Compost Best Management Practices and Benefits

CalRecycle

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Contractor's Report

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Executive Summary

This report presents the results of a research project that evaluated ways to conserve water and protect water quality as related to compost production and application. The project has four related objectives. The first objective considers the use of compost for remediating fire-damaged soils; the second looks at compost blankets as a means of restoring soils damaged by construction activity; the third investigates a potential Best Management Practice (BMP) for minimizing water pollution from compost operations, including a calculator developed to estimate a compost pile's potential water holding capacity; and the fourth is a literature review conducted on several topics related to the beneficial use of compost.

Background

Remediation of Fire-Damaged Soils

In California, the initial costs associated with wildfires, including suppression and structural damages, commonly exceed hundreds of millions of dollars each year. However, subsequent environmental damage, most prominently soil erosion and the associated water pollution, can substantially increase those costs. Fires eliminate vegetation, leaving soil particles exposed to the energy of falling precipitation. Under some circumstances, hydrophobic condensates from burning materials can increase stormwater runoff by decreasing the soil's infiltration capacity. Unimpeded by lack of vegetation or associated duff, dislodged soil particles will flow off of slopes as sediments, carrying with them not only nutrients but trace metals and other pollutants.

From research in other states, it is known that compost, whether incorporated or applied as a blanket, can decrease runoff and erosion as well as associated water pollution. Research in the eastern and Midwestern United States has focused on the remediation of construction sites using compost. Although the extension of compost use as a tool to protect and restore fire-damaged soil may seem straightforward, no formal studies have been reported. Because compost is rich in nutrients and organic matter, it stabilizes soils and facilitates revegetation which reduces sediment losses resulting from subsequent storms. When applying compost as a water quality BMP, composts contain nutrients, trace elements, and salts. The fate of these constituents must also be considered when evaluating compost use as a remediation alternative.

Remediation of Construction Soils

Construction activity, whether for erecting buildings or installing roadways, is a significant source of sediments. Construction commonly involves removing surface soil layers along with their accumulated humus and associated nutrients. Often the remaining soil is similar to decomposed bedrock in its characteristics. Alternatively, heavy clay or light sand may be exposed. Construction soils may also suffer from intentional or inadvertent compaction. Compost blankets have been shown to assist in controlling the erosion of soil damaged by construction activities. As with fire-damaged soil, compost blankets work by protecting the soil directly from the impact of falling rain. The compost blankets encourage infiltration into the damaged soil by slowing surface water movement and encouraging vegetative development.

Compost Production Best Management Practice

At compost production facilities, the need exists to manage operations so that their compost's macronutrients (nitrogen [N] and phosphorous [P]), trace elements, and salts are effectively conserved onsite and not exported into the environment as pollutants. Any waterborne pollutants exiting compost facility sites have the potential to eventually enter surface water and groundwater. It should be noted that many of the trace elements and salts contained in composts are also plant nutrients that will improve soil fertility. Compost production BMPs that conserve macronutrients, trace elements, and salts within the compost media enhance soil productivity while conserving water quality. Compost has a substantial water-holding capacity, and the active compost piles themselves may potentially be used to store precipitation water so that it does not move pollutants off-site. This study has afforded the opportunity to consider the use of compost's water storage capacity as a water quality BMP.

Literature Review

While the benefits of compost use are well-heralded, it is important to have scientific research which corroborates these benefits. With this study, the literature review assessed information on the benefits of compost applications with respect to specific environmental issues, and identified areas needing further scientific investigation.

Study Design

Fire-Damaged Soils

This study evaluated the use of compost blankets for mitigating soil erosion and the associated export of pollutants from burn areas. For the study, a controlled burn was conducted on an experimental area located at the University of California, Riverside. Three different compost were studied, including compost from a greenwaste feedstock (compost-greenwaste) in both a fine (less than 3/8 inch screen size) and coarse (greater than 3/8 inch screen size) grade, and co-composts from a mix of greenwaste and biosolids feedstocks (compost-biosolids) in a fine grade (less than 3/8 inch screen size). One- and two-inch blankets were included for each type of compost in the study, and an additional treatment involved the use of an incorporated two-inch blanket (i.e. two inches of compost was worked into the soil to a depth of three inches). Runoff volumes were measured following four storms that occurred during the months of December 2009 and January 2010. The study also measured the associated sediments, salts, nutrients, and trace elements in the runoff and compared the runoff results for compost treatments against the untreated controls.

Construction Soils

An adjacent experimental area to the Fire-Damaged Soils study at the University of California, Riverside location was used to evaluate the remediation of construction soils using compost. The experiment considered one inch applications of compost-greenwaste and compost-biosolids on a site simulating one that was recently damaged by construction activity, and included three seeded treatments: no reseeding; a basic native erosion control mix; and an inland sage scrub mix. Runoff volumes were measured following three storm events during January 2010. The study also measured the associated sediments, salts, nutrients, and trace elements in the runoff.

Compost Production

Water movement through active compost piles (fugitive water flows) can carry pollutants from the piles and into the environment. By controlling fugitive water flows, pollutants can be contained in the piles. Therefore, this study evaluated best management practices (BMPs) for compost production that are designed to minimize leaching and runoff losses by taking advantage of the ability of compost to absorb and hold water.

The goal of this series of experiments was to develop guidance for composters regarding BMPs for compost piles that reduce surface and groundwater pollution. In addition, part of the experiment was to develop a simple computer program that a composter could use in the field to easily determine how much precipitation a given pile could hold. Compost-greenwaste and compost-biosolids samples were collected from freshly formed piles for three different maturity dates (first, seventh, and fourteenth day of active composting). The samples were used to measure estimated water storage capacity of the composts, model movement of water through a compost pile during a precipitation event, and test management strategies to increase water infiltration into compost piles.

Literature Review

A review of the literature referenced in the bibliography was completed to identify topics related to compost use requiring additional research. The following themes were pursued: compost use and types of application; erosion control; vegetation establishment; stormwater quality; water conservation; fertilizer and pesticide reduction; and greenhouse gas (GHG) reduction.

Key Findings

Compost has the ability to absorb and store a considerable amount of water and concentrated nutrients. Therefore, the runoff volume of water during a rain event from soil treated with compost is significantly reduced. Although the concentration of nutrients in the runoff can be highly concentrated, due to the significantly lower volume of runoff, the overall mass of nutrients is comparatively low. Study results rendered the following key findings:

- Compost applications are very effective in reducing water runoff. On average, runoff volumes were reduced by 80 percent.
- Compost applications are very effective in reducing soil erosion. On average, sediments, total dissolved solids (TDS), and total suspended solids (TSS) were reduced by 95, 65, and 94 percent respectively.
- Compost applications had the following effect on water quality when compared to plots containing no compost (on average): nitrate was reduced by 80 percent, and salinity concentrations were increased by 467 percent. However, since salinity is only a measure of the concentration of salts and does not reflect the mass of salts being exported in runoff from the plots, it is more appropriate to consider the Total Dissolved Solids value which can be flow-weighted.
- Mass flux measurements are more appropriate water quality indicators than concentration values. Due to significantly reduced runoff volumes and potentially high concentration of

nutrient loadings from compost applications, mass flux measurements that take into account both concentration and flow rate are better water quality indicators for the total mass of constituents in the runoff water.

At a compost facility, BMPs for water management in compost piles can help leachate and water runoff by considering the ability of compost to absorb and hold water.

- Composters can consider using existing water storage capacity of compost piles to control the movement of leachate (water with nutrient concentrations) from their piles, reducing the potential to pollute surface water and groundwater. Composters can use the Storage Potential Calculator, an interactive Excel tool presented in this report, to evaluate the capacity of their piles to store water and subsequently take steps to minimize runoff in the event of rain.
- Compost windrows shaped with a flat top have improved water infiltration. The use of a surfactant improved infiltration into dry composts from a greenwaste feedstock.

The literature review indicates that existing research shows:

- Compost blankets are very effective at reducing sediments that pollute water;
- Compost can conserve water in landscapes, especially where soils are severely damaged by construction activity or erosion;
- Compost, whether incorporated or applied as a blanket, can speed up revegetation efforts and improve cover densities; and
- Compost improves soil fertility.

The literature review indicates research gaps for compost in the areas of: field-scale compost application studies (placement, depth, slope, support structures, wind erosion); compost berms, filters, and compost socks; revegetation and native species studies; integration of compost in fertilizer and pest management plans; and greenhouse gas emission studies.

Fire-Damaged Soils Study

Loss of life and property damage from wildfire is greater in Southern California than in any other part of the United States. Urban development in the region has been rapid in recent decades; homes and other structures are often built adjacent to flammable chaparral and grasslands. An average of 4,740 California wildfires were recorded annually from 2003 to 2008. Wildfires burn an average of 281,000 acres each year and consume an average of 1,860 structures and cost the state $394,000,000 annually for suppression and reconstruction (CAL FIRE, 2010). Fires in the area are exacerbated by dry conditions and high winds. Besides threatening life and property, wildfires endanger regional soil and water quality. Though exact figures are difficult to compute, the cost of remediating the environmental damage imposed by wildfires is likely far greater than structural and suppression costs (Dunn et al., 2003; Zybach, 2009).

In undisturbed landscapes, soils are protected from the energy of falling raindrops by vegetation. However wildfires strip away this vegetation, and without this protection, soil particles can be dislodged and carried away by both fluvial (water) and eolian (wind) forces. This project considers the use of compost for reducing the losses of fluvial pollutants from fire-affected soils. Following a fire, dislodged soil particles commonly accumulate downslope where they form sediments in streams, ponds, and lakes. Additional pollutants, such as nutrients, trace metals, and salts, may be dissolved, suspended in water, or bound to dislodged particles running off burned slopes.

The volume of pollutants contained in stormwater runoff following a fire can be expected to increase with each rain event. Normally, plants are slowly emerging from the landscape and physically distribute the pattern of flowing water across the soil surface so that infiltration can occur. When plants are destroyed by fire, water flows will concentrate into channels that will eventually form rills in a slope from the rapidly discharged water. The energy of these concentrated flows is more likely to suspend and saltate particles. Fires have also been reported to create hydrophobic layers beneath the surface of the soil, causing water to collect on the surface and not infiltrate into the ground. This hydrophobicity also increases runoff and associated soil loss.

Tools traditionally used by water quality professionals for reducing or controlling the pollution associated with wildfire events can be divided into two categories:

(1) Engineered structures for capturing sediments (aka sediment capture basins) after the sediments have been entrained and exported in runoff flows from a burned hillside; and
(2) Structures for reducing and capturing sediments before they can be entrained and exported. However, a disadvantage associated with these types of structures is the potential for failure. If there is structural failure, captured sediments are likely to be

lost. These structures may also concentrate flows creating conditions for soil scouring. Examples include:

- Silt fences;
- K-rail; and
- Straw wattles

Practices that reduce flows include compost application, compost blankets, hydro-mulching, and straw or coconut fiber netting. Compost blankets are installed to reduce sediment losses and often to encourage the development of vegetation. In fact, previous research suggests that compost blankets reduce sediment loss as effectively and in some cases significantly more effectively than alternatives while promoting the rapid establishment of vegetation (Faucette et al., 2006; Faucette et al., 2009; Persyn et al., 2004). However, compost blankets also can contain nutrients, salts, and trace elements that may concern water quality regulators if these constituents transfer into water running off from the site. It is important to compare the total mass flow of these constituents in runoff water from soils amended with and without compost in order to determine the overall effectiveness of the compost application in protecting water quality.

Methods

This experiment was designed to measure the effectiveness of compost use in remediating soils damaged by fires. Composts from three different feedstocks were studied including finished compost from a greenwaste feedstock (compost-greenwaste) in both a fine (less than 3/8 inch screen size) and course (greater than 3/8 inch screen size) grade, and finished co-composts from a mix of greenwaste and biosolids feedstocks (compost-biosolids) in a fine grade (less than 3/8 inch screen size). The three composts were applied as three different treatments and compared against a control. This resulted in 10 plots that were replicated three times for a total of 30 plots. Where appropriate, the study included mass flux results which were derived by multiplying measured concentrations by their corresponding runoff volumes and dividing by the plot area. Mass flux results, which represent the total mass of a constituent leaving an area, provide more informative regulatory guidance under most conditions, especially where runoff volumes are significantly reduced.

The objectives of the study were to:

A. Establish compost plots on recently burned land with each compostable material applied as:

    (1) 2.5 cm (1 inch) thick compost blanket,

    (2) 5 cm (2 inch) thick compost blanket, and

    (3) Soil amendment (5 cm of material incorporate into the soil).

B. Measure runoff volumes from four storm events over the period December 2009 – January 2010.

C. Measure potential pollutants in the runoff including turbidity, pH, salinity, total dissolved solids, total suspended solids, total sediments, total phosphorus, orthophosphate-P, nitrate-N, ammonium-N, and trace metals (arsenic, cadmium, copper, chromium, lead, molybdenum, nickel, mercury, and zinc.)

Site Establishment and Sampling

The research team initially endeavored to locate the study near the city of Yorba Linda, Calif., which had been severely impacted in late 2008 by the 30,000-acre “Freeway Complex Fire.” The research team contacted and collaborated with several local and state regulatory agencies as well as with the City of Yorba Linda Engineering Department but, after a protracted search, concluded that no suitable sites were available on public land. Most of the burned area either was on privately owned land or state park land and officials were hesitant to allow experiments to be conducted on land set aside for preservation. There were some burned areas available that were controlled by the city, but these sites tended to be on very steep and inaccessible slopes. Open areas within the city that seemed suitable were found to be restricted by the presence of right-of-ways maintained by outside utility agencies. For these reasons, as well as the ability to control the experimental site, the study was performed at the University of California, Riverside.

The university has a suitable area at the Citrus Research Center and Agricultural Experiment Station located within a secure fenced area on the campus (33°57’44.98” N 117°20’01.17” W). This facility provides a secure space with access to equipment and labor. The 362 m^2 site is located on a uniform 3:1 slope and thickly covered in vegetation typical of surrounding unmanaged areas. As part of the research study, on the morning of Aug. 8, 2009, members of the Riverside Fire Department conducted a controlled burn of the study area as shown in Figure 1.

Figure 1. Riverside Fire Department conducts a controlled burn.

The research team then installed a total of 30 experimental plots in three rows shown by Figure 2 below. Each plot was 4.27 m (14 ft) long and 1.22 m (4 ft) wide. Six-inch plastic edging was installed completely around each plot to a depth of 2.5 cm (1 inch). Composts were then installed using a split-plot design. There were ten different treatments with three replications each. Mulch treatments were applied to the soil surface, and the incorporated treatments were mixed into the surface of the soil to a depth of 7.6 cm (3 in) using:

- GWF1: (compost-greenwaste) 2.5 cm (1 inch) of finished compost from greenwaste feedstocks fines (less than 3/8 inch screen size) applied as a mulch.

