff from areas treated with yard waste compost was significantly lower than for areas treated with biosolids compost (but not significantly lower than total runoff from areas treated with bio-industrial compost).

Depth of compost applications significantly affected the steady state interrill runoff rate on un-vegetated treatments, but not on vegetated treatments.

Key performance questions and statistically significant differences (unless otherwise noted) regarding interrill runoff are as follows.

1. Does runoff from compost-treated test plots differ significantly from runoff produced by untreated areas (control) or those treated with topsoil?

UN-VEGETATED CONDITIONS

Runoff Rate

- Steady-state runoff rates from compost-treated test plots were significantly lower than those observed on control plots (21 to 60 % of runoff rates on control plots, table 7).

- Steady state runoff rates from test plots blanketed with biosolids compost did not differ significantly from those treated with topsoil, but runoff rates from yard waste and bio-industrial composts were significantly lower (29 to 58% of that for topsoil, table 7).

Time to Initiate Runoff

- The duration of rainfall necessary to initiate runoff on compost plots was 4 –12 X longer than for control and topsoil plots (table 8).

Total Runoff – 30-minute Rainfall

- Total runoff from compost-treated plots was significantly lower (0.5 % or less of runoff from topsoil or control plots, table 9).

VEGETATED CONDITIONS

Runoff Rate

- All compost types produced significantly lower runoff rates (6 to 36% of those for topsoil or compacted subsoil, table 7).

Time to Initiate Runoff

- The time to initiate runoff on compost plots was 5-15 X longer than for control and topsoil plots (table 8).

Total Runoff - 30-minute Rainfall

- Runoff from all compost-treated plots was significantly lower (0.77 % or less of that from topsoil or control plots, table 9).

2. Does the depth of blanket applications of compost significantly affect steady-state interrill runoff rates?

UN-VEGETATED CONDITIONS

- Runoff rates for 5-cm (2-inch) compost applications were significantly higher (1.5X) than runoff rates for 10-cm (4 inch) compost applications.

VEGETATED CONDITIONS

- Runoff rates from 5- and 10-cm (2- & 4-inch) compost applications did not differ significantly.

3. Did compost type significantly affect steady-state interrill runoff from the test plots?

UN-VEGETATED CONDITIONS

- As shown in table 7, the yard waste compost had a significantly lower interrill runoff rate (35% of biosolids, and 50% of bio-industrial runoff rates).

VEGETATED CONDITIONS

- Here again, the yard waste compost exhibited a significantly lower interrill runoff rate (23% of the bio-industrial, and 17 % of the biosolids, table 7).

4. Did vegetative cover significantly affect steady-state runoff rates?

- Runoff rates were not significantly different between vegetated and un-vegetated treatments.

Table 7. Mean steady state runoff rates.

Treatment	N	Un-Vegetated		Vegetated	
		Mean Runoff Rate (mm/hr)	Standard Deviation	Mean Runoff Rate (mm/hr)	Standard Deviation
Biosolids	12	39.40[b,c]	22.28	20.02[b]	19.95
Yardwaste	12	13.94[a]	8.37	3.39[a]	5.01
Bio-industrial	12	27.39[b]	20.72	15.03[a,b]	24.55
Control	12	65.44[d]	23.33	55.10[c]	28.77
Topsoil 15-cm	12	47.58[c]	12.89	56.35[c]	21.00

Means in the same column with different letter designations are significantly different ($p<0.05$).

Table 8. Mean time to initiate runoff.

Media	N	Un-Vegetated		Vegetated	
		Mean Time (min)	Standard Deviation	Mean Time (min)	Standard Deviation
Biosolids	12	31.08[c]	39.03	29.33[b]	31.71
Yard Waste	12	56.92[d]	47.99	62.92[c]	46.81
Bio-industrial	12	32.17[c,d]	21.46	46.58[b,c]	43.14
Control	12	4.67[a]	2.02	5.58[a]	4.91
Topsoil 15-cm	12	7.83[b]	3.79	4.25[a]	2.86

Means within the same column different letter designations are significantly different ($p<0.05$).

Table 9. Total runoff during a 30-minute storm.

Parameter (units)	N	Biosolids		Yard Waste		Bio-industrial		Control		Topsoil	
		Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ
Un-vegetated Plots											
Runoff (mm)	12	0.13[b]	8.70	<0.01[a]	2.32	0.08[a,b]	3.47	26.22[c]	9.91	15.54[c]	6.30
Vegetated Plots											
Runoff (mm)	12	0.07[b]	7.42	<0.01[a]	1.71	0.03[a,b]	7.13	10.44[c]	13.75	15.01[c]	12.58

Means within the same row with different letter designations are significantly different ($p<0.05$).

INTERRILL EROSION

Major Findings

Under both un-vegetated and vegetated conditions, compost treated test areas exhibited significantly lower interrill erosion rates and total interrill erosion than conventional soil treatments.

Depth of compost application did not significantly affect interrill erosion rates.

Interrill erosion (rates and total) under un-vegetated conditions were significantly lower for areas blanketed with yard waste compost than for test plots treated with biosolids- or bio-industrial compost.

Key performance questions and statistically significant differences (unless otherwise noted) regarding interrill erosion are as follows.

1. Does interrill erosion on compost-treated test plots differ significantly from erosion on untreated areas (control) or those treated with topsoil?

UN-VEGETATED CONDITIONS

Erosion Rate

- Mean interrill erosion rates on compost-treated plots were 2.8 to 24% of those exhibited by plots treated with topsoil or those consisting of compacted-subsoil (table 10).

Total Erosion - 30-minute Rainfall

- Mean total erosion from compost-treated test plots during the 1st 30 minutes of rainfall was 0.02% (or less) of that from topsoil or compacted subsoil plots (table 11).

VEGETATED CONDITIONS

Erosion Rate

- Mean interrill erosion rates for compost-treated test plots were only 0.12 to 29.9% of those for the topsoil and compacted subsoil treatments (table 10).

Total Erosion - 30-minute Rainfall

- Compost-treated test areas produced less than 0.02% of the total erosion measured on the topsoil and control test areas (table 11).

2. **Does the <u>depth</u> of blanket applications of compost significantly affect interrill erosion rates?**

UN-VEGETATED CONDITIONS

<u>Erosion Rate</u>

- Erosion rates from un-vegetated test areas blanketed with 5-cm (2-inches) of compost and those treated with 10-cm (4-inches) did <u>not</u> differ significantly (table 10).

VEGETATED CONDITIONS

<u>Erosion Rate</u>

- Erosion rates from vegetated test areas blanketed with 5-cm (2-inches) of compost and those treated with 10-cm (4-inches) did <u>not</u> differ significantly (table 10).

3. **Did compost <u>type</u> significantly affect interrill erosion from the test plots?**

UN-VEGETATED CONDITIONS

<u>Erosion Rate</u>

- The mean interrill erosion rate for the yard waste compost was significantly lower, averaging less than 1/3 of the erosion measured on the biosolids and bio-industrial composts. Erosion rates for the biosolids and bio-industrial composts did <u>not</u> differ significantly (table 10).

<u>Total Erosion - 30-minute Rainfall</u>

- Yard waste compost produced less than 0.8 % of the total erosion measured on biosolids and bio-industrial composts (table 11).

VEGETATED CONDITIONS

<u>Erosion Rate</u>

- Yard waste compost had a significantly lower vegetated interrill erosion rate that was less 2.5% of that measured on the other two composts. Interrill erosion rates for the biosolids and bio-industrial composts did not differ significantly (table 10).

<u>Total Erosion –30-minute Rainfall</u>

- Mean total erosion on the yard waste compost was less than 0.6% of that from the biosolids compost. Mean total erosion from the bio-industrial compost fell between the other two, and did not differ significantly from either of them (table 11).