- GWF2: 5 cm (2 inches) of finished compost from greenwaste feedstocks (compost-greenwaste) fines (less than 3/8 inch screen size) applied as a mulch
- GWFInc: 5 cm (2 inches) of finished compost from greenwaste feedstocks (compost-greenwaste) (less than 3/8 inch screen size) incorporated into the soil
- GWC1: 2.5 cm (1 inch) of finished compost from greenwaste feedstocks (compost-greenwaste) overs (greater than 3/8 inch screen size) applied as a mulch
- GWC2: 5 cm (2 inches) of finished compost from greenwaste feedstocks (compost-greenwaste) (greater than 3/8 inch screen size) applied as a mulch
- GWCInc: 5 cm (2 inches) of finished compost from greenwaste feedstocks (compost-greenwaste) overs (greater than 3/8 inch screen size) incorporated into the soil
- BS1: 2.5 cm (1 inch) of finished compost from a mix of biosolids and greenwaste feedstocks (compost-biosolids) (less than 3/8 inch screen size) applied as a mulch.
- BS2: 5 cm (2 inches) of finished compost from a mix of biosolids and greenwaste feedstocks (compost-biosolids) (less than 3/8 inch screen size) applied as a mulch
- BSInc: 5 cm (2 inches) of finished compost from a mix of biosolids and greenwaste feedstocks (compost-biosolids) (less than 3/8 inch screen size) incorporated into the soil
- Control: Undisturbed soil only

At the bottom of each plot, a collection area was installed including 6 cm of aluminum flashing and 10.2 cm (4 in) inner diameter PVC collection pipe running the width of the plot perpendicular to the slope, demonstrate in Figure 4. Each collection pipe was then connected through a 90° elbow to an additional 10.2 cm (4 in) PVC pipe running down slope to a covered 113 L (30 gal) plastic bin at the bottom of the slope, shown in Figure 5. To prevent inadvertent entry of precipitation directly into the bins, the bins were covered with anchored waterproof tarps. The system was cleaned and inspected prior to each rain event, as seen in Figure 6.

Runoff was measured and sampled following four separate rain events:

- Dec. 15, 2009, following a 12.5 mm storm that fell over 48 hours
- Jan. 19, 2010, following a 32 mm storm that fell over 36 hours
- Jan. 21, 2010, following a 39 mm storm that fell over 36 hours
- Jan. 23, 2010, following a 49 mm storm that fell over 36 hours

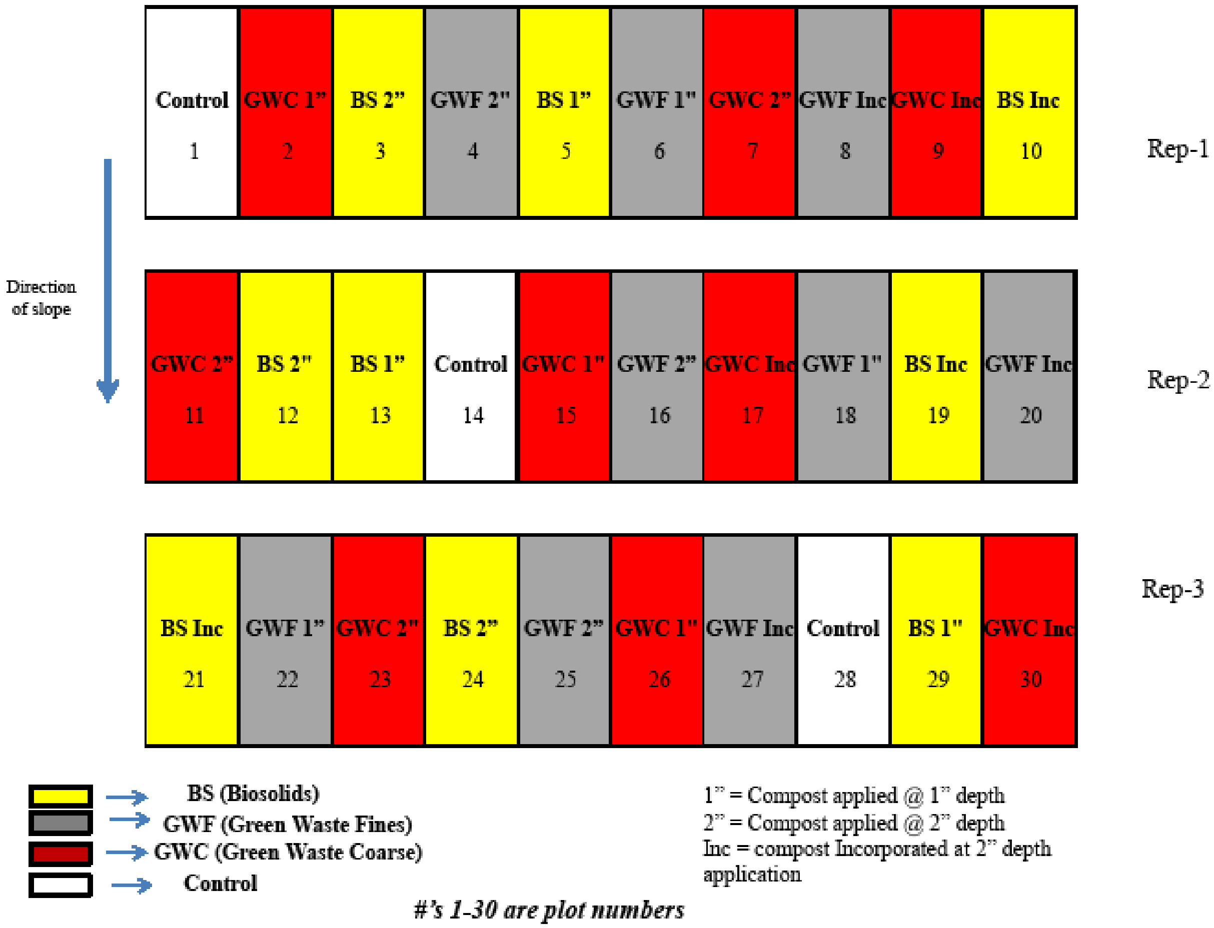


Figure 2. 30 Experimental plots

Figure 3. Fire-damaged study slope

Figure 4. Installed plots

Figure 5. Runoff collection bins

Figure 6. Plot maintenance

Analysis

Sample Collection and Processing

Runoff samples were collected from 30 individual experimental plots on the controlled burn slope. One liter (L) samples were collected from the 114 L (30 gal) bins installed at the foot of each plot. To take a representative sample of the entire runoff, the sample in the bin was thoroughly mixed either by using a paint mixer or mixed by hand. A 1L plastic HDPE sampling bottle was used to collect the samples which were taken within a few seconds after mixing. Sample bottles were labeled with the date of collection, rain event number and the corresponding plot number from which the sample was collected. All sample bottles were immediately stored in an ice chest and moved to a cold room in the laboratory for analysis. Rainfall data, temperature, wind speed and direction, and other weather data were obtained from CIMIS weather station (station# 44) located in very close proximity to the research site.

After the samples were collected, the pH, electrical conductivity (EC) and turbidity of each individual water sample was measured within a holding time of 48 hours (per U.S. EPA stipulations). The pH and EC were measured using U.S. EPA method 150.1 for pH and 120.1 for Electrical Conductivity. A Fisher Scientific Accumet model 15 pH-meter was used for measuring the pH and a Fisher Scientific Accumet model AR 50 conductivity-meter was used to measure the EC. Turbidity was measured using a Micro 100 Turbidimeter (from Scientific Inc.) following U.S. EPA method 180.1. This method uses a dilution factor to dilute the samples if turbidity values are more than 40 nephelometric turbidity units (NTU). However the instrument used during this study had a measurement range from 0.002 NTU to 1200 NTU. All samples fell within the measurement range of the instrument and samples for the turbidity measurements were not diluted. After these measurements were completed, the samples were held for filtration.

Filtration, Chemical Analysis, and Sediment Analysis

A portion of the collected runoff samples were filtered to obtain filtrate samples for further chemical analyses, including total dissolved solids (TDS) and total suspended solids (TSS). U.S EPA methods 160.1 and 160.2 were respectively used for calculating TDS and TSS on the water samples. The standard testing protocol uses a 0.45 µm glass fiber filter for normal water samples, but given the high particulate content in the collected water samples, as well as the large number of samples, it was impossible to filter the samples using a 0.45 µm filter. Instead a 0.70 µm glass fiber filter was used with a Millipore 47 mm glass vacuum filter holders (filtration apparatus) from Fisher Scientific. After the filtrate was obtained, some of the samples were used for estimating TDS and some of them were stored for later chemical analysis. TSS and TDS were both reported in "mg/L" units.

A portion of the filtered sample (about 10 ml) was acid-stabilized using 0.1 ml nitric acid to analyze for metals. This allowed the samples, if necessary, to be stored for longer periods of time before analysis. Another 10 ml of the filtered sample was used to analyze for nitrate, ammonia, phosphate-p and total-phosphorus. U.S. EPA methods 353.2 for nitrate/nitrite nitrogen, 310.2 for ammonium-N, 310.1 for orthophosphate-P and method 365.4 for estimating total-P were used. A Technicon Autoanalyzer-II system with an Alpkem solution sampler and FasPac flow analyzer software package were used for the analysis of nitrate-N, ammonia-N, orthophosphate-P, and total phosphorus. Determination of metals and trace elements was done using EPA method 200.7 with a Perkin Elmer Optima 3000DV ICP-AES (Inductively Coupled Plasma –Atomic Emission Spectrometry) analyzer. The analytes of interest include all EPA part 503 metals. Due to time and expense constraints, analysis of mercury was conducted only on the samples collected after the first rain event when mercury would most likely be observed. All samples used for nitrate and phosphorus analysis were frozen before their actual analysis to prevent degradation. Samples for metal analysis, after acid stabilization, were stored at $4 \pm 2^{o}C$ until actual analysis. For quality analysis and control, a standard check was performed after every 15 samples and samples were duplicated randomly during the chemical analysis to check the accuracy of measurements.

Sediment analysis was conducted on the raw water samples (using ASTM standard test method, D3977-97-A) by evaporation to estimate the sediment concentration in the samples. The original runoff samples, previous to filtration, were allowed to stand without any disturbances for a specific period of time. This allows all the sediments to settle at the bottom of the container. The top clear water was then decanted and sediments were transferred to a 75 ml aluminum drying pan with a known volume of water. These pans with sediment and water mixture were oven dried at $90^{o}C$ for 24 hours until all the water evaporated. The final concentration of sediments in a given sample was calculated and provided in "gm/L."

Results

The results for the runoff experiment are reported in both concentration and mass flux statistics (where appropriate). The complete data set is located in Appendix B: Fire-affected Soil Runoff Statistics. Mass flux values represent the mass of a water quality parameter exported per square meter of land. Mass flux values, while more challenging to determine since they require both a volume and a concentration measurement in order to calculate them, are more informative for evaluating the extent that pollutants are exported from a particular activity rather than just using concentration values especially when runoff volumes are significantly different between control plots and study plots.

$$Flux\ \left(\frac{mg}{m^2}\right) = \frac{Concentration\ \left(\frac{mg}{L}\right) \cdot Runoff\ Volume\ (L)}{Plot\ Area\ (m^2)}$$

Total Runoff Volume

All compost treatments dramatically reduced volumetric runoff when compared to the controls by an order of 1.6 to 23 times, a 37 to 95 percent reduction. The runoff volume reductions due to compost treatments for each rain event are summarized in Table 1 below.

Rain Event	Total Runoff Volume (L)		
	Control	Compost	Percent Reduction
Dec. 14, 2009	1.90	0.33-1.2	37%-83%
Jan. 19, 2010	44.8	4.3-14.4	68%-90%
Jan. 21, 2010	33.2	1.4-4.2	87%-95%
Jan. 23, 2010	27.0	4.0-10.2	62%-85%

Table 1. Fire-damaged site water runoff volume reductions for compost plots compared to control plots

The compost-biosolids generally retained more water than the compost-greenwaste, although this was not consistent for all treatments. The method by which these composts were applied to the soil did not seem to affect runoff rates. As shown in Figure 7, applying 5 cm (2 inches) of compost to the soil did not significantly increase the retention of water on the slopes when compared to the application of a single inch of compost. The runoff depths in the figure were determined by dividing the runoff volume (L) by the area of the plots (5.2 m^2). The result represents the runoff water depth in mm, a measure that can offer a more intuitive understanding of runoff potential as it is independent of the plot area. Incorporation of the compost into the soil retained water similarly to the plots where composts were applied as blankets.

Although the Jan. 23 rain event was largest in magnitude, the Jan. 19 event was associated with the most runoff. There were two reasons for this. First, the compost was still dry beneath the surface and dry compost can be slightly hydrophobic under high precipitation conditions. Second, the Jan. 19 event included periods of high intensity precipitation, including hail, which likely contributed to the elevated runoff measures.

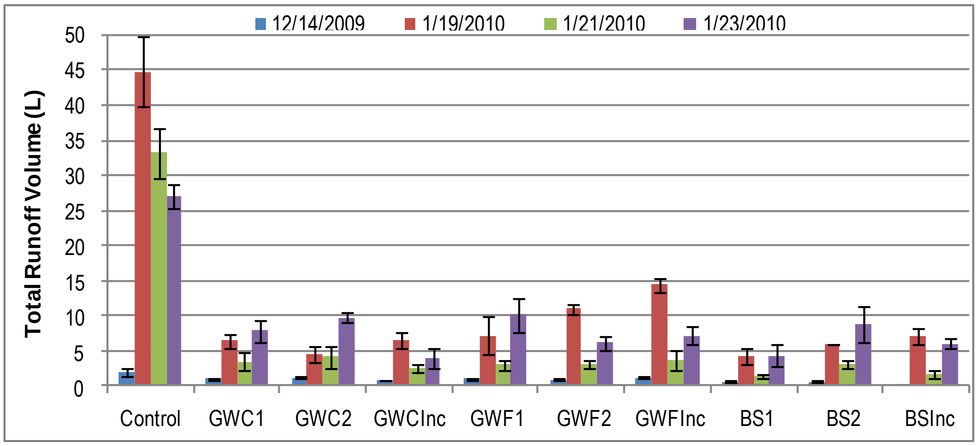


Figure 7. Fire-damaged site water runoff volumes (L) and corresponding depths (mm); mean±standard error, n=3

Turbidity

Turbidity is a measure of how well water transmits light, and is measured in nephelometric turbidity units (NTU). Waters carrying large amounts of sediments (turbid) transmit light poorly. Compost treatments improved turbidity when compared to the controls by an order of 1.3 to 45.4 times, 24-98 percent reduction, as demonstrated in Table 2 below. Turbidity values from the control plots were in the range of 550-850 NTU. Turbidity values from the compost treatments were in the range of 20-540 NTU.

Rain Event	Turbidity (NTU)		
	Control	Compost	Percent Reduction
Dec. 14, 2009	568	86-172	70%-85%
Jan. 19, 2010	708	133-536	24%-81%
Jan. 21, 2010	848	59-257	70%-93%
Jan. 23, 2010	771	17-291	62%-98%

Table 2. Fire-damaged site water runoff Turbidity reductions (min-max), compost treatments compared to control

The controls had substantially more turbidity than the compost treatments during rain events 1, 3, and 4 and graphically depicted in Figure 8. During rain event 2, the turbidity associated with all of the incorporated composts as well as the 1-inch compost-greenwaste blankets could not be distinguished from the controls, although turbidity remained highest for the controls in absolute terms. For the other events, the difference between incorporated composts and compost blankets was not statistically significant, although turbidity from the incorporated plots seemed to be elevated. When turbidity is a significant concern, compost blankets may be a better choice than the use of incorporated composts.