4. **Does vegetative cover significantly affect erosion?**

- As would be expected, erosion rates from vegetated test areas were less than half of those measured on un-vegetated test plots, regardless of type of compost or soil type (table 10).

5. **How does erosion from <u>un-vegetated</u> areas treated with compost blankets compare to erosion on <u>vegetated</u> soil treatments?**

TOTAL EROSION – 30-MINUTE RAINFALL

- Un-vegetated compost treated test plots provided superior erosion protection, producing less than 0.11% of erosion measured on either of the two vegetated soil treatments (table 11).

6. **Do topsoil treatments provide significantly different erosion control than compacted highway embankment soil?**

UN-VEGETATED CONDITIONS

Erosion Rate & Total Erosion – 30-minute Rainfall

- There were no statistically significant differences between topsoil and compacted embankment soil.

VEGETATED CONDITIONS

Erosion Rate & Total Erosion – 30-minute Rainfall

- There were no statistically significant differences between topsoil and compacted embankment soil.

Table 10. Mean steady state interrill erosion rates.

Treatment	N	Un-Vegetated		Vegetated	
		Mean Interrill Erosion Rate (mg/m^2-sec)	Standard Deviation	Mean Interrill Erosion Rate (mg/m^2-sec)	Standard Deviation
Biosolids	12	28.10[b]	27.49	5.98[b]	10.32
Yard Waste	12	4.68[a]	5.27	0.10[a]	0.09
Bio-industrial	12	14.38[b]	15.74	4.03[b]	7.75
Control	12	116.06[c]	97.98	20.01[c]	17.12
Topsoil 15-cm	12	166.89[c]	116.81	83.63[c]	104.62

Means in the same column with different letter designations are significantly different ($p<0.05$).

Table 11. Total erosion during a 30-minute storm.

Parameter (units)	N	Biosolids		Yard Waste		Bio-industrial		Control		Topsoil	
		Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ
Un-vegetated Plots											
Eroded Solids (mg)	12	7.84[b]	12,536	0.02[a]	1,253.8	2.52[b]	3,590.9	42,714[c]	85,585	40,046[c]	32,991
Vegetated Plots											
Eroded Solids (mg)	12	1.65[b]	11,376	<0.01[a]	134.84	0.06[a,b]	2,124.1	7,385.3[c]	13,529	24,867[c]	57,180

Means within the same row with different letter designations are significantly different ($p<0.05$).

RILL EROSION

> ***Major Findings***
>
> *Under un-vegetated conditions, rill solids concentrations for compost-treated and control plots were less than 1/3 of the concentrations in rill runoff from topsoil-treated plots.*
>
> *Under both vegetated and un-vegetated conditions, areas blanketed with yard waste compost produced significantly lower solids concentrations than areas treated with biosolids- or bio-industrial compost.*

Key performance questions and statistically significant differences (unless otherwise noted) regarding rill erosion are as follows.

1. Do compost blanket applications significantly affect rill erosion?

UN-VEGETATED CONDITIONS

- As shown in table 12, rill solids concentrations for compost-treated and control plots were less than 1/3 of the concentrations in rill runoff from topsoil-treated plots.
- Among compost-treated areas, solids in rill runoff from yard waste compost was significantly lower (<25% of concentrations in biosolids or bio-industrial compost runoff).

VEGETATED CONDITIONS

- As shown in table 12, all compost types (and the compacted subsoil) have significantly lower solids concentrations than the topsoil.
- The yard waste compost and the compacted subsoil have the lowest solids concentration.

Table 12. Rill solids concentrations.

Treatment	Un-Vegetated			Vegetated	
	N	Rill Solids Conc. (g/g)	Standard Deviation	Rill Solids Conc. (g/g)	Standard Deviation
Biosolids (A)	12	0.058^{b}	0.023	0.019^{b}	0.015
Yard Waste (B)	12	0.014^{a}	0.008	0.006^{a}	0.005
Bio-industrial (C)	12	0.060^{b}	0.020	0.018^{b}	0.012
Control (P)	6	$0.038^{a,b}$	0.026	0.004^{a}	0.003
Topsoil (T)	6	0.221^{c}	0.130	0.041^{c}	0.031

Means within the same column with different letter designations are significantly different ($p<0.05$).

ERODIBILITY FACTORS

> ***Major Findings***
>
> *Interrill erodibility factors show composts are more resistant to interrill erosion than the topsoil or control under un-vegetated conditions.*

Key performance questions and statistically significant differences (unless otherwise noted) regarding the potential for compost and conventional treatments to produce interrill and/or rill erosion are discussed below using calculated erodibility factors. Erodibility factors are a common tool used in soil erosion research to quantify the susceptibility of a soil to erosion.

1. Does the interrill erosion potential on compost-treated test plots differ significantly from interrill erosion potential on untreated areas (control) or those treated with topsoil?

UN-VEGETATED CONDITIONS

- Mean interrill erodibility factors on compost-treated plots were less than 1/5 of those exhibited by plots treated with topsoil or those consisting of control soil (table 13). These comparisons reflect similar patterns to those discussed in the interrill runoff and erosion sections.

VEGETATED CONDITIONS

- Mean interrill erodibility factors on yard waste and bio-industrial plots were less than 4/5 of those exhibited by plots treated with topsoil or those consisting of control soil (table 13).

- Erodibility factors for biosolids and control plots were not statistically different.

2. Does the rill erosion potential on compost-treated test plots differ significantly from rill erosion potential on untreated areas (control) or those treated with topsoil?

- Quantification of rill erosion data is currently ongoing. Composts have different physical properties (bulk density, particle size distribution, etc) that affect their performance, especially with respect to how they detach and move down a small channel of flowing water. The project team is investigating alternative methods that may better quantify these results, and will make those available upon completion.

Table 13. Mean interrill erodibility factors for un-vegetated and vegetated plots.

Treatment	N	Un-Vegetated		Vegetated	
		Mean Interrill Erodibility Factor x 10^{-6} (kg-sec/m^4)	Standard Deviation	Mean Interrill Erodibility Factor x 10^{-6} (kg-sec/m^4)	Standard Deviation
Biosolids	12	0.12[b]	0.12	0.05[b,c]	0.04
Yard Waste	12	0.05[a]	0.04	0.01[a]	0.01
Bio-industrial	12	0.11[b]	0.06	0.05[a,b]	0.11
Control	12	0.67[c]	0.13	0.06[c]	0.03
Topsoil 15-cm	12	0.72[d]	0.39	0.32[d]	0.38

Means within the same column with different letter designations are significantly different ($p<0.05$).

WATER QUALITY

Major Findings

Concentrations of several heavy metals were significantly higher in the biosolids and bio-industrial composts than in the two soils. All metal concentrations (in the composts and the soils), however, were well below EPA Part 503 rules governing maximum allowable metal concentrations in "high quality" biosolids that can be land applied in potentially sensitive locations.

Concentrations of nutrients were significantly higher in all of the composts than in the two soils.

Despite higher concentrations of all nutrients and several metals in two of the composts, runoff from compost-treated plots contained significantly lower total masses of all soluble and adsorbed forms of nutrients and metals (except P) than were contained in runoff from conventionally-treated test plots. The only exception to this was for the total mass of soluble P in runoff from the biosolids compost, which was statistically equal to total soluble P in runoff from the two soils.

Key performance questions and statistically significant differences (unless otherwise noted) regarding chemicals in the tested composts and soils (and in the runoff that they produce) are as follows.

1. Do nutrient and heavy metal concentrations in the composts differ significantly from concentrations found in topsoil or highway embankment soil?

- Concentrations of 7 out of 10 metals analyzed were significantly higher in the biosolids compost than in either of the two soils (table 15).
- Concentrations of 4 out of 10 metals analyzed were significantly higher in bio-industrial compost than in either of the two soils (table 15).
- Concentrations of only 1 out of 10 metals analyzed were significantly higher in yard waste compost than in either of the two soils (table 15).
- All composts contained significantly higher concentrations of N, P, and K than either of the two soils (table 15).

2. Do metal concentrations in any of the composts exceed concentrations stipulated by EPA Part 503 rules which are established to prevent harmful soil contamination caused by land application of biosolids?

- Although the biosolids and bio-industrial composts contained higher concentrations of certain metals than were found in the two soils, concentrations in these composts were well below concentrations permitted by EPA Part 503 rules (table 14) for "high quality" biosolids which are allowed to be sold to the public and/or applied to sensitive land areas.

3. Were the <u>concentrations</u> of soluble or absorbed (soil-attached) nutrients and metals contained in the runoff from compost-treated areas significantly higher than in runoff from highway embankment soils or embankments treated with topsoil?

UN-VEGETATED CONDITIONS

Soluble Metals & Nutrients

- Concentrations of soluble zinc in runoff from biosolids and yard waste compost were significantly higher (6X-12X) than in runoff from either of the two soils (table 16). (Note: Reliable estimates of mean soluble concentrations of metals other than Zn could not be calculated or compared due to a relatively large proportion of samples in which concentrations were below detection limits.)

- Concentrations of soluble phosphorus in runoff from the biosolids and yard waste composts were significantly higher (9X-24X) than in runoff from the topsoil and embankment soil (table 16).

- Concentrations of soluble potassium in runoff from all composts were significantly higher (2X-15X) than in runoff from the two test soils (table 16).

- Reliable estimates of the mean concentrations of soluble NO_3-N and NH_4-N in runoff could not be calculated or compared due to a relatively high proportion of samples with concentrations below detection limits (table 16).

Adsorbed Metals & Nutrients

- Adsorbed chromium concentrations in runoff from the biosolids compost were significantly higher (3X) than in runoff from either of the soils, and runoff from the yard waste compost contained significantly higher (1.3X) concentrations than runoff from topsoil (table 18).

- Adsorbed copper concentrations in runoff from all composts were significantly higher (2X-11X) than in runoff from the soils (table 18).

- Adsorbed zinc concentrations in runoff from <u>all</u> composts were significantly higher (3X-16X) than in the runoff from the soils (table 18).

- Runoff from all three composts contained significantly higher (3X-23X) concentrations of adsorbed phosphorous than did the runoff from the two soils (table 18).

- Runoff from the biosolids and yard waste composts contained significantly higher (1.8X-3.6X) concentrations of potassium than did runoff from either of the two soils.

VEGETATED CONDITIONS

Soluble Metals & Nutrients

- Reliable estimates of mean soluble metal concentrations (and soluble nitrogen) in runoff from vegetated test plots could not be computed or statistically compared due to a preponderance of samples in which soluble metal concentrations were below the detection limit (table 17).

- Runoff from biosolids compost contained significantly higher (5X) concentrations of soluble phosphorus than runoff from either of the two test soils (table 17).

- Runoff from yard waste compost contained significantly higher (1.7X) concentrations of soluble potassium than runoff from the control (compacted embankment) soil (table 17).

Adsorbed Metals & Nutrients

- Adsorbed concentrations of chromium in runoff from biosolids compost were significantly higher (2X-3X) than in runoff from either of the soils (table 19).

- Adsorbed concentrations of copper in runoff from the biosolids and bio-industrial composts were significantly higher (2X-7X) than in runoff from either of the soils (table 19).

- Adsorbed concentrations of zinc in runoff from all composts were significantly higher (2X-7X) than in runoff from either of the soils (table 19).

- Adsorbed concentrations of nitrogen in runoff from the biosolids compost was significantly higher (2X-4X) than in runoff from either of the soils, and adsorbed nitrogen concentrations in the bio-industrial compost runoff were significantly higher (2X) than in runoff from topsoil (table 19).

- Adsorbed concentrations of phosphorus in runoff from the biosolids and bio-industrial composts were significantly higher (1.8X-12X) than in runoff from either of the soils, and adsorbed nitrogen concentrations in the yard waste compost runoff were significantly higher (1.8X) than in runoff from topsoil (table 19).

4. Do the soluble metal concentrations in compost runoff exceed USEPA Toxicity Characteristic Leaching Protocol (TCLP) maximum concentrations that determine if a solid waste leachate is toxic?

- All soluble mean and maximum concentrations reported for both un-vegetated (table 16) and vegetated plots (table 17) were below the TCLP maximum concentrations (table 14).

5. Do the adsorbed metal concentrations in runoff from compost exceed concentrations stipulated by EPA Part 503 rules to prevent harmful soil contamination caused by land application of biosolids?

- The geometric mean concentration (or maximum concentration in cases where a high number of below-detection-limit results precluded calculation of a reliable estimate of the mean) for all adsorbed metals (table 18 and table 19, except for mercury and molybdenum on vegetated plots) were below the ceiling concentrations stipulated by EPA Part 503 rules (table 14). The maximum adsorbed values shown for mercury and molybdenum concentrations in eroded solids from vegetated plots reflect results of a single test result (all others below detection limit) and may be inflated due to a high dilution factor.

6. Is the total mass of any individual metal or nutrient in runoff from compost-treated areas significantly greater than in runoff from embankment soil or topsoil?

UN-VEGETATED CONDITIONS

Total Mass of Metals & Nutrients – 30-minute Rainfall

- None of the compost-treated areas produced runoff containing significantly higher total masses of any soluble or adsorbed pollutant species than was carried in runoff from the two test soils (table 20). The total mass of soluble phosphorus in runoff from the biosolids compost was statistically equivalent to that contained in runoff from the two soils. In all other cases, the total mass of any of the soluble or absorbed pollutant species in runoff from any of the compost-treated areas was significantly less than in runoff from the test soils.

VEGETATED CONDITIONS

Total Mass of Metals & Nutrients – 30-minute Rainfall

- Again, none of the compost-treated areas produced runoff containing significantly higher total masses of any soluble or adsorbed pollutant species than was carried in runoff from the two test soils (table 21). In all cases, the total mass of any of the soluble or absorbed pollutant species in runoff from any of the compost-treated areas was significantly less than in runoff from the test soils.

Table 14. USEPA pollutant limits for land application of biosolids and Toxicity Characteristic Leaching Protocol (TCLP)[1] maximum concentrations.

Element	Ceiling Concentrations (mg/kg)	"High Quality" Pollutant Concentrations (mg/kg)	TCLP Maximum Concentrations (mg/L)
Arsenic	75	41	5.0
Cadmium	85	39	1.0
Chromium	3000	1200	5.0
Copper	4300	1500	--
Lead	840	300	5.0
Mercury	57	17	0.2
Molybdenum	75[2]	--[3]	--
Nickel	420	420	--
Selenium	100	36	1.0
Zinc	7500	2800	--

[1]TCLP is a set of regulatory standards set by EPA to determine if the concentration in a leachate from a solid waste is toxic.
[2]Molybdenum requirement is currently under review by the EPA.
[3]-- No standard reported.

Table 15. Metal and nutrient concentrations in compost, topsoil, and roadway embankment soil (control).