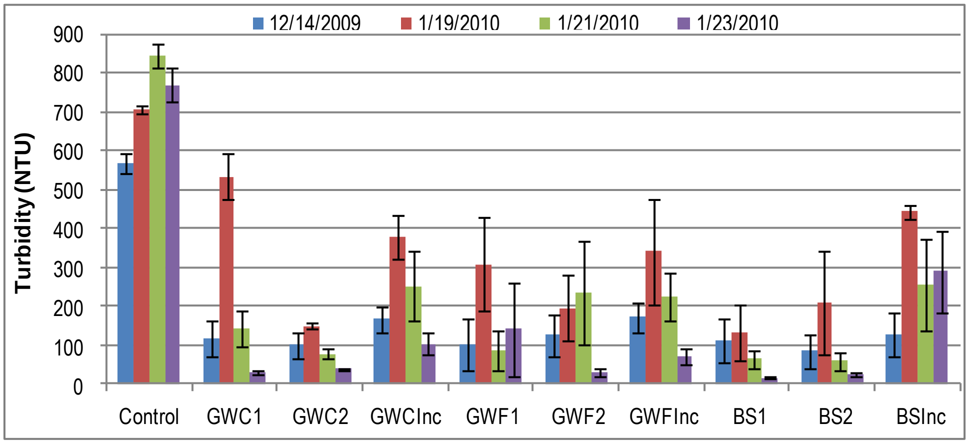


Figure 8. Fire-damaged site Turbidity results (NTU); mean±standard error, n=3

pH

Runoff pH values did not vary significantly between the treatments and the controls, although values during the first storm did appear to be slightly lower than later ones. This is probably due to the intensity of the later storms. Higher flows dilute the effect of soils and composts on runoff pH values, demonstrated by Figure 9. All values were around neutral with a pH of 7.

Rain Event	pH	
	Control	Compost
Dec. 14, 2009	6.87	6.4-7.0
Jan. 19, 2010	7.30	6.7-7.1
Jan. 21, 2010	7.23	7.1-7.5
Jan. 23, 2010	7.33	6.7-7.2

Table 3. Fire-damaged site water runoff pH change (min-max), compost treatments compared to control

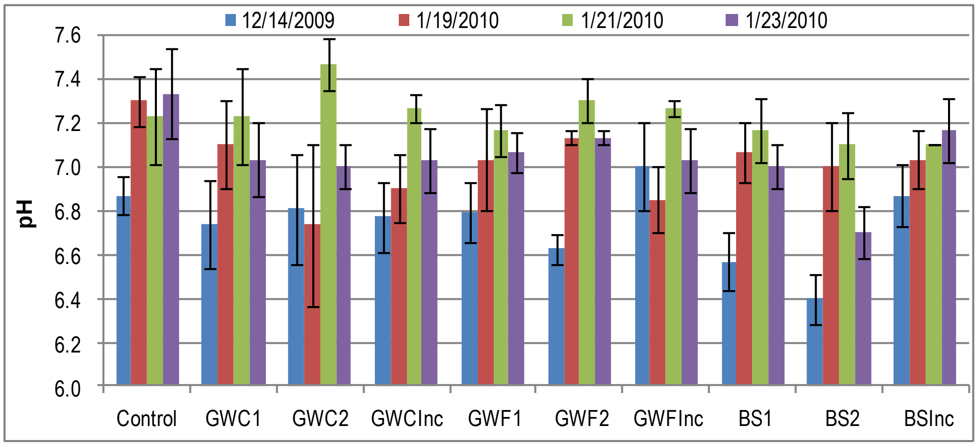


Figure 9. Fire-damaged site runoff pH values; mean±standard error, n=3

Salinity

Salinity is assessed indirectly by measuring the electrical conductivity (EC) of the runoff water. As demonstrated in Table 4, compost-biosolids increased the salinity value of the runoff water when compared to the controls by as much as 7.3 times, over a 600 percent increase, with the largest increase coming from the 2-inch compost-biosolids surface applications. Salinity measures for the compost-greenwaste treatments were slightly larger than for the controls with a 1.2 to 1.7 times increase, but differences were, in most cases, not statistically significant (one-tailed t-test, $p=0.05$).

[Note: While salinity increased from the compost treatments, runoff volumes from the compost treated plots were significantly lower than the control plots. It is therefore important to look at the total mass flow of salts in runoff as an indicator rather than the concentration of salts. For example, compost-biosolids plots had lower total runoff volumes but showed a significantly higher salinity value in the runoff, which does not necessarily indicate that the compost-biosolids released the most salts. The mass of salts leaving a site can be calculated by multiplying observed concentrations by runoff volumes. Although flow weighted adjustments for salinity may be inappropriate because no mass concentration value is involved, such adjustments are possible using Total Dissolved Solids (TDS) concentrations, shown in Table 5. Also salinity does not take into consideration the speciation of salts.]

Figure 10 shows that salinity was highest following the first storm. Compost-biosolids were associated with the highest salinity concentrations, particularly the 5 cm (2-inch)(BS2) applications.

Rain Event	Salinity (dS/m)		
	Control	Compost	Percent Increase
Dec. 14, 2009	0.31	0.19-2.3	(39%)*-629%
Jan. 19, 2010	0.06	0.06-0.40	0.0%-566%
Jan. 21, 2010	0.03	0.04-0.23	33%-667%
Jan. 23, 2010	0.03	0.03-0.13	0.0%-333%

Table 4. Fire-damaged site water runoff EC change (min-max), compost treatments compared to control

** This particular value demonstrated a reduction of 38 percent.*

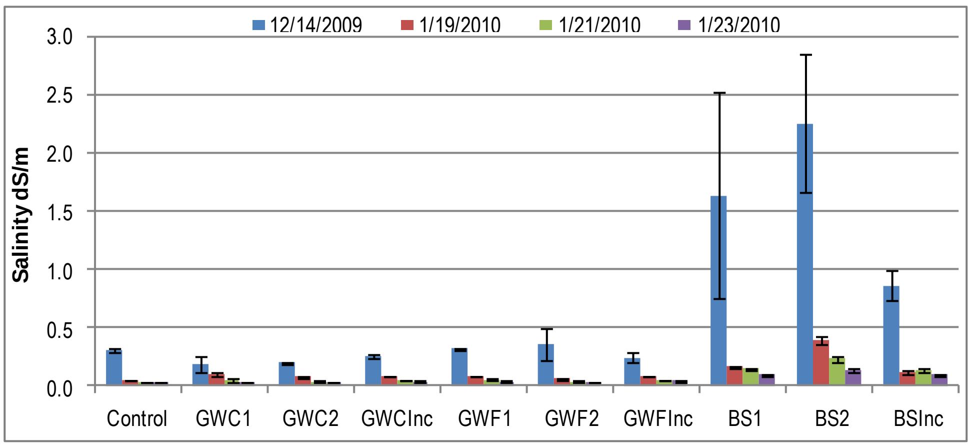


Figure 10. Fire-damaged site Salinity (electrical conductivity, dS/m); mean±standard error, n=3

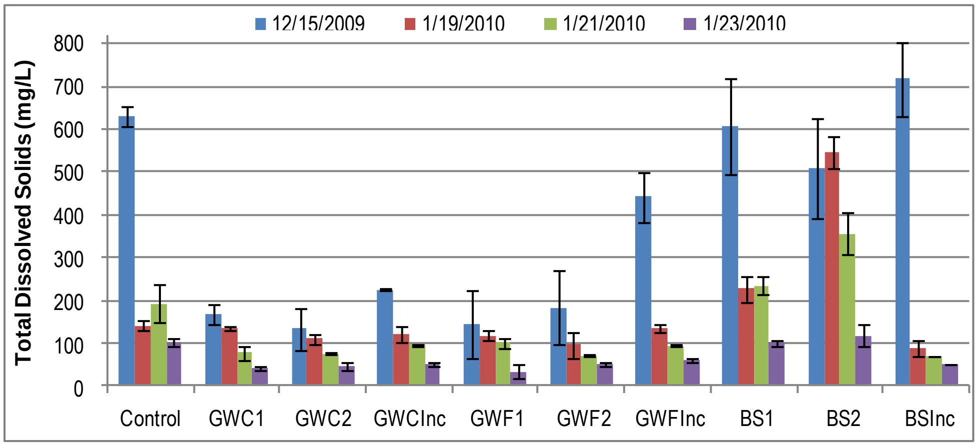
Total Dissolved Solids

Compost treatments reduced the export of Total Dissolved Solids (TDS) on a mass flux basis by an order of 1.2-10.6 times, 15-91 percent reduction, when compared to the controls as seen in Table 5 below. Table 27 in the appendix demonstrates that, when mass flux losses are considered, the controls were significantly elevated compared to the compost-greenwaste and in fact far exceed the losses from the compost-biosolids by margins averaging from 2:1 to 5:1. Total Dissolved Solid values directly measure the concentrations of the dissolved salts and other minerals in runoff water are shown in Table 24 in Appendix B.

Rain Event	Total Dissolved Solids (mg/m2)		
	Control	Compost	Percent Reduction
Dec. 14, 2009	247.6	27.1-99.0	60%-89%
Jan. 19, 2010	743.2	101-632	15%-86%
Jan. 21, 2010	445.5	41.9-211	53%-91%
Jan. 23, 2010	267.6	39.5-178.1	33%-85%

Table 5. Fire-damaged site water runoff, Total Dissolved Solids decrease (min-max) on a mass flux basis, compost treatments compared to control

As with salinity, TDS concentrations were highest in water leaving the compost-biosolids plots, particularly the 2-inch treatments, as seen in Figure 11. BS2 treatments also released significantly more suspended solids than either BS1 or BSInc. Use of 5 cm (2 inches) of compost provided no benefit compared to the use of 2.5 cm (1 inch), and in the case of the compost-biosolids, 5 cm (2 inches) exported more dissolved solids. It should be noted that the controls exported the largest concentrations of TDS associated with the first rain event.



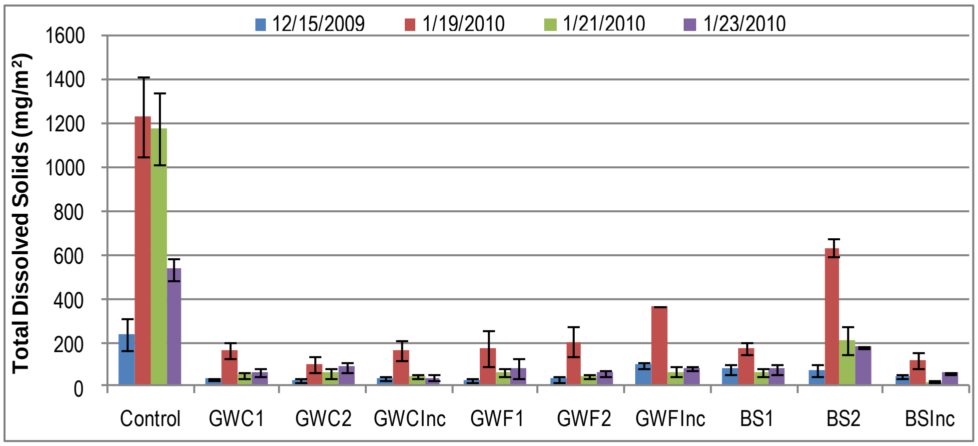


Figure 11. Fire-damaged site Total Dissolved Solids concentrations (mg/L) and mass fluxes (mg/m^2); mean±standard error, n=3

Total Suspended Solids

Compost treatments dramatically reduced Total Suspended Solids (TSS) by an order of 3.6 to 438 times, 72-100 percent reduction, when compared to the controls on a mass flux basis, as demonstrated in Table 6.

Rain Event	Total Suspended Solids (mg/m2)		
	Control	Compost	Percent Reduction
Dec. 14, 2009	15.68	1.62-4.32	72%-90%
Jan. 19, 2010	478.6	2.95-44.6	91%-99%
Jan. 21, 2010	329.1	0.75-13.1	96%-100%
Jan. 23, 2010	181.5	4.79-27.5	85%-97%

Table 6. Fire-damaged site water runoff, Total Suspended Solids decrease (min-max) on a mass flux basis, compost treatments compared to control

When considering just the compost treatments, losses were generally higher from the 5 cm (2 inch) and incorporated treatments than from the 2.5 cm (1 inch) treatments, though these differences were not statistically significant as seen in Figure 12.

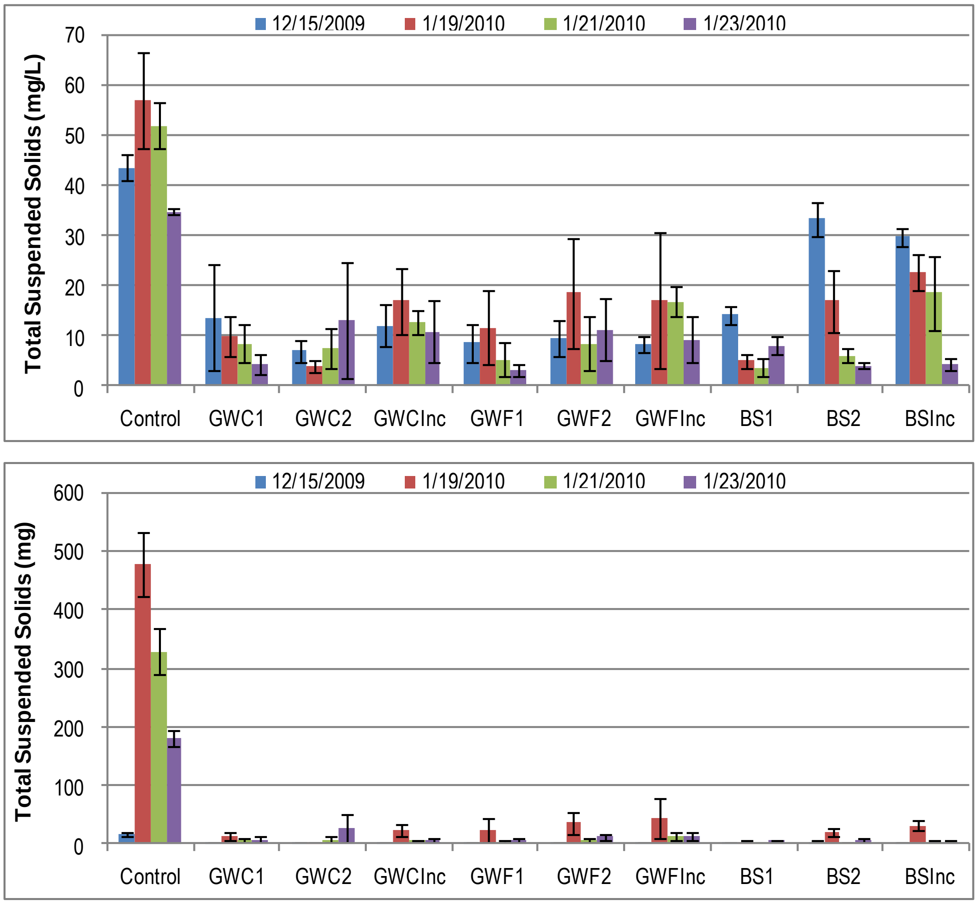


Figure 12. Fire-damaged site Total Suspended Solids concentrations (mg/L) and mass fluxes (mg/m^2); mean±standard error, n=3

Total Sediments

Compost treatments significantly reduced total sediments in runoff water compared to the controls. As seen in Table 7, differences were extreme for the mass flux values where compost treatments reduced total sediments by 7.5 to 536 times, 87-100 percent reduction.

Rain Event	Total Sediments (gm/m2)		
	Control	Compost	Percent Reduction
Dec. 14, 2009	15.98	0.25-2.11	87%-98%
Jan. 19, 2010	435.2	5.68-45.2	90%-99%
Jan. 21, 2010	338.7	0.63-16.75	95%-100%
Jan. 23, 2010	233.7	1.02-18.4	92%-100%

Table 7. Fire-damaged site water runoff, Total Sediments decrease (min-max) on a mass flux basis, compost treatments compared to control

Figure 13 shows concentrations of total sediments coming from the compost treatments were 3 to 40 times lower than from the controls. The lowest loss rates were associated with BS1, GWF1 and GWC1, suggesting that 2-inch mulch provides optimal control of TS.