Element	N	Biosolids		Yard Waste		Bio-industrial		Control		Topsoil	
		Mean[1] (mg/kg)	σ	Mean (mg/kg)	σ	Mean (mg/kg)	σ	Mean (mg/kg)	σ	Mean (mg/kg)	σ
As	6	BDL^{a}	0.000	4.620^{c}	1.328	1.968^{b}	0.973	4.817^{c}	1.167	3.815^{c}	1.370
Cd	6	1.630^{b}	0.182	BDL^{a}	0.000	BDL^{a}	0.000	BDL^{a}	0.000	BDL^{a}	0.000
Cr	6	61.687^{d}	6.632	9.118^{b}	0.364	15.985^{c}	2.400	9.778^{a,b}	2.249	8.253^{a}	0.633
Cu	6	193.573^{d}	27.481	21.325^{b}	3.893	69.458^{c}	8.039	6.950^{a}	2.810	8.733^{a}	3.433
Hg	6	2.370^{b}	1.131	1.607^{a,b}	0.838	BDL^{a}	0.000	BDL^{a}	0.000	BDL^{a}	0.000
Mo	6	7.492^{b}	3.297	0.882^{a}	0.689	1.625^{a}	1.340	BDL^{a}	0.000	BDL^{a}	0.000
Ni	6	18.743^{c}	3.562	9.900^{b}	0.351	14.680^{b}	1.621	11.928^{a,b}	3.522	8.635^{a,b}	1.600
Pb	6	70.443^{d}	4.528	26.085^{b}	2.030	59.118^{c}	7.302	19.658^{a,b}	9.747	13.715^{a}	1.866
Se	6	BDL^{a}	0.000	BDL^{a}	0.000	BDL^{a}	0.000	BDL^{a}	0.000	BDL^{a}	0.000
Zn	6	1,033.54^{d}	91.655	139.358^{b}	14.311	307.632^{c}	85.973	42.672^{a}	15.449	45.722^{a}	13.189
N	6	25,560.0^{d}	3,430.87	18,962.7^{c}	1,935.66	11,758.3^{b}	694.073	1,070.08^{a}	437.105	1,391.33^{a}	262.321
P	6	15,702.8^{d}	1,424.88	2,582.33^{b}	265.242	2,887.55^{c}	166.538	332.532^{a}	76.531	438.955^{a}	178.216
K	6	5,951.81^{c}	1,208.36	10,906.6^{d}	1,030.73	3,269.08^{b}	219.352	858.030^{a}	248.920	746.385^{a}	213.477

Means within the same row with different letter designations are significantly different ($p<0.05$).
[1]BDL - all samples analyzed were below the analytical detection limit.

Table 16. Soluble metal and nutrient concentrations in runoff from un-vegetated test plots.

Element	N	Biosolids		Yard Waste		Bio-industrial		Control		Topsoil	
		[Max Value][1] or Geo. Mean[2] (mg/L)	σ	[Max Value] or Geo. Mean (mg/L)	σ	[Max Value] or Geo. Mean (mg/L)	σ	[Max Value] or Geo. Mean (mg/L)	σ	[Max Value] or Geo. Mean (mg/L)	σ
As	12	BDL[3]	0.000	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Cd	12	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Cr	12	[0.015]	--	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Cu	12	0.028	0.073	0.031	0.010	0.028	0.006	[0.027]	--	[0.030]	--
Hg	12	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Mo	12	[0.544]	--	[0.026]	--	BDL	0.000	BDL	0.000	BDL	0.000
Ni	12	[0.039]	--	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Pb	12	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Se	12	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Zn	12	0.167[b]	0.347	0.176[b]	0.490	0.019[a]	0.086	0.015[a]	0.025	0.027[a]	0.224
NO_3-N	12	1.08	22.08	[30.40]	--	[8.57]	--	[1.71]	--	[2.07]	--
NH_4-N	12	5.91	85.80	[2.07]	--	[90.10]	--	[0.72]	--	[1.74]	--
P	12	3.097[b]	4.547	1.259[b]	2.969	0.359[a]	0.219	0.141[a]	0.296	0.130[a]	0.19
K	12	20.006[c]	153.278	47.327[d]	280.284	10.942[b]	79.526	5.046[a]	4.398	3.093[a]	1.620

Means within the same row with different letter designations are significantly different ($p<0.05$).

[1]If >25% of samples were below the analytical detection limit, 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 given in Table 14.

[2]If <25% of samples were below the detection limit, the geometric (geo.) mean of the detectible values is tabulated.

[3]BDL - all samples analyzed were below the analytical detection limit.

Table 17. Soluble metal and nutrient concentrations in runoff from vegetated test plots.

Element	N	Biosolids [Max Value][1] or Geo. Mean[2] (mg/L)	Biosolids σ	Yard Waste [Max Value] or Geo. Mean (mg/L)	Yard Waste σ	Bio-industrial [Max Value] or Geo. Mean (mg/L)	Bio-industrial σ	Control [Max Value] or Geo. Mean (mg/L)	Control σ	Topsoil [Max Value] or Geo. Mean (mg/L)	Topsoil σ
As	12	BDL[3]	0.000	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Cd	12	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Cr	12	BDL	0.000	BDL	0.000	BDL	0.000	[0.056]	--	BDL	0.000
Cu	12	[0.033]	--	0.026	0.002	0.026	0.003	[0.026]	--	<0.025	--
Hg	12	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Mo	12	[0.013]	--	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Ni	12	BDL	0.000	BDL	0.000	BDL	0.000	[0.013]	--	BDL	0.000
Pb	12	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Se	12	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Zn	12	0.029	0.032	0.027	0.381	[0.160]	--	[0.050]	--	[0.321]	--
NO_3-N	12	[1.34]	--	[2.18]	--	[1.56]	--	[1.57]	--	[1.47]	-
NH_4-N	12	[1.40]	--	BDL	0.000	BDL	0.000	[0.39]	--	[0.59]	--
P	12	0.555^{b}	0.447	[2.363]	--	0.079^{a}	0.255	0.099^{a}	0.101	0.115^{a}	0.111
K	12	5.059^{a,b}	2.361	7.489^{b}	41.896	5.124^{a,b}	13.317	6.975^{b}	4.003	4.311^{a}	1.909

Means within the same row with different letter designations are significantly different ($p<0.05$).
[1]If >25% of samples were below the analytical detection limit, 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 given in Table 14.
[2]If <25% of samples were below the detection limit, the geometric (geo.) mean of the detectible values is tabulated.
[3]BDL - all samples analyzed were below the analytical detection limit.

Table 18. Adsorbed metal and nutrient concentrations in runoff from un-vegetated test plots.

Element	N	Biosolids		Yard Waste		Bio-industrial		Control		Topsoil	
		[Max Value][1] or Geo. Mean[2] (mg/kg)	σ	[Max Value] or Geo. Mean (mg/kg)	σ	[Max Value] or Geo. Mean (mg/kg)	σ	[Max Value] or Geo. Mean (mg/kg)	σ	[Max Value] or Geo. Mean (mg/kg)	σ
As	12	[33.708]	--	BDL[3]	0.000	[17.447]	--	5.744	4.584	3.999	3.442
Cd	12	BDL	0.000	BDL	0.000	BDL	0.00	[3.448]	--	BDL	0.000
Cr	12	67.545[c]	25.964	24.857[b]	9.594	21.409[a,b]	6.129	21.551[a,b]	4.562	18.949[a]	5.699
Cu	12	183.76[e]	60.61	35.989[c]	19.36	75.339[d]	16.23	23.999[b]	6.57	16.561[a]	6.28
Hg	12	[36.279]	--	[15.000]	--	BDL	0.000	[5.144]	--	[3.841]	--
Mo	12	[64.186]	--	[41.823]	--	[4.847]	--	BDL	0.000	BDL	0.000
Ni	12	15.787[b]	8.038	8.610[a]	4.687	10.704[a]	3.099	22.390[c]	4.591	16.741[b,c]	4.110
Pb	12	44.556[c]	33.885	16.899[a]	9.112	43.669[c]	17.234	42.571[c]	18.095	23.747[b]	6.034
Se	12	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Zn	12	1,618.4[d]	1,432.6	562.63[c]	422.90	520.96[c]	272.51	153.39[b]	49.71	99.601[a]	37.81
N	12	13,416[a]	10,425	11,636[a]	16,670	6,302.0[a]	7,073.1	6,242.7[a]	9,421.2	5,290.7[a]	12,964
P	12	17,345[d]	10,214	4,342.5[c]	3,604.6	2,902.6[b]	549.97	853.90[a]	229.86	725.94[a]	229.08
K	12	4,337.7[b]	9,304.1	6,376.9[c]	14,142	2,351.9[a]	1,910.0	2,433.4[a]	760.93	1,787.1[a]	612.78

Means within the same row with different letter designations are significantly different ($p<0.05$).

[1]If >25% of samples were below the analytical detection limit, statistically reliable values of the mean and standard deviation could not be calculated. In these cases, the maximum value (indicated inside brackets [ ]) is reported and can be compared with regulatory values given in Table 14.

[2]If <25% of samples were below the detection limit, the geometric (geo.) mean of the detectible values is tabulated.

[3]BDL - all samples analyzed were below the analytical detection limit.

Table 19. Adsorbed metal and nutrient concentrations in runoff from vegetated test plots.

Element	N	Biosolids		Yard Waste		Bio-industrial		Control		Topsoil	
		[Max Value][1] or Geo. Mean[2] (mg/kg)	σ	[Max Value] or Geo. Mean (mg/kg)	σ	[Max Value] or Geo. Mean (mg/kg)	σ	[Max Value] or Geo. Mean (mg/kg)	σ	[Max Value] or Geo. Mean (mg/kg)	σ
As	12	BDL[3]	0.000	BDL	0.000	[22.059]	--	[8.578]	--	[6.806]	--
Cd	12	BDL	0.000	BDL	0.000	BDL	5.98	BDL	0.000	BDL	0.000
Cr	12	46.509[b]	86.228	17.153[a]	15.791	20.237[a]	14.363	21.549[a]	6.459	15.876[a]	7.531
Cu	12	92.046[d]	78.921	[25.604]	--	35.434[c]	20.664	18.368[b]	16.889	12.978[a,b]	5.173
Hg	12	[168.00]	--	[51.969]	--	[52.941]	--	[9.949]	--	[9.469]	--
Mo	12	[192.00]	--	BDL	0.000	[26.966]	--	[11.704]	--	BDL	0.000
Ni	12	12.969[b,c]	63.761	[23.622]	--	6.557[a,b]	7.746	18.131[c]	6.190	12.811[b,c]	10.042
Pb	12	30.626[b]	79.588	BDL	0.000	19.157[b]	15.983	31.692[b]	11.621	18.996[b]	10.857
Se	12	BDL	--	BDL	0.000	BDL	0.000	BDL	0.000	BDL	0.000
Zn	12	862.43[c]	1,307.4	389.90[b]	562.15	412.15[b]	458.47	208.28[a]	125.68	119.65[a]	90.287
N	12	11,193[c]	7,074.8	5,038.0[a,b]	5,375.2	6,818.2[b,c]	6,651.5	4,624.7[a,b]	6,635.6	2,835.8[a]	4,909.3
P	12	8,636.3[d]	11292.88	1,309.7[b,c]	1639.97	1,924.1[c]	1351.89	1,046.5[a,b]	828.51	730.82[a]	259.04
K	12	2,587.8[a]	4,565.1	2,583.6[a]	6,456.1	2,030.6[a]	1,807.0	2,735.8[a]	1,230.4	1,719.7[a]	774.94

Means within the same row with different letter designations are significantly different ($p<0.05$).
[1]If >25% of samples were below the analytical detection limit, 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 given in Table 14.
[2]If <25% of samples were below the detection limit, the geometric (geo.) mean of the detectible values is tabulated.
[3]BDL - all samples analyzed were below the analytical detection limit.

Table 20. Soluble and adsorbed metal and nutrient mass in 30-minute storm runoff from un-vegetated test plots.

Parameter	N	Biosolids		Yard Waste		Bio-industrial		Control		Topsoil	
		Geo. Mean[1] (mg)	σ	Geo. Mean (mg)	σ	Geo. Mean (mg)	σ	Geo. Mean (mg)	σ	Geo. Mean (mg)	σ
Soluble											
Zn	12	<0.01[a]	0.536	<0.01[a]	0.63	<0.01[a]	0.20	0.15[b]	0.26	0.16[b]	0.78
P	12	0.17[b,c]	8.937	<0.01[a]	5.89	0.01[a,b]	0.70	1.38[c]	3.51	0.76[c]	1.34
K	12	1.08[a]	64.171	0.09[a]	789.67	0.29[a]	133.17	49.55[b]	46.18	18.01[b]	18.10
Adsorbed											
Cr	12	0.01[b]	0.67	<0.01[a]	0.03	<0.01[b]	0.09	0.92[c]	1.65	0.76[c]	0.83
Cu	12	0.02[b]	1.87	<0.01[a]	0.05	0.01[b]	0.32	1.03[c]	1.98	0.66[c]	0.73
Ni	12	<0.01[b]	0.25	<0.01[a]	0.01	<0.01[b]	0.05	0.96[c]	1.81	0.67[c]	0.55
Pb	12	0.01[b]	0.95	<0.01[a]	0.02	<0.01[b]	0.22	1.82[c]	2.65	0.95[c]	0.94
Zn	12	0.10[b]	12.53	<0.01[a]	0.50	0.03[b]	4.70	6.55[c]	9.73	3.99[c]	3.42
N	12	0.47[b]	205.63	<0.01[a]	45.90	0.09[a,b]	13.41	266.65[c]	1,892.90	211.87[c]	942.78
P	12	0.45[b]	145.94	<0.01[a]	8.15	0.09[a,b]	11.36	36.47[c]	77.28	29.07[c]	27.55
K	12	0.17[b]	26.66	<0.01[a]	45.13	0.09[a,b]	12.48	103.94[c]	203.75	71.57[c]	83.16

Means within the same row with different letter designations are significantly different ($p<0.05$).
[1]Geometric (Geo.) Mean

Table 21. Soluble and adsorbed metal and nutrient mass in 30-minute storm runoff from vegetated test plots.

Parameter	N	Biosolids Geo. Mean[1] (mg)	Biosolids σ	Yard Waste Geo. Mean (mg)	Yard Waste σ	Bio-industrial Geo. Mean (mg)	Bio-industrial σ	Control Geo. Mean (mg)	Control σ	Topsoil Geo. Mean (mg)	Topsoil σ
Soluble											
P	12	0.02[b]	1.97	--[2]	--	<0.01[a,b]	1.81	0.39[c]	1.01	0.65[c]	1.00
K	12	0.15[a]	13.65	0.01[a]	83.90	0.03[a]	111.01	27.29[b]	49.61	24.22[b]	21.70
Adsorbed											
Cr	12	<0.01[b]	0.42	<0.01[a]	<0.01	<0.01[a]	0.04	0.16[c]	0.29	0.40[c]	0.70
Cu	12	<0.01[b]	0.83	--	--	<0.01[a]	0.09	0.14[c]	0.27	0.32[c]	0.69
Ni	12	<0.01[b]	0.23	--	--	<0.01[a]	0.03	0.13[c]	0.29	0.32[c]	0.66
Pb	12	<0.01[b]	0.58	--	--	<0.01[a]	0.07	0.23[c]	0.47	0.47[c]	0.86
Zn	12	0.03[b]	6.37	--	--	<0.01[a]	0.62	1.54[c]	2.27	2.98[c]	3.96
N	12	0.11[b]	25.77	<0.01[a]	2.66	<0.01[a]	2.26	34.16[c]	42.20	70.52[c]	456.62
P	12	0.11[b]	73.96	<0.01[a]	0.65	<0.01[a]	4.61	7.73[c]	13.12	18.17[c]	36.35
K	12	0.06[b]	26.92	<0.01[a]	1.96	<0.01[a,b]	5.03	20.21[c]	42.32	42.77[c]	70.58

Means within the same row with different letter designations are significantly different ($p<0.05$).
[1]Geometric (Geo.) Mean
[2]Treatment with >25% of samples below the analytical detection limit.