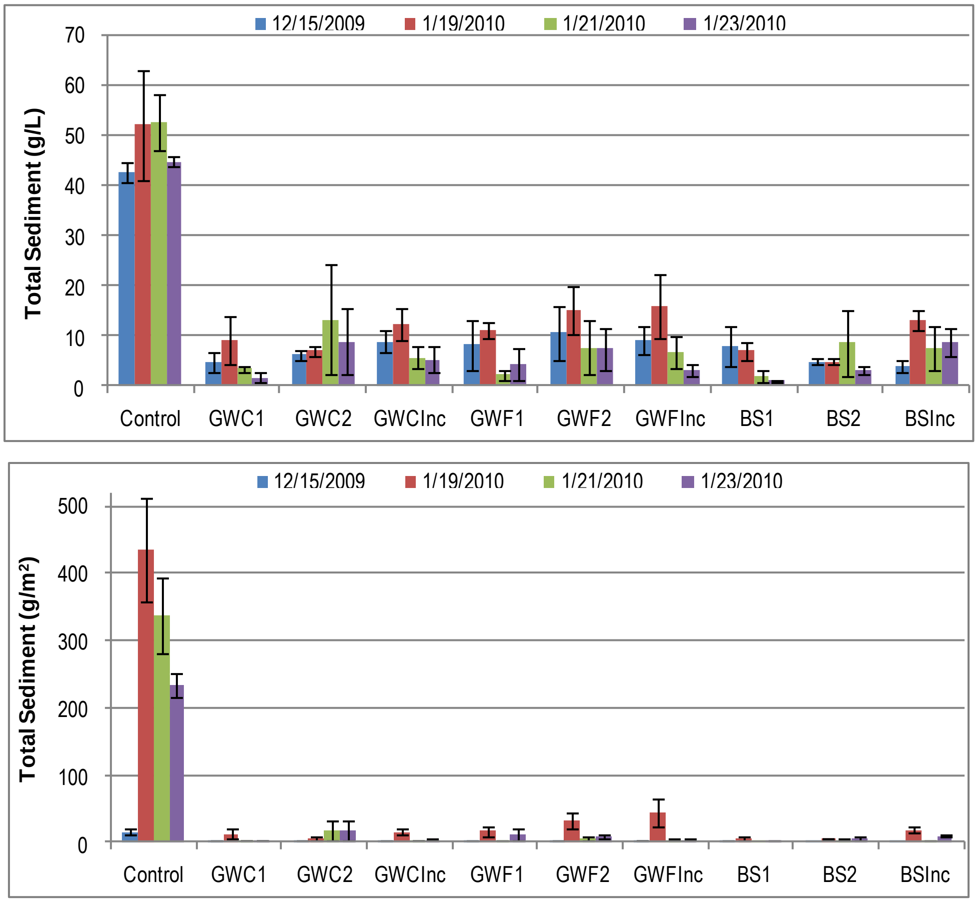


Figure 13. Fire-damaged site Total Sediment concentrations (g/L) and mass fluxes (g/m^2); mean±standard error, n=3

Total Phosphorus

Total phosphorus values were reduced by almost all of the compost treatments. On a mass flux basis, total phosphorus was reduced by up to 15 times compared to the controls, as demonstrated in Table 8 below. Mass flux losses were statistically significantly at their highest in the controls during the last three rain events. Compost-biosolids treatment mass fluxes were elevated during the first storm by a statistically significant amount, not variability, compared to the controls and other treatments.

Rain Event	Total Phosphorus (mg/m2)		
	Control	Compost	Percent Reduction
Dec. 14, 2009	0.695	0.275-6.07	(774%)*-60%
Jan. 19, 2010	12.00	1.03-6.13	49%-91%
Jan. 21, 2010	4.201	0.280-1.21	71%-93%
Jan. 23, 2010	2.172	0.174-1.72	20%-92%

Table 8. Fire-damaged site water runoff, Total Phosphorus decrease (min-max) on a mass flux basis, compost treatments compared to control

** This particular value demonstrated an increase of 774 percent.*

Concentrations were highest in the compost-biosolids plots, though differences were statistically significant only for the last two rain events. Concentrations following the first rain event were considerably higher from the compost-biosolids plots, but values were highly variable, suggesting that losses are initially dominated by erosive high phosphorus particles, demonstrated in Figure 14 below. Values stabilized after the first event and no further outliers were observed. The explanation for this is not clear. To avoid eutrophication in receiving waters, phosphorus is intentionally removed as part of the wastewater treatment process at sewage treatment plants. During treatment, phosphorus in the water combines with added aluminum, iron, or other chemicals and is converted to insoluble forms through a process that encourages coagulation and flocculation (Jiang and Graham, 1998; Maguire et al., 2001; Morse et al., 1998). It may be that erodible high phosphorus flocs were initially present in the compost-biosolids; however, this should have been detected during the later high-intensity storms, not just in the first storm event.

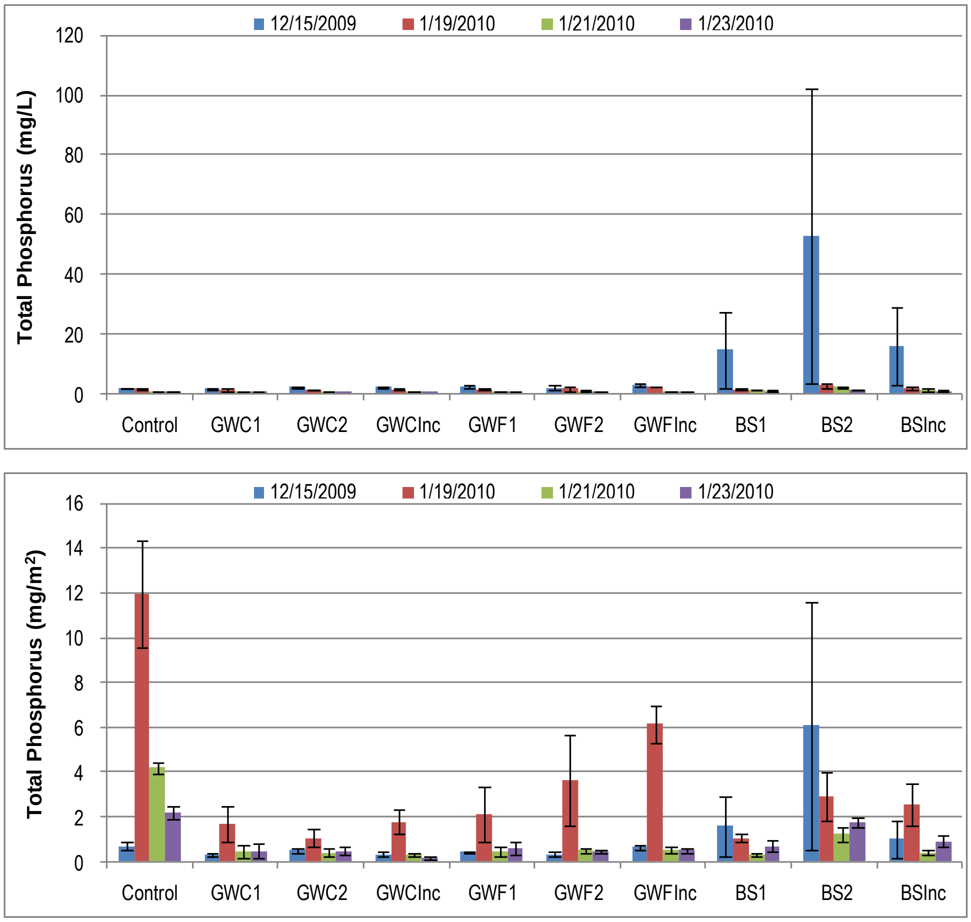


Figure 14. Fire-damaged site Total Phosphorus concentrations (mg/L) and mass fluxes (mg/m^2); mean±standard error, n=3

Orthophosphate-P

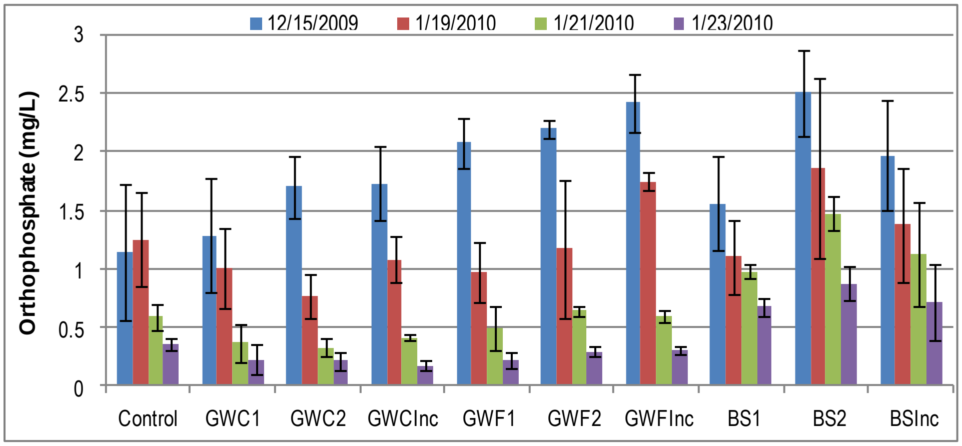
Orthophosphate-P values were reduced by almost all of the compost treatments. On a mass flux basis, orthophosphate-P was reduced by up to 18.3 times when compared to the controls as shown in Table 9. Orthophosphate-P mass flux losses were generally significantly higher in the controls during events 2, 3, and 4.

Rain Event	Orthophosphate-P (mg/m2)		
	Control	**Compost**	**Percent Reduction**
Dec. 14, 2009	0.310	0.130-0.545	(76%)*-58%
Jan. 19, 2010	10.26	0.746-4.85	53%-93%
Jan. 21, 2010	3.622	0.198-0.880	76%-94%
Jan. 23, 2010	1.884	0.125-1.39	26%-93%

Table 9. Fire-damaged site water runoff, Orthophosphate-P decrease (min-max) on a mass flux basis, compost treatments compared to control

** This particular value demonstrated an* <u>*increase*</u> *of 75.8 percent.*

Orthophosphate-P concentrations tended to be higher from the compost-biosolids treatments than from the compost-greenwaste treatments as seen in Figure 15, however, concentration differences were only significant during the last two events. Unlike total phosphorus, orthophosphate-P was not particularly elevated in the compost-biosolids during the first event, confirming the key role of erodible particulates from the compost-biosolids after initial installation.



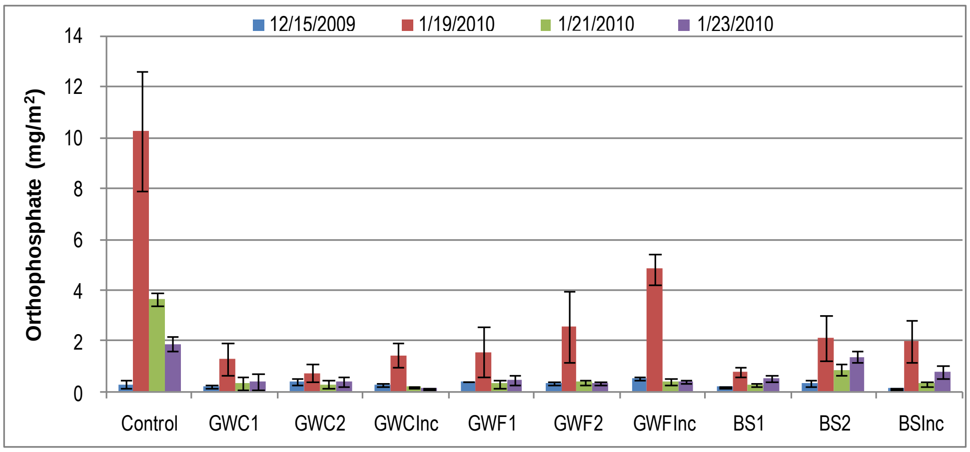


Figure 15. Fire-damaged site Orthophosphate-P concentrations (mg/L) and mass fluxes (mg/m^2); mean±standard error, n=3

Nitrate-N

Table 10 demonstrates that Nitrate-N was reduced 1.6 to 25.7 times, 39-96 percent reduction, by the compost treatments compared to the controls on a mass flux basis. Mass flux losses were greatest from the control plots, even though concentrations from the controls remained relatively low after the first event. This was due to the high volumes escaping the bare control soils. Statistically, the control plot mass fluxes were comparable to the compost-biosolids plots.

Rain Event	Nitrate-N (mg/m2)		
	Control	**Compost**	**Percent Reduction**
Dec. 14, 2009	3.70	0.22-0.89	76%-94%
Jan. 19, 2010	4.06	0.80-2.3	43%-80%
Jan. 21, 2010	1.44	0.07-0.77	46%-95%
Jan. 23, 2010	0.77	0.03-0.47	39%-96%

Table 10. Fire-damaged site water runoff, Nitrate-N decrease (min-max) on a mass flux basis, compost treatments compared to control

Nitrate-N values also include nitrite-N, which is normally quickly oxidized to nitrate in the environment. During the first runoff event, concentrations were highest in the controls and compost-biosolids treatments, though differences with the other treatments were not statistically significant due to substantial variability, shown in Figure 16 below. Concentrations fell steadily during subsequent storms. In all cases except one (rain event 1 BSInc value of 11.1) mean concentrations were below the U.S. EPA's 10 mg/L drinking water standard for Nitrate-N. Concentrations in subsequent events were all less than 2.5 mg/L.

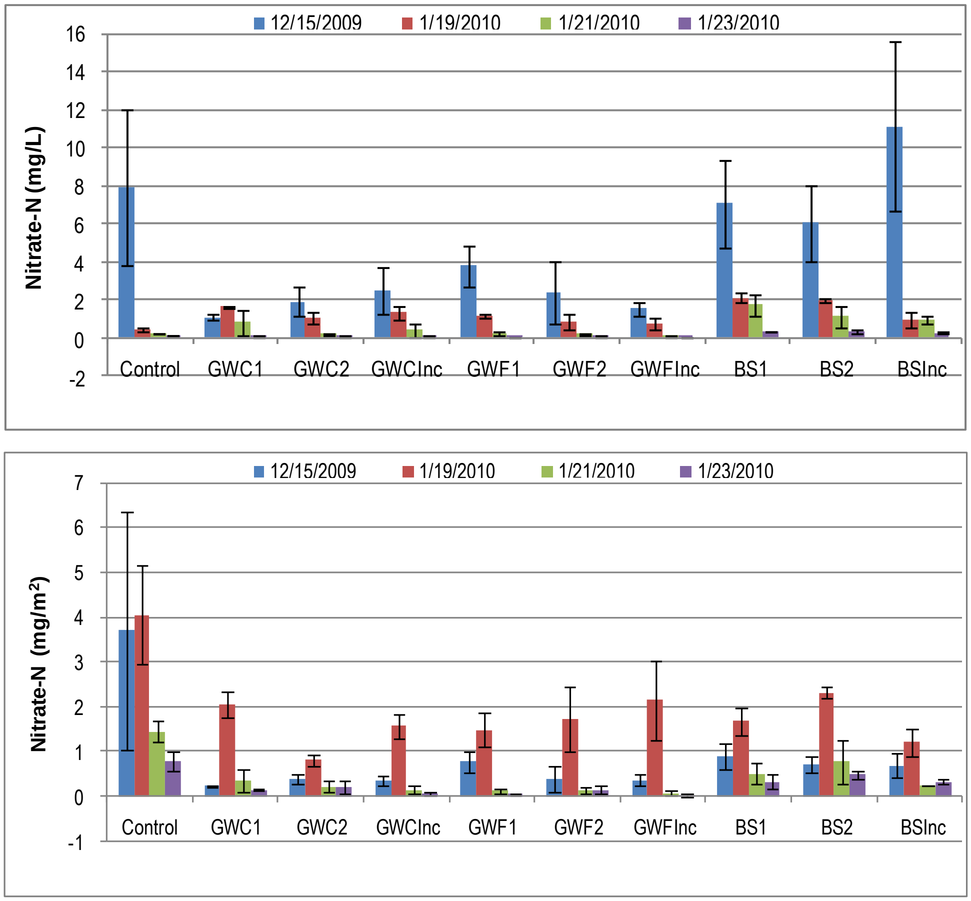


Figure 16. Fire-damaged site Total Nitrate-N concentrations (mg/L) and mass fluxes (mg/m²); mean±standard error, n=3

Ammonium-N

Ammonium-N values were lower in all of the compost-greenwaste treatments by 1.2 to 27 times, 15-96 percent reduction, compared to the controls on a mass flux basis, with the only exception occurring with GWC1 on the first storm event which was a 7.2 times increase. Compost-biosolids treatments values, however, were increased when compared to the controls on a mass flux basis by 1.6 to 132 times, 58-13,054 percent increase. While the mass flux values from the BS1 and BSInc treatments were elevated, except for event 4, they were not statistically significantly different from other treatments. Following all four rain events, mass flux values from the BS2 plots was significantly elevated compared to all other treatments.

Rain Event	Ammonium-N (mg/m2)				
	Control	Compost		Percent Reduction	Percent Increase
		GW	BS	GW	BS
Dec. 14, 2009	0.13	0.05-0.93	1.6-17.1	(615%)*-61%	1,130%-13,054%
Jan. 19, 2010	4.11	0.49-1.67	6.5-40.4	59%-88%	58%-880%
Jan. 21, 2010	0.81	0.03-0.12	1.3-11.6	85%-96%	65%-1,332%
Jan. 23, 2010	0.61	0.12-0.31	2.4-11.8	49%-80%	298%-1,834%

Table 11. Fire-damaged site water runoff, Ammonium-N decrease (min-max) on a mass flux basis, compost treatments compared to control

** This particular value demonstrated an increase of 615 percent.*

Ammonium values were highest in the BS2 treatments, approximately 300 times the control values following event 1, and averaged 106 times higher during subsequent events on a concentration basis. Concentrations in the BS1 and BSInc treatments were lower than BS2, but significantly elevated compared to both the controls and compost-greenwaste treatments as demonstrated in Figure 17 below. Most of the ammonium released from the compost-biosolids will be converted to nitrate, a significant source of groundwater pollution. For this reason, the results suggest that compost-biosolids should not be applied at depths greater than 2.5 cm (1 inch).

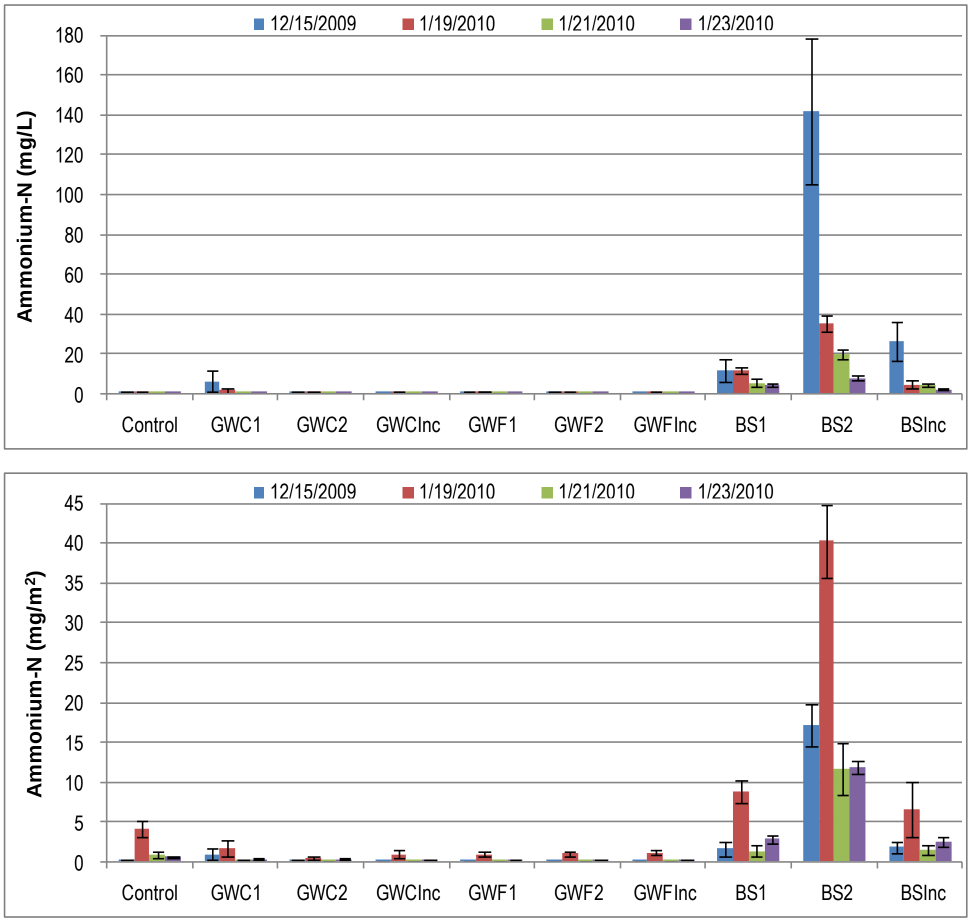


Figure 17. Fire-damaged site Total Ammonium-N concentrations (mg/L) and mass fluxes (mg/m^2); mean±standard error, n=3

Metals

Due to the importance of comparing the values against both the California/U.S. EPA Drinking water standard and the California Toxic Rule Criteria (U.S. EPA) Inland Surface Water Freshwater Aquatic Life Protection Maximum Concentration (1-hour average), the analysis below only considers concentration values and not mass flux values. The Total Recoverable Maximum Concentration (1-hour average) for the lowest listed hardness, 25 mg/L $CaCO_3$, from the "A Compilation of Water Quality Goals (August 2003) compiled by the California Regional Water Quality Control Board—Central Valley Region was used as applicable for cadmium, copper, lead, nickel, and zinc. Although mercury has been observed to accumulate in soils following wildfires (Burke et al., 2010), no mercury was detected in the runoff from this study (analysis of mercury limited to the first rain event). The complete data tables can be found in Appendix B: Table 30 to Table 39.

Arsenic: Arsenic was detected in 7 of 9 compost treatment runoff samples from the first rain event, but only once in each of the subsequent events. Recorded values were just above the detection limit of 0.01 mg/L at 0.0105 mg/L. Control values were below the detection limit. On average, arsenic's concentrations were 1.3 times greater than the California/U.S. EPA Drinking Water Standard, but 28 times lower than the Freshwater Aquatic Life standard.

Cadmium: Cadmium was present during the first two rain events, but was only detected twice afterwards (from the BS2 treatments). The control values were below the detection limit. On average, cadmium's concentrations were 8.2 times lower than the California/U.S. EPA Drinking Water standard and 1.5 times lower than the Freshwater Aquatic Life standard.

Chromium: Chromium concentrations lowered with each rain event and the final rain event yielded only 2 detections. On average, chromium's concentrations were 3.7 times lower than the California/U.S. EPA Drinking Water standard. There is no Freshwater Aquatic Life standard for chromium.

Copper: Copper was detected in all samples for all events. On average, copper's concentrations were 3.2 times greater than the control values, 58 times lower than the California/U.S. EPA Drinking Water standard, and 13.3 times greater than the Freshwater Aquatic Life standard. However, the control values were also (on average) 6.7 times greater than the Freshwater Aquatic Life standard.

Nickel: Nickel was detected in all of the compost treatment runoff samples from the first three rain events and in 6 of 9 samples from the fourth rain event. Concentrations, however, decreased steadily with each rain event. On average, nickel's concentrations were 3.6 times greater than the control, 36 times lower than the California/U.S. EPA Drinking Water standard, and 54 times lower than the Freshwater Aquatic Life standard.

Lead: Lead was not detected from either the control or compost treatments.

Selenium: Selenium was only detected twice from the compost-greenwaste treatments runoff, and in 4 of 27 compost-biosolids treatments (values were exactly at the detection limit). Selenium's concentrations were (on average) 2 times lower than the California/U.S. EPA Drinking Water standard (one detect at 1.3 times greater than the standard), and (on average) were 1.5 times greater than the Freshwater Aquatic Life standard.

Zinc: Zinc was detected in all runoff samples, but the concentration decreased with each storm event. On average, zinc's concentrations were 2.2 times greater than the control and 3.8 times greater than the Freshwater Aquatic Life standard. There is no drinking water standard for zinc.

Molybdenum: Molybdenum runoff concentrations were on average 3.4 times greater than the controls. However, BS2's treatments' average was 13.3 times greater than the control. Concentrations for compost-greenwaste runoff values were 1.3 times greater than the control.

Construction Soil Study

Compost treatments can be used to remediate soils damaged by either construction activities or fire. Construction activities commonly strip soils of organic matter which is needed to maintain the soils' structure. Further, heavy equipment moving on soils results in compaction which decreases the soils' infiltration potential and increases water runoff. This compaction of soils is also associated with rilling due to erosion. Intentional soil compaction is sometimes done as a method for preventing moisture movement or to help stabilize steep slopes. Compost treatments can slow water movement through soil, decreasing the amount of rilling and improving infiltration. Compost treatments will increase the soil's organic matter content, fertility and structure, which will allow water and air to penetrate through, and be held by, the soil. As a result, compost use will increase the germination and growth of plants, furthering to the interception of falling precipitation so that soil particles are not dislodged, decreasing runoff.

Methods

This experiment considered one-inch applications of (1) fine compost-greenwaste, and (2) compost-biosolids. The objectives of the study were to:

A. Establish compost plots on a site recently damaged by construction activity. Both compost materials were applied as a 2.5 cm (1 inch) thick compost blanket. In addition, three seeded treatments were made: (1) no reseeding, (2) a basic native erosion control mix and (3) an inland sage scrub mix. Each treatment included three replicates for a total of 27 plots.

B. Measure runoff volumes from three storm events during January 2010. Because revegetation was not expected by this time, data from the different seed mix treatments were combined. There were nine compost-biosolids plots, nine compost-greenwaste plots, and nine control plots providing superior statistical power.

C. Measure potential pollutants in the runoff including turbidity, pH, salinity, total dissolved solids, total suspended solids, total sediments, total phosphorus, orthophosphate-P, nitrate-N, ammonium-N, and trace metals (arsenic, cadmium, copper, chromium, lead, molybdenum, nickel, mercury, and zinc.)

D. Make recommendations as to the use of compost for reducing water pollution from construction sites

Site Establishment and Sampling

This experiment was also located at the Citrus Research Center and Agricultural Experiment Station on the same slope where the fire-damaged soil plots were located. As previously mentioned, the site has a uniform 4:1 slope and was thickly covered in vegetation typical of surrounding unmanaged areas. In late November 2009, using a front-end loader, the area was completely denuded of its vegetation by removing the topsoil and all of its plants to represent a typical construction soil. Twenty-seven plots identical in size to the plots used for the fire-damaged soils study, 4.27 m (14 ft) long and 1.22 m (4 ft) wide, were established.

Treatments included:

- 2.5 cm (1 inch) compost from a mix of biosolids and greenwaste feedstocks (compost-biosolids) applied as a mulch
- 2.5 cm (1 inch) fine compost from a greenwaste feedstock (compost-greenwaste) applied as a mulch
- An undisturbed control

In addition, native seed mixes were purchased from S&S Seeds so that each compost treatment included one of three seed mixes (SM):

- SM1, a basic native erosion control mix;
- SM2, an inland sage scrub mix; and
- SM3, an unseeded control.

Seeds were applied in the third week of December 2009, and hand incorporated to a depth of 6 mm at twice the recommended application rate of 32 lbs/acre for SM1 and 46 lbs/acre for SM2. Figure 18 illustrates the split-plot design layout implemented for the study. Three replications were included for each treatment. There were nine treatments. Mulch treatments were applied to the soil surface.

The species included in SM1, the basic native erosion control mix included:

- *Bromus carinatus* "Cucamonga" (Cucamonga Brome);
- *Trifolium tridentatum* (Tomcat Clover); and
- *Vulpia microstachys* (Small Fescue).

SM2, the inland sage scrub mix, included the following species:

- *Artemisia californica* (California Sagebrush)
- *Atriplex canescens* (Four-wing Saltbrush)
- *Baccharis sarothroides* (Broom Baccharis)
- *Encelia actonii* (Acton Bush Encelia)
- *Eriogonum fasciculatum* (Hairy Yerba Santa)
- *Eriogonum fasciculatum* (California Buckwheat)
- *Eriophyllum confertiflorum* (Golden Yarrow)
- *Eschscholzia californica* (California Poppy)
- *Isomeris arborea* (Bladderpod)
- *Lasthenia glabrata* (Goldfields)
- *Lotus scoparius* (Deerweed)
- *Lupinus succulentus* (Arroyo Lupine)
- *Salvia apiana* (White Sage)
- *Salvia mellifera* (Black Sage)
- *Vulpia microstachys* (Small Fescue)

As in the fire-damaged study, a collection area was installed at the bottom of each plot including 6 cm of aluminum flashing and a 10.2 cm (4 in) inner diameter PVC collection pipe running the width of the plots perpendicular to the slope. Each collection pipe was then connected through a 90° elbow to an additional 10.2 cm (4 in) PVC pipe running down slope to covered 113 L (30 gal) plastic bins at the bottom of the slope. To prevent inadvertent entry of precipitation directly into the bins, the bins were also covered with anchored waterproof tarps. The system was cleaned and inspected prior to each rain event.

SM1- Seed Mix type-1
SM2- Seed Mix type-2
SM3- Seed Mix type-3 (no actual seed mix)

Figure 18. Construction Study plot design

Runoff was measured and sampled following three separate storm events.

- Jan. 19, 2010, following a 32 mm storm that fell over 36 hours
- Jan. 21, 2010, following a 39 mm storm that fell over 36 hours
- Jan. 23, 2010, following a 49 mm storm that fell over 36 hours

The water sampling procedure was identical to the fire-damaged soil plots. Because no significant vegetation had emerged at the time runoff was sampled, the seed treatments were lumped together so that there were 9 treatments with a 2.5 cm (1 inch) compost-greenwaste blanket, 9 treatments with a 2.5 cm (1 inch) compost-biosolids blanket, and 9 untreated controls. This significantly increased the statistical validity of the analysis.

Emergent vegetation was later surveyed on March 26, 2010 by Andrew C. Sanders, curator and museum scientist of the University of California, Riverside Herbarium.

Results

Since the Fire-Damaged Soil Study and the Construction Soil Study were conducted simultaneously and shared much of the same data, their results had similar characteristics. Concentration and mass flux statistics from the runoff experiments are included in Appendix B: Complete Data Tables. Mass flux values represent the mass of a water quality parameter exported per square meter of land. Mass flux values, while more challenging to determine since they require both a volume and a concentration measurement in order to calculate them, are more informative for evaluating the extent that pollutants are exported from a particular activity rather than just using concentration values especially when runoff volumes are significantly different between control plots and study plots.

$$Flux\ \left(\frac{mg}{m^2}\right) = \frac{Concentration\ \left(\frac{mg}{L}\right) \cdot Runoff\ Volume\ (L)}{Plot\ Area\ (m^2)}$$

Total Runoff Volume

Total runoff volumes for the control plots were 77-87L. Total runoff volumes for plots treated with compost were 3-17 times lower than the controls. Plots treated with compost-greenwaste showed total runoff volumes in the range of 15-25L and plots treated with compost-biosolids showed total runoff volumes in the range of 5-8L. As a result, compost treatments were very effective in reducing total runoff volumes by 68-94 percent as demonstrated in Table 12 below.