CONCLUSIONS

BLANKET APPLICATIONS

The conclusions summarized in this section reflect performance exhibited by compost and topsoil that were applied as blankets on top of a highway embankment soil. This research was not designed to evaluate the performance of compost or topsoil that has been tilled ("incorporated") into underlying embankment soil. Readers are cautioned that runoff, erosion, and weed growth for incorporated compost applications are likely be higher than the results reported for blanket applications.

RUNOFF QUANTITY

Due to their relatively high infiltration rate and ability to store water, it took compost-treated test plots significantly longer than conventional soil treatments to produce runoff. Even after runoff was initiated under intense rainfall, steady state runoff rates for the composts were only about 21-60% of those exhibited by the test soils.

Due to both the runoff delay and reduced steady state runoff rates, total runoff from compost-treated test plots exposed to 30-minutes of high intensity rainfall was less than 0.5% of that produced by embankment soil or topsoil.

Probably as a result of increased pore volume available to store water, the runoff rate produced by 5-cm deep compost blankets was about 1.5X of that produced by 10-cm compost applications.

EROSION

Due to their significant ability to reduce runoff, the compost blankets also provided significant interrill erosion protection immediately upon application (before vegetation was established). Data collected during 30-minute high intensity rain storms showed, in fact, that un-vegetated compost blankets produced less than 0.1 % of the total mass of eroded solids generated on vegetated test areas constructed from compacted embankment soil or embankment soil capped with topsoil.

Field data collected during this study also were used to calculate interrill erodibility factors, which are used in the USDA Water Erosion Prediction Program to predict erosion under a variety of rainfall and site conditions. Like the 30-minute total erosion data cited above, the erodibility factors indicate significantly lower erosion potential for each of the composts than for the soils.

Compost depth did not significantly affect interrill erosion. The 30-minute interrill erosion produced by 10-cm deep blankets was nearly the same as for the 5-cm deep compost blankets.

Rill erosion (produced by concentrated runoff), which can be quite destructive to nearly any type of soil or soil cover material under un-vegetated conditions, was about the same for the composts and the control soil. Rill erosion on areas treated with topsoil, however, was significantly higher than on any of the other materials.

RUNOFF QUALITY

Chemical analyses of the composts and soils used in this study showed that they all contained relatively low metal concentrations that easily meet USEPA regulations for safe land application. Concentrations of eight metals in the biosolids compost, and four metals in the bio-industrial compost, however, were significantly higher than in either of the soils. And, concentrations of all three major nutrients (nitrogen, phosphorus, potassium) were significantly higher in the composts as well.

Despite initially higher concentrations of metals and nutrients in the parent material, the total masses of heavy metals and nutrients (soluble and adsorbed forms) in interrill runoff from un-vegetated test plots (during 30-minute rainfall) were significantly lower than in runoff from the two test soils. The only exception to this was in the mass of soluble phosphorus in biosolids compost runoff, which was statistically equal to the mass of soluble phosphorus in runoff from the test soils.

These results attest to the importance of considering hydrology, as well as chemistry, when predicting the pollution potential of runoff from various types of materials. The total mass of pollutant leaving an area is controlled by the volume of water and mass of eroded particles that are available to carry the soluble and adsorbed pollutants from the source area. In this instance, the superior ability of the composts to retain rainfall and resist interrill erosion also results in excellent retention of potential pollutants.

As noted earlier, composts were generally no better at resisting rill erosion than the soils. So, to avoid pollutant movement with eroded solids that are detached and transported by rill erosion processes, it will be essential to minimize exposure of compost-treated areas to concentrated runoff and rill formation.

VEGETATION

Establishment of good ground cover is essential to long-term erosion control and acceptable construction site aesthetics. Measurements of the above-ground mass of planted species produced by the test plots showed no statistically significant differences between compost- and conventionally-treated areas.

In addition to providing cover crop growth comparable to that obtained on conventionally treated embankments, compost-treated areas exhibited significantly less weed growth. The weed suppression is believed to be due primarily to blanket application of the composts. Heat produced during processing has long been known to significantly reduce the population of viable weed seeds in composted materials. As a result, application of a 5- or 10-cm layer of relatively weed-free material provides a favorable growth environment for species that are planted into the compost while simultaneously suppressing emergence and growth of weed seeds in the underlying soil. In addition to improving construction site aesthetics, weed suppression provided by blanket applications of compost offers potential cost savings in terms of reduced need for herbicide applications and replanting of desirable species.

APPLICATION CONSIDERATIONS

Due to the immediate interrill runoff and erosion control offered by compost blankets, they are potentially useful in overcoming difficult construction site and/or weather conditions. Common examples include construction sites that lack soils capable of supporting good vegetative growth, or construction projects that must be initiated during weather conditions (drought, cold weather) that do not favor rapid establishment of good vegetative cover. Steep or wet slopes that prevent use of heavy equipment to spread topsoil, seed, and fertilizer, also may be amenable to compost applications, since compost blankets can be applied using a blower truck and air-hose delivery systems.

Although serious rill erosion is unlikely to occur in materials that suppress runoff, concentrated runoff from adjoining land areas or impervious surfaces require special attention. As noted earlier, compost blankets were not highly resistant to rill erosion. These results emphasize the importance of using site management practices, such as compost berms, silt fences, hay bales, or structural measures that diffuse or redirect concentrated flow before it enters a compost-treated area.

COMPOST TYPE

In general, all of the composts that were tested possessed reasonably good runoff and erosion control characteristics that support their adoption. Yard waste compost, however, typically produced significantly less runoff, erosion, and exported pollutants than the other two composts.