Rain Event	Total Runoff Volume (L)				
	Control	Compost		Percent Reduction	
		GWC	BS	GWC	BS
Jan. 19, 2010	77.0	24.3	5.5	68%	92%
Jan. 21, 2010	86.9	15.8	5.1	82%	94%
Jan. 23, 2010	86.0	16.9	7.7	80%	91%

Table 12. Construction site water runoff Total Volume decrease (min-max), compost treatments compared to control

While there was more runoff from the compost-greenwaste than from the compost-biosolids, the differences were not statistically significant as demonstrated by Figure 19. Both compost treatments contributed significantly less runoff than the controls.

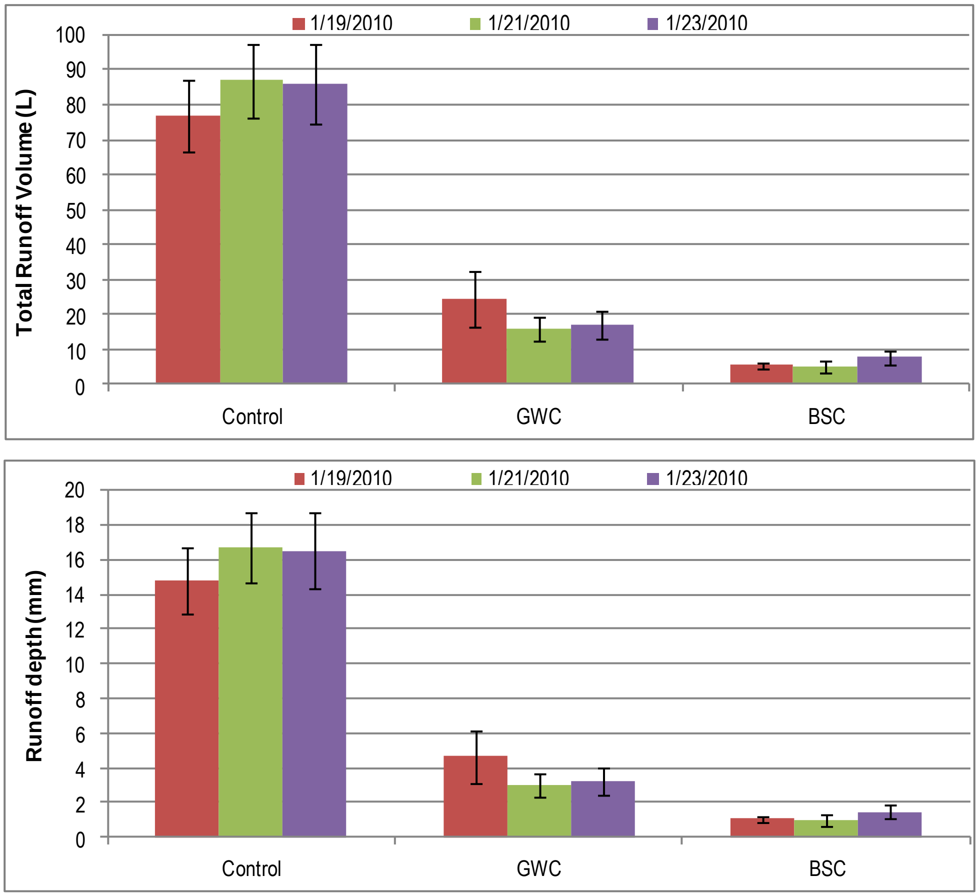


Figure 19. Construction site water Runoff volumes (L) and corresponding depths (mm); mean±standard error, n=9

Turbidity

Turbidity was significantly reduced by both GWC and BSC compost treatments 1.9 to 6.1 times, 48 - 84 percent reduction, when compared to the control as shown in Table 13.

Rain Event	Turbidity (NTU)				
	Control	Compost		Percent Reduction	
		GWC	BS	GWC	BS
Jan. 19, 2010	954	494	467	48%	51%
Jan. 21, 2010	975	203	368	79%	62%
Jan. 23, 2010	859	139	248	84%	71%

Table 13. Construction Site water runoff Turbidity decrease (min-max), compost treatments compared to control

Figure 20 shows that turbidity was, on average, 4.3 times higher in the control runoff than in the compost-greenwaste runoff.

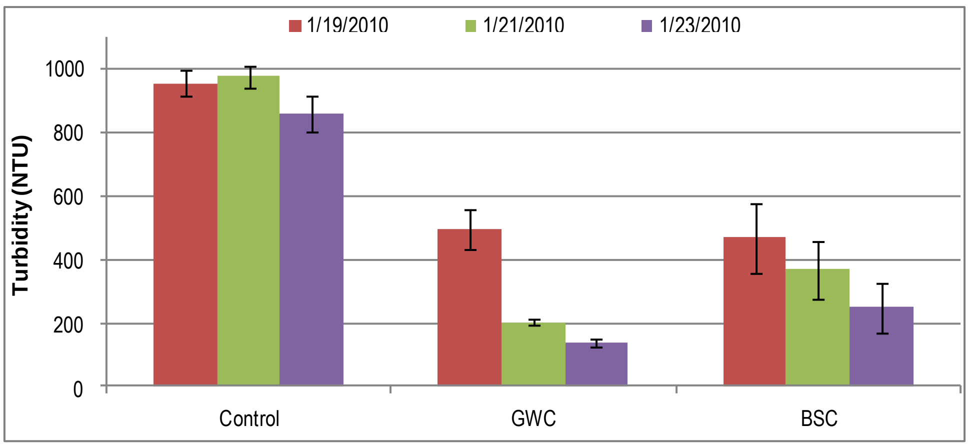


Figure 20. Construction site Turbidity results (NTU); mean±standard error, n=9

pH

pH values were reduced by 1-8 percent when compared to the controls for both CWC and BSC, as demonstrated in Table 14 below.

Rain Event	**Control**	**pH**	
		GWC	BS
Jan. 19, 2010	7.13	6.6	6.5
Jan. 21, 2010	7.46	7.1	6.9
Jan. 23, 2010	7.33	7.2	7.0

Table 14. Construction site water runoff pH decrease (min-max), compost treatments compared to control

pH was slightly lower in the runoff from the compost treatment than from the control, though all values were in the neighborhood of neutral, shown in Figure 21 below. This difference was statistically significant. Mean values were 7.3, 7.0, and 6.8 for the control, compost-greenwaste and compost-biosolids runoff respectively. Compost treatment values were higher during the last two storm events, probably as a result of flushing of ammonium and possibly organic acids during the first storm.

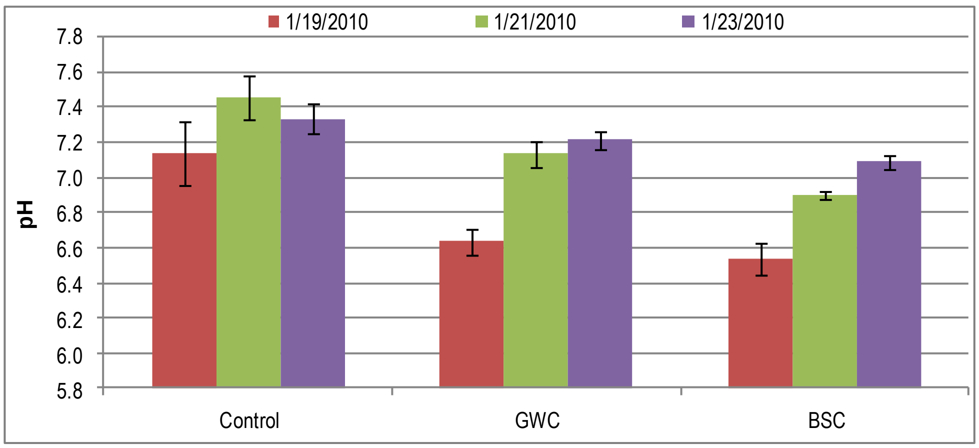


Figure 21. Construction site runoff pH values; mean±standard error, n=9

Salinity

Salinity was significantly higher in runoff from the compost treatments compared to the control (one-sided t-test, p=0.05). Values were increased by the compost treatments 4.4 to 11.8 times, 340-1,080 percent increase, over the control.

[Note: While salinity increased from the compost treatments, runoff volumes from the compost treated plots were significantly lower than the control plots. It is important to look at the total mass flow of salts in runoff rather than an indicator of the concentration of salts. For example, compost-biosolids plots had lower total runoff volumes but showed a significantly higher salinity value in the runoff which does not necessarily indicate that the compost-biosolids released the most salts. The mass of salts leaving a site can be calculated by multiplying observed concentrations by runoff volumes. Although flow weighted adjustments from salinity may be inappropriate because no mass concentration value is involved, such adjustments are possible using Total Dissolved Solids (TDS) concentrations, shown in Figure 22. Also salinity does not take into consideration the speciation of salts.]

Rain Event	Salinity (dS/m)				
	Control	Compost		Percent Increase	
		GWC	BS	GWC	BS
Jan. 19, 2010	0.020	0.232	0.190	1060%	850%
Jan. 21, 2010	0.010	0.079	0.118	690%	1080%
Jan. 23, 2010	0.015	0.066	0.128	340%	753%

Table 15. Construction site water runoff Salinity decrease (min-max), compost treatments compared to control

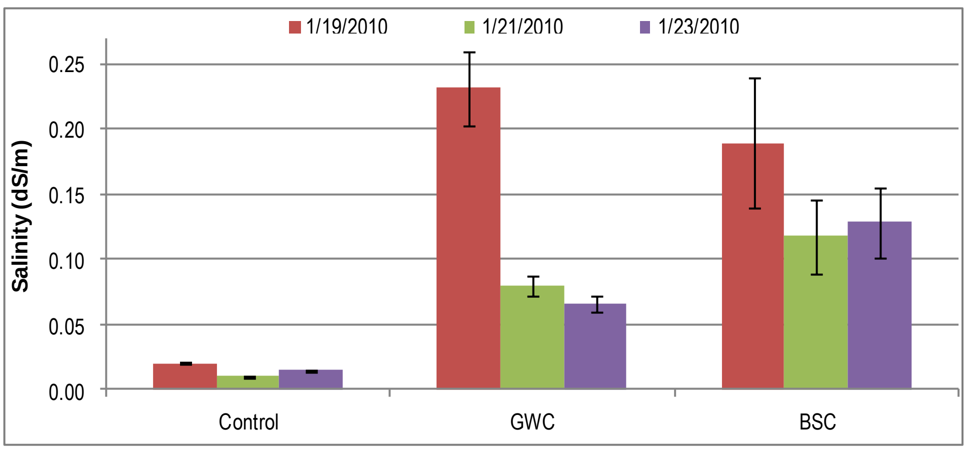


Figure 22. Construction site Salinity (electrical conductivity, dS/m); mean±standard error, n=9

Total Dissolved Solids

Total dissolved solid (TDS) values for the control plots were in the range of 600-1,000 mg/m2. TDS in runoff from plots treated with compost were 1-6.5 times lower on a mass flux basis. Plots treated with compost-greenwaste showed TDS in the range of 270-1,200 mg/m2 and plots treated with compost-biosolids showed TDS in the range of 115-230 mg/m2. Therefore, compost treatments were effective in reducing TDS in the runoff, resulting in up to 85 percent reduction with one exception occurring with compost-greenwaste during the Jan. 19 storm event, which increased TDS by 23 percent as seen in Table 16 below.

.

Rain Event	Total Dissolved Solids (mg/m2)				
	Control	Compost		Percent Reduction	
		GWC	BS	GWC	BS
Jan. 19, 2010	1004	1238	229	(23%)*	77%
Jan. 21, 2010	758	327	116	57%	85%
Jan. 23, 2010	637	273	116	57%	82%

Table 16. Construction site water runoff Total Dissolved Solids decrease (min-max), compost treatments compared to control on a mass flux basis

** This particular value demonstrated an increase of 23 percent.*

While TDS average concentrations from the control, compost-greenwaste, and compost-biosolids were, respectively, 55, 20, and 23 mg/L, their corresponding mass flux average values were 800, 613, and 154 mg/m^2 respectively, demonstrated in Figure 23. The compost-biosolids contributed the least TDS, despite its higher salinity value. It should be noted that losses from the compost-greenwaste decrease substantially after the first rain event (Jan. 19, 2010), though mass flux values remained about twice those from the compost-biosolids.

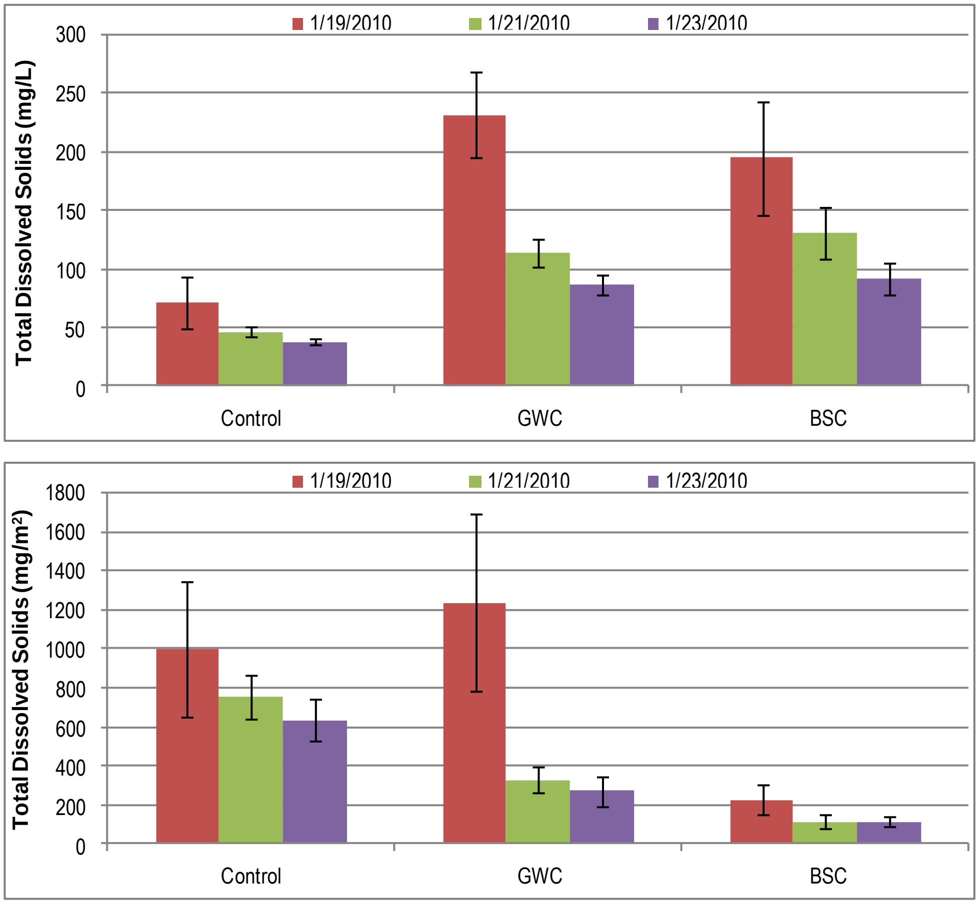


Figure 23. Construction site Total Dissolved Solids concentrations (mg/L) and mass fluxes (mg/m²); mean±standard error, n=9

Total Suspended Solids

Total Suspended Solid (TSS) values for the control plots were in the range of 800-1,000 mg/m2. TSS values in the runoff for plots treated with compost were 8-59 times lower on a mass flux basis. Plots treated with greenwaste showed TSS in the range of 60-100 gm/m2 and plots treated with compost-biosolids showed TSS in the range of 15-30. Therefore, compost treatments were very effective in reducing TSS in the runoff, resulting in 88 to nearly 100 percent reduction as demonstrated in Table 17.

Rain Event	Total Suspended Solids (mg/m2)				
	Control	Compost		Percent Reduction	
		GWC	BS	GWC	BS
Jan. 19, 2010	834	102.4	27.6	88%	97%
Jan. 21, 2010	879	59.3	15	93%	98%
Jan. 23, 2010	972	67	29	93%	97%

Table 17. Construction site water runoff Total Suspended Solids decrease (min-max), compost treatments compared to control on a mass flux basis.

And Figure 24 shows that TSS concentrations were 2.7 and 2.8 times lower in the compost-greenwaste and compost-biosolids respectively compared to the controls.

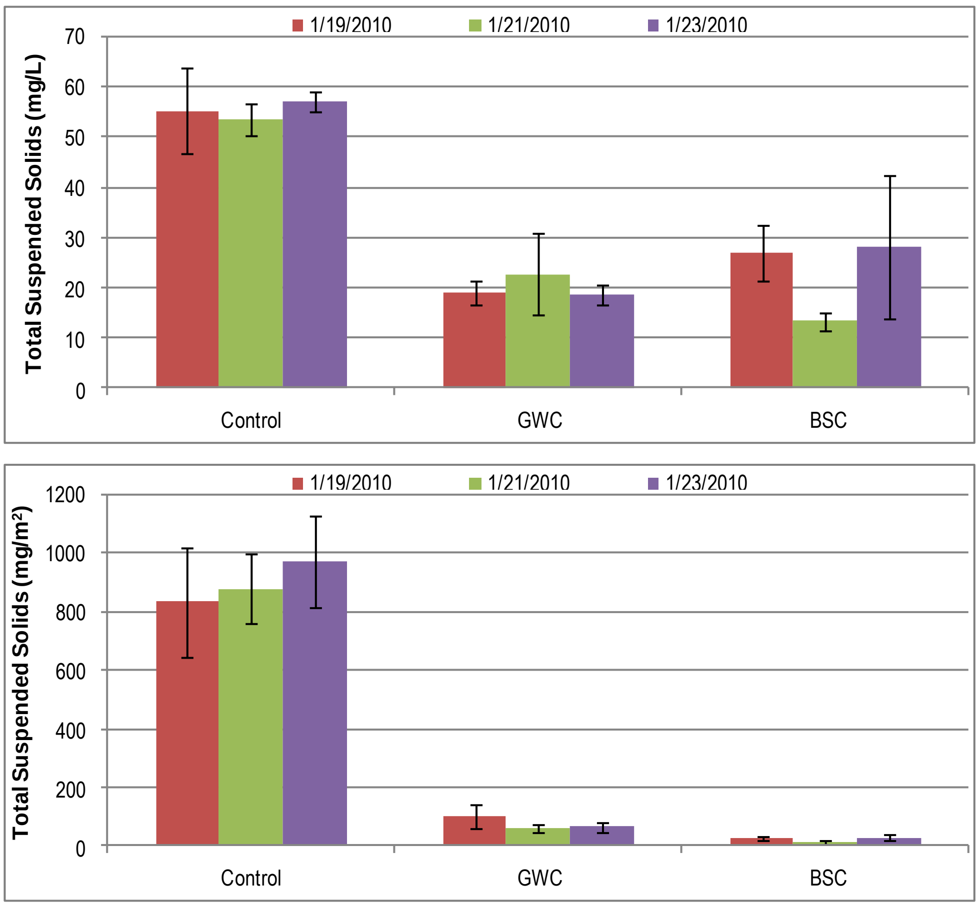


Figure 24. Construction site Total Suspended Solids concentrations (mg/L) and mass fluxes (mg/m^2); mean±standard error, n=9

Total Sediments

Compost treatments effectively reduced total sediments by 4.7 to 94.8 times, 79 - 99 percent reduction, when compared to the controls on a mass flux basis as demonstrated in Table 18, and the difference increased with each storm. Compost-greenwaste values were approximately 5, 27, and 60 times lower than the control values for the Jan. 19, 21, and 23 storms, respectively. The difference was still greater for the compost-biosolids which reduced total sediments by 24, 37, and 95 times compared to the control.

Rain Event	Total Sediments (gm/m2)				
	Control	Compost		Percent Reduction	
		GWC	BS	GWC	BS
Jan. 19, 2010	1030	218.1	42.3	79%	96%
Jan. 21, 2010	617	22.7	16.7	96%	97%
Jan. 23, 2010	882	14.8	9.3	98%	99%

Table 18. Construction site water runoff Total Sediments decrease (min-max), compost treatments compared to control on a mass flux basis.

Sediment loss concentrations were also lower from the compost treatments for all rain events, as seen below in Figure 25. Differences were statistically significant for the Jan. 21 and Jan. 23 rain events, but not for the initial Jan.19 storm.

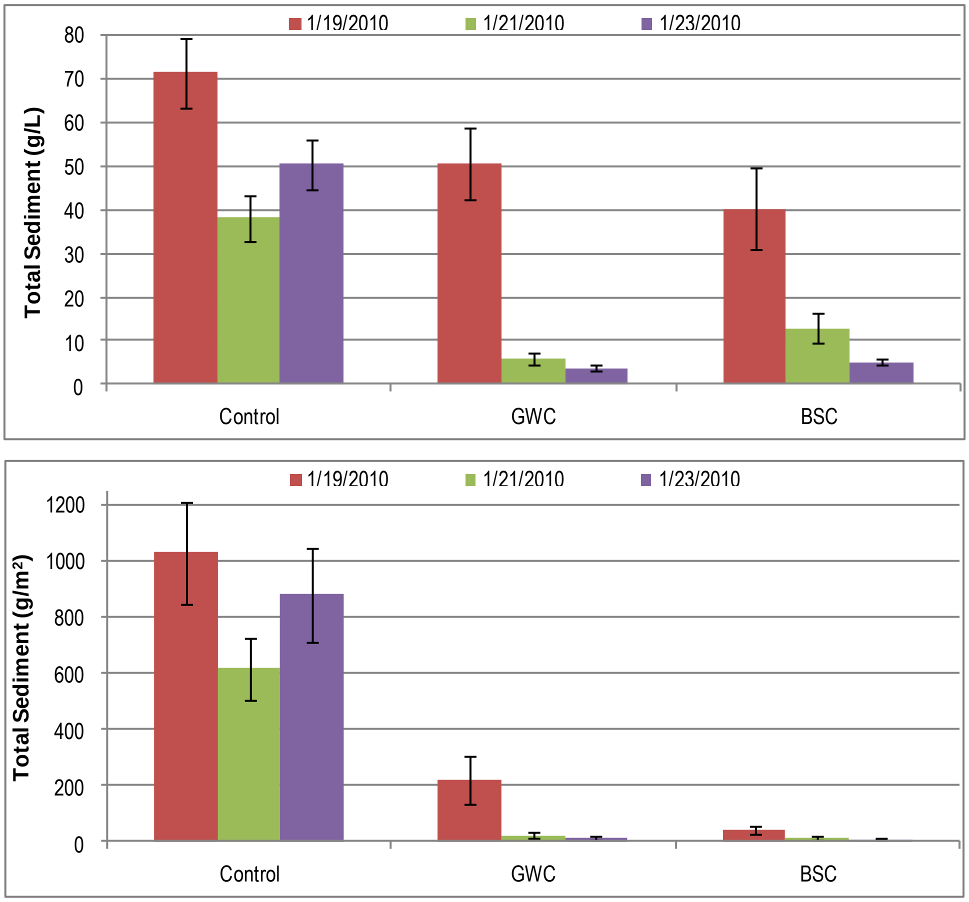


Figure 25. Construction site Total Sediment concentrations (g/L) and mass fluxes (g/m^2); mean±standard error, n=9

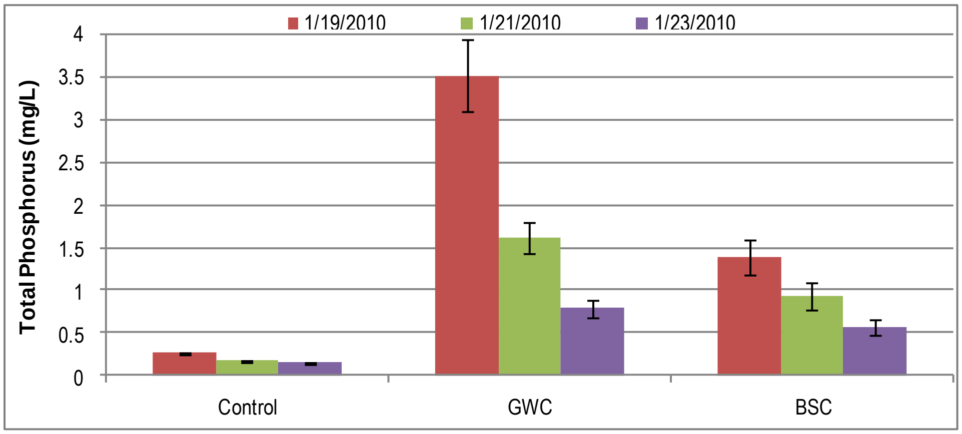
Total Phosphorus

Total phosphorus (Total P) was increased by the compost-greenwaste 1.0 to 4.4 times, 3-344 percent increase, and was decreased by the compost-biosolids 2.8 to 3.4 times, 64-71 percent reduction, when compared to the control on a mass flux basis. As seen in Table 19 below, mass flux values from the compost-greenwaste were much larger than in the controls but the compost-greenwaste values fell quickly so that by the third storm their values were approximately equivalent. Mass flux values from the compost-biosolids were less than the controls during each of the three measured storms, but differences were only statistically significant during the final rain event.

Rain Event	Total Phosphorus (mg/m2)				
	Control	Compost		Percent Increase	Percent Reduction
		GWC	BS	GWC	BS
Jan. 19, 2010	3.99	17.7	1.42	344%	64%
Jan. 21, 2010	2.91	5.45	0.84	87%	71%
Jan. 23, 2010	2.53	2.62	0.75	3%	70%

Table 19. Construction site water runoff Total Phosphorus decrease (min-max), compost treatments compared to control on a mass flux basis.

Figure 14 shows that highly elevated Total P concentration values were observed in three of the samples collected from the compost-biosolids fire-damaged plots, but nothing like this was observed in the construction plots (Figure 26). A different batch of compost-biosolids was applied to the construction plots and the feedstock may or may not have originated from a different source. Total Phosphorus concentrations were 11 and 18 percent of the control values for the compost-greenwaste and compost-biosolids, respectively. The construction experiment, with 9 reps per treatment, did not confirm the presence of erodible high phosphorus flocs in the compost-biosolids, and in this experiment, compost-biosolids were superior with respect to Total P emissions than compost-greenwaste.



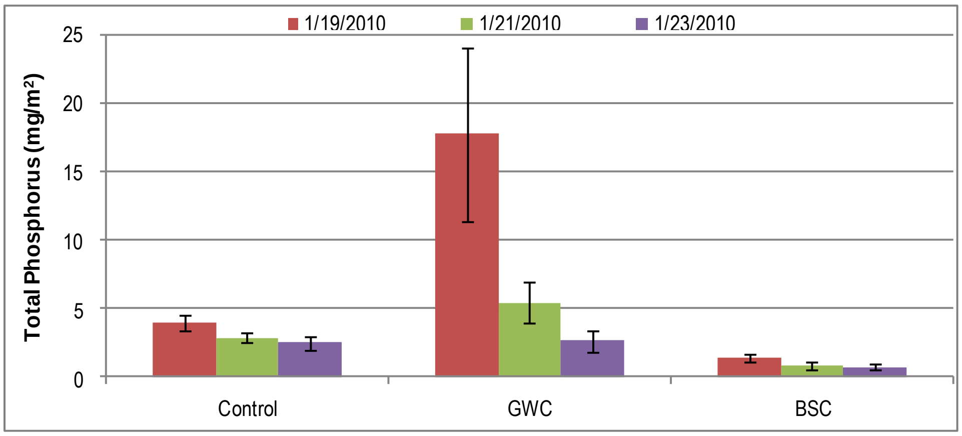


Figure 26. Construction site Total Phosphorus concentrations (mg/L) and mass fluxes (mg/m^2); mean±standard error, n=9

Orthophosphate-P

Orthophosphate-P values for the control plots were in the range of 1-3 mg/m2. Ortho-P values in the runoff for plots treated with compost-greenwaste were in the range of 2-15 mg/m2 and plots treated with compost-biosolids were in the range of 0.6-1 mg/m2. Therefore, compost-greenwaste increased orthophosphate-P 1-7 times and compost-biosolids reduced orthophosphate-P 1-3 times compared to the control on a mass flux basis as shown here in Table 20.

Rain Event	Orthophosphate-P (mg/m2)				
	Control	Compost		Percent Increase	Percent Reduction
		GWC	BS	GWC	BS
Jan. 19, 2010	2.6	15.2	0.96	484%	63%
Jan. 21, 2010	0.70	4.74	0.58	577%	17%
Jan. 23, 2010	2.05	2.35	0.61	15%	70%

Table 20. Construction site water runoff Orthophosphate-P decrease (min-max), compost treatments compared to control on a mass flux basis.