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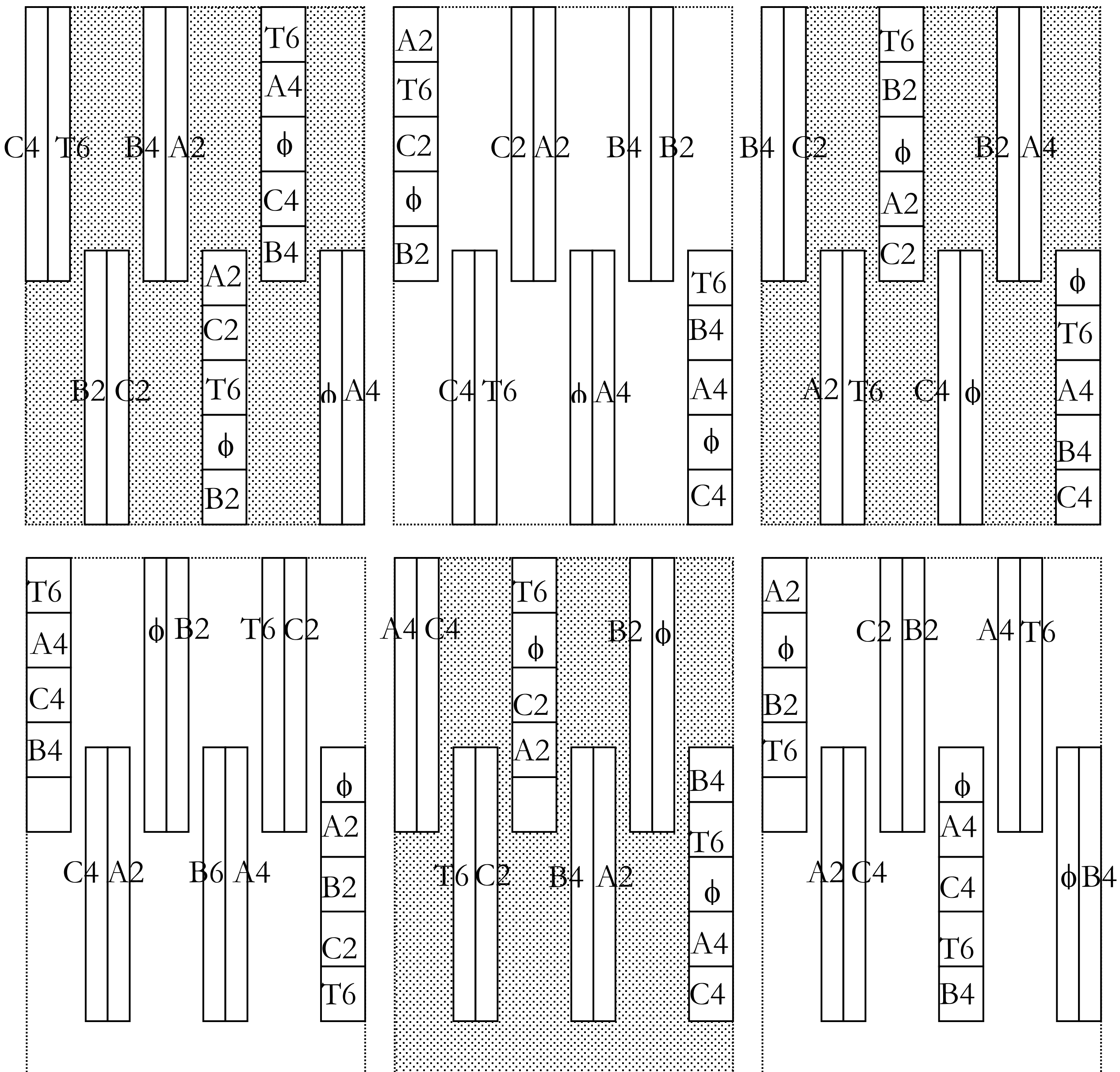
APPENDIX A: PROJECT SITE LAYOUT



YEAR 1 LAYOUT

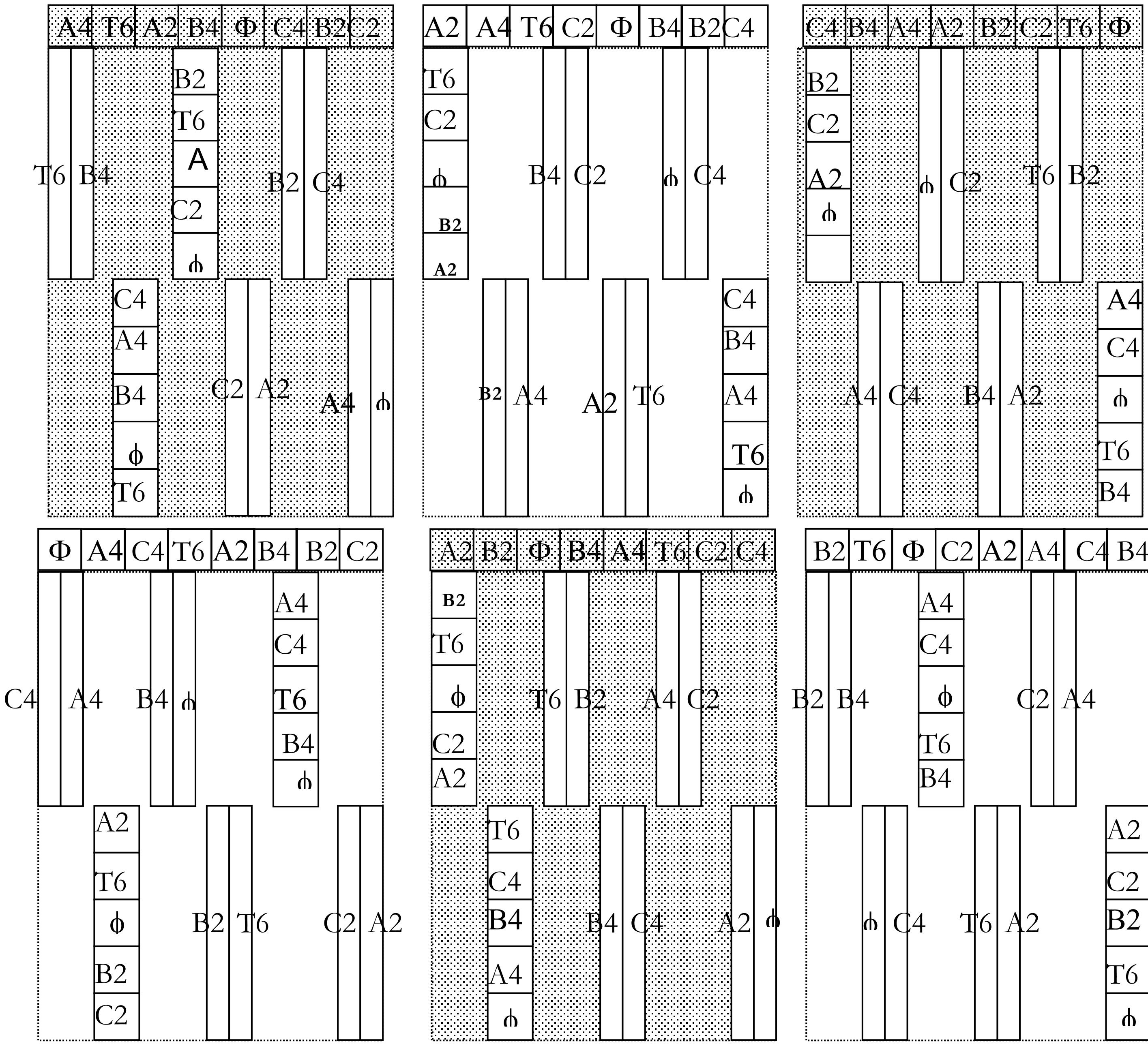
grassed

bare soil

Treatments:

- 3 composts (A, B, and C) at 2 depths (2" and 4")
  - A2, A4, B2, B4, C2, C4
- 1 natural soil control (no amendment)
  - ϕ
- 1 topsoil treatment at the 6"-depth
  - T6

A = Davenport Biosolids Compost
B = Des Moines Yard Waste Compost
C = Cedar Rapids Bio-industrial Compost
T = Topsoil
ϕ = Compacted Subsoil (control)



YEAR 2 LAYOUT

grassed

bare soil

Treatments:

- 3 composts (A, B, and C) at 2 depths (2" and 4")
  - A2, A4, B2, B4, C2, C4
- 1 natural soil control (no amendment)
  - ϕ
- 1 topsoil treatment at the 6"-depth
  - T6

A = Davenport Biosolids Compost
B = Des Moines Yard Waste Compost
C = Cedar Rapids Bio-industrial Compost
T = Topsoil
ϕ = Compacted Subsoil (control)

APPENDIX B: 1ST HOUR RUNOFF DATA

RUNOFF

1. Does runoff from compost-treated test plots differ significantly from runoff produced by untreated areas (control) or those treated with topsoil?

UN-VEGETATED CONDITIONS

Total Runoff - 1st-Hour Runoff

- Total runoff was significantly less from the three composts (table B1).

VEGETATED CONDITIONS

Total Runoff - 1st-Hour Runoff

- Total runoff during the 1st-hour of runoff was significantly less on the yard waste and bio-industrial composts (table B1).

- No statistical difference was found in the total runoff from the biosolids and the two soil treatments.

Table B1. Total runoff during the 1st hour of runoff on un-vegetated and vegetated test plots.

Parameter (units)	N	Biosolids		Yard Waste		Bio-industrial		Control		Topsoil	
		Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ
Un-vegetated Plots											
Runoff (mm)	12	23.42[b]	18.74	8.62[a]	6.19	15.41[b]	21.60	58.45[c]	19.49	42.59[c]	10.76
Vegetated Plots											
Runoff (mm)	12	9.61[b]	18.34	0.35[a]	4.75	1.34[a]	20.56	31.40[b]	28.06	38.69[b]	20.88

Means within the same row with different letter designations are significantly different ($p<0.05$).

INTERRILL EROSION

1. Does interrill erosion on compost-treated test plots differ significantly from erosion on untreated areas (control) or those treated with topsoil?

UN-VEGETATED CONDITIONS

Total Erosion - 1st-Hour Runoff

- Mean total erosion produced by compost-treated plots during the 1st hour of runoff was less than the two soil treatments (table B2).

VEGETATED CONDITIONS

Total Erosion - 1st-Hour Runoff

- Mean total erosion from compost-treated test plots during the 1st-hour of runoff was less than that from topsoil-treated plots (table B2).

- Total erosion from the soil-like biosolids compost did not differ significantly from the control treatment, but erosion from the yard waste and bio-industrial composts were less of that from highway embankment (control) plots (table B2).

WATER QUALITY

1. Is the total (soluble + adsorbed) mass of any individual metal or nutrient in runoff from compost-treated significantly greater than in runoff from embankment soil or topsoil?

UN-VEGETATED CONDITIONS

Total Mass of Metals & Nutrients – 1st Hour Runoff

- The total mass of soluble phosphorus in runoff from biosolids compost was the only pollutant found in significantly higher amounts than in runoff from either of the test soils. The total masses of all other soluble or adsorbed pollutant species in runoff from any of the composts were the same or significantly lower than in runoff from compacted embankment soil or topsoil (table 21). Runoff from the yard waste and bio-industrial composts typically contained significantly lower total masses of soluble or absorbed pollutants than found in runoff from the two test soils.

VEGETATED CONDITIONS

Total Mass of Metals & Nutrients – 1st Hour Runoff

- None of the compost-treated areas produced a significantly greater total mass of any of the soluble or adsorbed pollutant species in their runoff than was found in runoff from either of the test soils (table 22). As was the case in the un-vegetated test condition, runoff from the yard waste and bio-industrial composts typically contained significantly lower total masses of soluble or absorbed pollutants than were found in runoff from the two test soils.

Table B2. Total erosion during the 1st hour of runoff on un-vegetated and vegetated test plots.

Parameter (units)	N	Biosolids		Yard Waste		Bio-industrial		Control		Topsoil	
		Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ	Geo. Mean	σ
Un-vegetated Plots											
Eroded Solids (mg)	12	11,960[b]	30,128	2,957.1[a]	5,406.3	9,499.1[b]	21,638	97,503[c]	154,477	140,048[c]	121,779
Vegetated Plots											
Eroded Solids (mg)	12	2,417.2[b]	19,178	26.86[a]	204.63	148.15[a]	7,523.0	15,985[b,c]	23,403	57,060[c]	113,819

Means within the same row with different letter designations are significantly different ($p<0.05$)

Table B3. Soluble and adsorbed metal and nutrient mass in 1st-hour runoff from un-vegetated test plots.

Parameter	N	Biosolids		Yard Waste		Bio-industrial		Control		Topsoil	
		Geo. Mean[1] (mg)	σ	Geo. Mean (mg)	σ	Geo. Mean (mg)	σ	Geo. Mean (mg)	σ	Geo. Mean (mg)	σ
						Soluble					
Zn	12	1.47[c]	5.53	0.57[b,c]	2.54	0.11[a]	1.17	0.33[a,b]	0.62	0.44[b]	3.11
P	12	27.18[b]	77.82	4.07[a]	20.38	2.07[a]	4.58	3.08[a]	7.59	2.07[a]	3.01
K	12	175.55[b]	2,422.67	153.03[a,b]	2,418.38	63.09[a]	1,137.92	110.47[a,b]	91.47	49.33[a]	43.57
						Adsorbed					
Cr	12	0.81[c]	1.62	0.07[a]	0.12	0.20[b]	0.53	2.10[d]	2.81	2.65[d]	1.89
Cu	12	2.20[c]	4.70	0.11[a]	0.25	0.72[b]	1.76	2.34[c]	3.50	2.32[c]	1.59
Ni	12	0.19[b]	0.56	0.03[a]	0.08	0.10[b]	0.34	2.18[c]	3.14	2.35[c]	1.92
Pb	12	0.53[b]	2.30	0.05[a]	0.16	0.42[b]	1.52	4.15[c]	4.58	3.33[c]	2.50
Zn	12	19.37[c]	32.34	1.66[a]	1.91	4.95[b]	16.06	14.96[c]	16.59	13.95[c]	7.14
N	12	160.46[b]	603.64	34.41[a]	200.51	59.86[a,b]	310.82	608.68[c]	3,306.49	740.95[c]	4,291.50
P	12	207.45[b]	497.53	12.84[a]	26.20	27.57[a]	70.23	83.26[b]	132.99	101.67[b]	57.59
K	12	51.88[a]	359.54	18.86[a]	122.20	22.34[a]	57.47	237.26[b]	346.81	250.28[b]	175.07

Means within the same row with different letter designations are significantly different ($p<0.05$).
[1]Geometric (Geo.) Mean

Table B3. Soluble and adsorbed metal and nutrient mass in 1[st]-hour runoff from vegetated test plots.

Parameter	N	Biosolids		Yard Waste		Bio-industrial		Control		Topsoil	
		Geo. Mean (mg)	σ	Geo. Mean (mg)	σ	Geo. Mean (mg)	σ	Geo. Mean (mg)	σ	Geo. Mean (mg)	σ
						Soluble					
P	12	0.02[b]	1.97	--[2]	--	<0.01[a,b]	1.81	0.39[c]	1.01	0.65[c]	1.00
K	12	0.15[a]	13.65	0.01[a]	83.90	0.03[a]	111.01	27.29[b]	49.61	24.22[b]	21.70
						Adsorbed					
Cr	12	0.11[c]	0.73	<0.01[a]	<0.01	<0.01[b]	0.14	0.34[c,d]	0.55	0.91[d]	1.49
Cu	12	0.22[c]	1.48	--	--	0.01[b]	0.48	0.29[c]	0.47	0.74[c]	1.65
Ni	12	0.03[c]	0.39	--	--	<0.01[b]	0.10	0.29[d]	0.51	0.73[d]	1.61
Pb	12	0.07[c]	1.00	--	--	<0.01[b]	0.35	0.51[d]	0.72	1.08[d]	1.88
Zn	12	2.09[c]	11.15	0.02[a]	0.25	0.13[b]	2.38	3.33[c]	4.03	6.83[c]	8.15
N	12	27.06[c]	52.41	0.21[a]	4.02	1.40[b]	72.38	73.93[c]	113.54	161.81[c]	674.62
P	12	20.88[c]	131.21	0.06[a]	1.02	0.55[b]	20.24	16.73[c]	23.24	41.70[c]	79.13
K	12	6.26[b]	45.71	0.13[a]	3.28	0.60[a]	15.66	43.73[c]	80.93	98.13[c]	142.23

Means within the same row with different letter designations are significantly different ($p<0.05$).
[1]Geometric (Geo.) Mean
[2]Treatment with >25% of samples below the analytical detection limit, a reliable estimate of mean value could not be calculated.