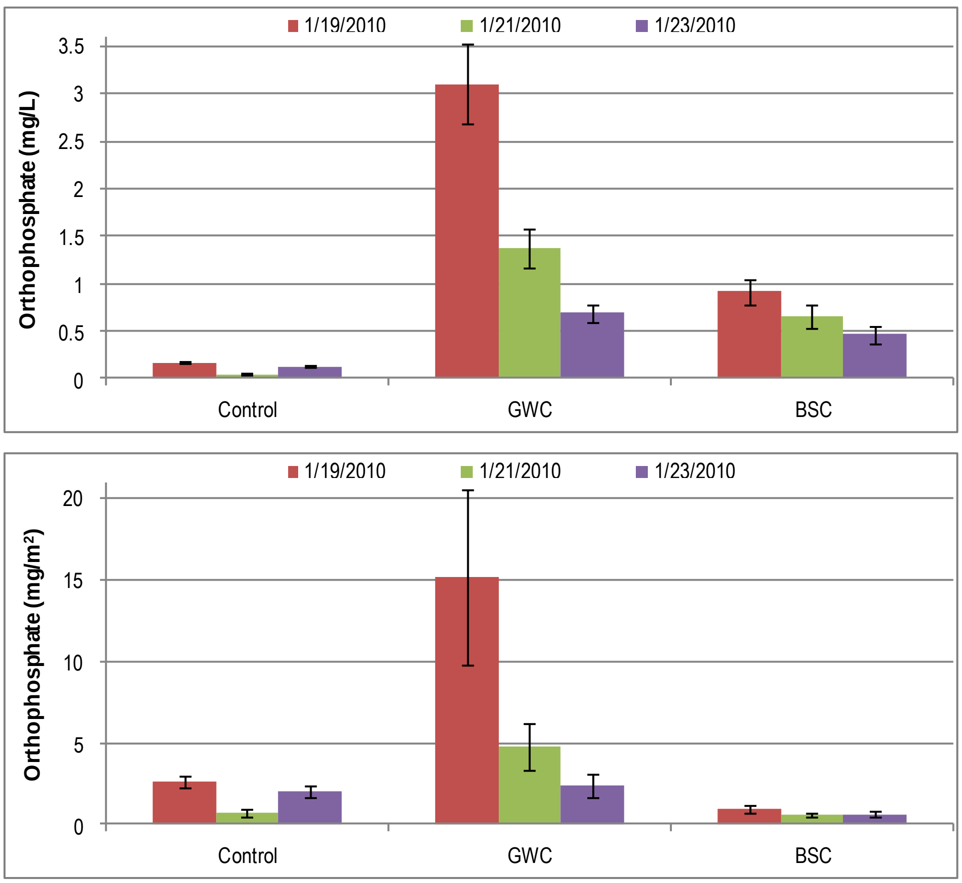


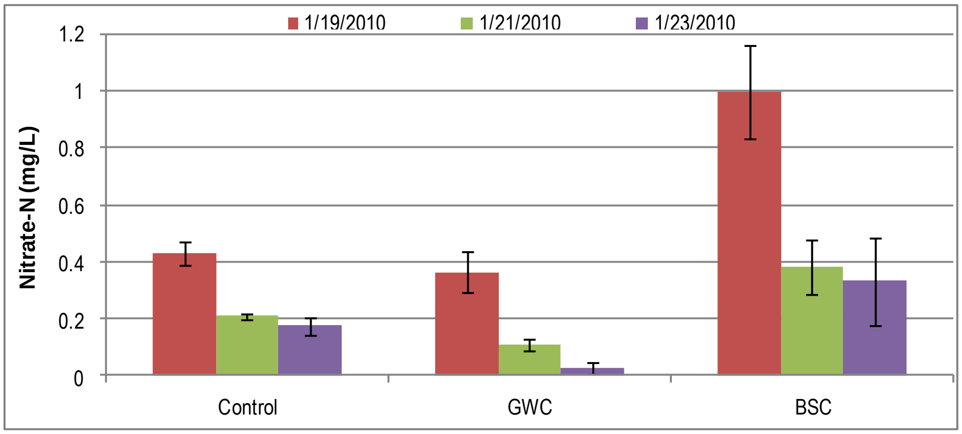
Figure 27. Construction site Orthophosphate-P concentrations (mg/L) and mass fluxes (mg/m²); mean±standard error, n=9

Nitrate-N

Nitrate-N values from the control plots were in the range of 3-6.5 mg/m2. Nitrate-N values in the runoff from plots treated with compost were 3-50 times lower. Plots treated with compost-greenwaste showed nitrate-N values in the range of 0.05-2 mg/m2 and plots treated with compost-biosolids showed nitrate-N values in the range of 6-9 mg/m2. Therefore, compost treatments were very effective in reducing nitrate-N in the runoff, resulting in 70 to 88 percent reduction.

Rain Event	Nitrate-N (mg/m2)				
	Control	Compost		Percent Reduction	
		GWC	BS	GWC	BS
Jan. 19, 2010	6.42	1.91	1.11	70%	83%
Jan. 21, 2010	3.52	0.31	0.43	91%	88%
Jan. 23, 2010	3.04	0.06	0.35	98%	88%

Table 21. Construction site water runoff Nitrate-N decrease (min-max), compost treatments compared to control on a mass flux basis.



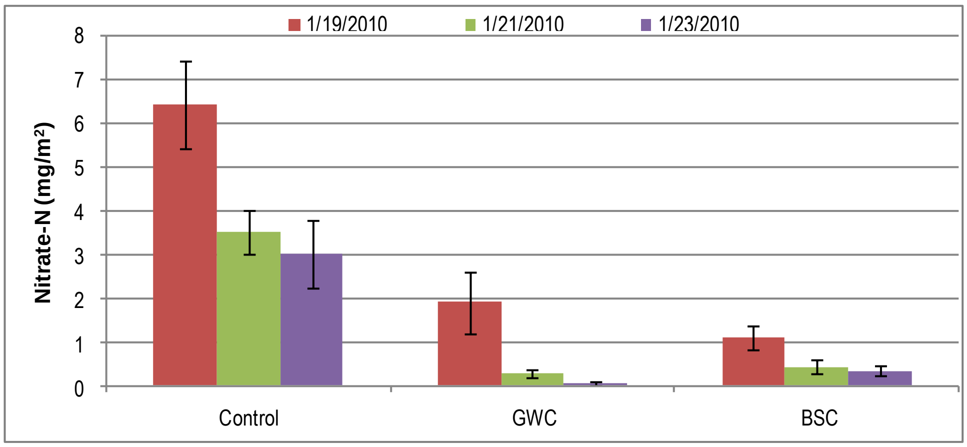


Figure 28. Construction site total Nitrate-N concentrations (mg/L) and mass fluxes (mg/m^2); mean±standard error, n=9

Ammonium-N

Mass fluxes of ammonium-N were lowest from the compost-greenwaste, though statistical significance emerged only in the latter rain events. Ammonium-N was reduced by the compost-greenwaste 1.7 to 6.6 times, 40-85 percent reduction, and increased by the compost-biosolids 1.5 to 3.6 times, 49-264 percent increase, compared to the controls on a mass flux basis.

Rain Event	Ammonium-N (mg/m2)				
	Control	Compost		Percent Reduction	Percent Increase
		GWC	BS	GWC	BS
Jan. 19, 2010	6.53	3.86	11.5	40%	76%
Jan. 21, 2010	1.55	0.40	5.64	74%	264%
Jan. 23, 2010	2.85	0.43	4.25	85%	49%

Table 22. Construction site water runoff Ammonium-N decrease (min-max), compost treatments compared to control on a mass flux basis.

As with the fire-damaged experiment, Figure 29 shows that ammonium concentrations were highest from the compost-biosolids plots. Concentrations values from the compost-greenwaste and control plots were statistically similar. During the experiment, compost-biosolids values on a concentration basis averaged 7.4 mg/L, while values for the control and compost-greenwaste were 0.24 mg/L and 0.36 mg/L respectively. Assuming that all ammonium-N was nitrified without subsequent denitrification, the 10 mg/L drinking water standard for nitrate would be violated only from the compost-biosolids effluent following the Jan. 19 event (1 mg/L nitrate-N + 12 mg/L ammonium-N). Although not studied here, denitrification and dilution would likely reduce this 13 mg/L value below 10 mg/L).

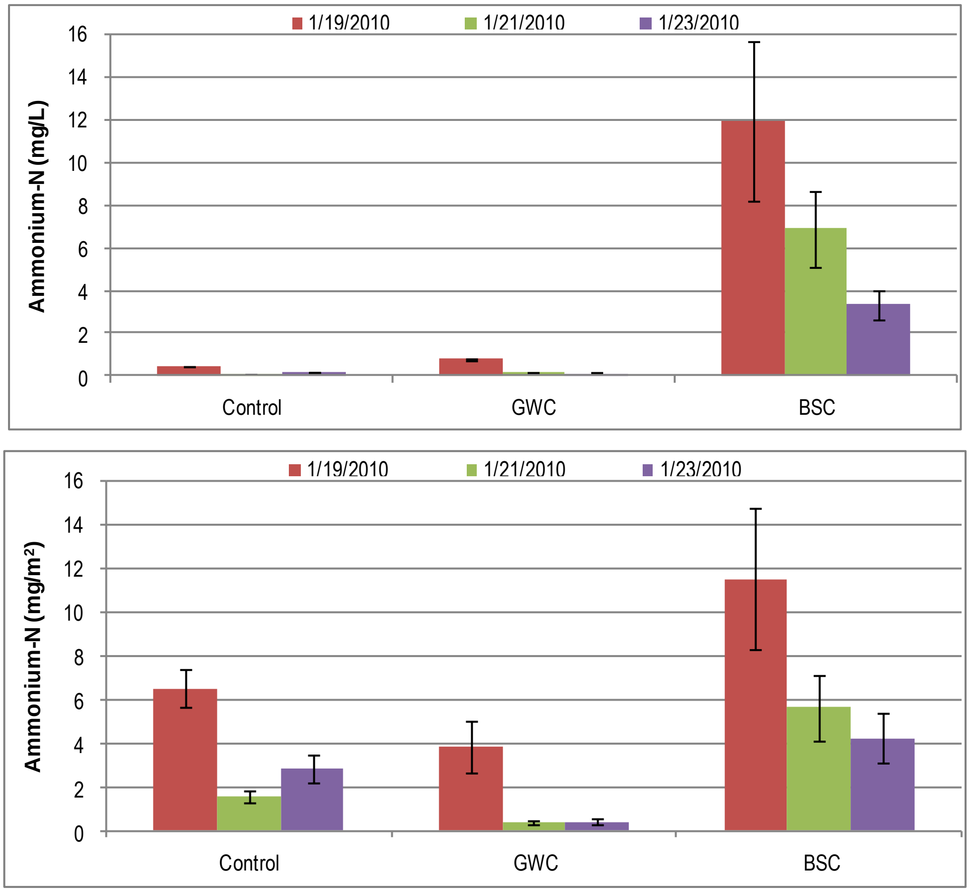


Figure 29. Construction site total Ammonium-N concentrations (mg/L) and mass fluxes (mg/m^2); mean±standard error, n=9

Metals

Unlike the previous analysis which contained metal concentration as well as mass flux statistics for the three sampling dates associated with the construction experiment, the analysis below only considers concentration values. This is because of the importance of comparing the values against both the California/U.S. EPA Drinking Water standard and the California Toxic Rule Criteria (U.S. EPA) Inland Surface Water Freshwater Aquatic Life Protection Maximum Concentration (1-hour Average). Where applicable (Cadmium, Copper, Lead, Nickel, and Zinc), the Total Recoverable Maximum Concentration (1-hour average) for the lowest listed hardness, 25 mg/L $CaCO_3$, from the "A Compilation of Water Quality Goals (August 2003)," compiled by the California Regional Water Quality Control Board—Central Valley Region was used. Mercury was not measured for this study. The complete data tables can be located in Appendix B from Table 43 to Table 45.

Arsenic: Arsenic was detected three times and only once after the initial rain event which came from the compost-greenwaste during the second rain event. All three measured values were just over the detection limit. The detection limit for arsenic is the same value as the California/U.S. EPA Drinking Water standard and, on average, the runoff values from the compost plots were just 1.1 times greater than the standard. Arsenic values were on average 32 times lower than the Freshwater Aquatic Life standard.

Cadmium: After the first rain event, cadmium was only detected once which came from the compost-biosolids during the second rain event. Detected values were on average 12 times lower than the California/U.S. EPA Drinking Water standard and 2.3 times lower than the Freshwater Aquatic Life standard. Cadmium was not detected in any of the control samples.

Chromium: Four out of the five detected values for chromium were, on average, 1.2 times below the control values. The one detected value greater than the control which was 1.7 times greater. Chromium concentration values were 4.3 times lower than the California/U.S. EPA Drinking Water standard. There is no Freshwater Aquatic Life standard.

Copper: Copper was detected in all runoff samples. The compost-greenwaste plots yielded copper concentrations that were 3.0 times lower than the compost-biosolids concentrations. On average, copper concentration values in the runoff from compost treated plots were 3.3 times higher than the control, but 50 times lower than the California/U.S. EPA Drinking Water standard and 25 times greater than the Freshwater Aquatic Life standard. Mass fluxes were statistically greater (t-test, $p<0.05$) from the controls than from the compost-biosolids on all three measured dates.

Nickel: Nickel concentration values were detected in all runoff samples. Compost-greenwaste yielded concentration values that were 2.4 times lower than compost-biosolids values. On average, the runoff from the compost treated plots yielded nickel concentrations values that were 2.1 times greater than the control, but 50 times lower than the California/U.S. EPA Drinking Water standard and 74 times lower than the Freshwater Aquatic Life standard.

Lead: Lead was not detected from either the control or compost treatment.

Selenium: Selenium was only detected twice which occurred from the compost-biosolids. On average, the runoff from the compost-biosolids yielded selenium concentration values that were 2.4 times lower than the California/U.S. EPA Drinking Water standard and 1.04 times greater than the Freshwater Aquatic Life standard. The selenium concentration values from the control were all non-detect.

Zinc: Zinc was detected in all runoff samples. On average, zinc concentrations from the runoff of the compost treated plots were 1.5 times greater than the control values and 2 times greater than the Freshwater Aquatic Life standard. Mass fluxes were statistically (t-test, $p<0.05$) greater from the controls than from the compost-biosolids on all three measured dates.

Molybdenum: Molybdenum runoff concentrations were detected in all of the compost runoff samples, but was detected only once for the controls. On average, the compost-greenwaste values were 1.5 times greater than the control while the compost-biosolids values were 4.4 times greater than the control. The compost-greenwaste concentration values were 6.2 times lower than the compost-biosolids concentration values.

Seeded Mix Development

Vegetation on the construction plots was surveyed at the end of March 2010 for the emergence of seeded species. The site was dominated by common fiddleneck, which was not planted but which is common in the area. To preserve the vegetation on the plots for future use and study, no destructive sampling was conducted. It was apparent during the survey that vegetation on the compost-biosolids plots was significantly fuller than on either the control or the compost-greenwaste plots. Compost-biosolids plots appear in the upslope foreground of Figure 30.

Initially none of the seeded species were found. Upon close inspection, however, a number of the planted species were located and shown in the top left corner of Figure 30. The development of these plants appeared to be stunted relative to the development of other plants growing on the plots, most particularly *Amsinckia menziesii*. It may be that the seeds were incorporated too late in the season to properly develop, though they were planted just following the first significant rains of the season. Nevertheless, the following plants included in the seed mixes were observed.

SM1, the basic native erosion control mix successfully introduced:

- *Bromus carinatus* "Cucamonga" (Cucamonga Brome),

While SM2, the inland sage scrub mix, introduced the following species:

- *Artemisia californica* (California Sagebrush)
- *Eriophyllum confertiflorum* (Golden Yarrow)
- *Lasthenia glabrata* (Goldfields)
- *Lupinus succulentus* (Arroyo Lupine), and
- *Salvia mellifera* (Black Sage).

Interestingly, the compost-biosolids treatments on the construction plots supported substantially more growth than the other treatments but the reverse was true on the fire-damaged plots where the compost-biosolids blanket plots displayed noticeably less vegetation than either the compost-greenwaste or the controls. This is evident in Figure 31 below, a photograph of the fire-damaged plots taken at the end of March 2010 and can be compared to the fire-damaged plot site map in Figure 2. While the two experiments used separate deliveries of compost-biosolids there is no explanation for this.

Figure 30. Vegetative cover on the construction plots, March 26, 2010.

Figure 31. Vegetative cover on the fire-damaged plots, March 26, 2010.

Conclusions: Fire-Damaged Soils Study and Construction Soils Study

Compost use clearly reduced the mass export of most pollutants, particularly sediments. For the Fire-Damaged Soil study, runoff was measured and sampled following four separate storm events on Dec. 15, 2009 (12.5 mm storm), Jan. 19, 2010 (32 mm), Jan. 21, 2010 (39 mm), and Jan. 23, 2010 (49 mm). The last three dates were also sampled for the Construction Soil study.

Note that discussion of total dissolved solids, total suspended solids, total sediments, total Phosphorus, orthophosphate-P, nitrate-N, and ammonium-N refer to mass flux values (mg/m^2) derived by adjusting concentration measures according to their corresponding runoff volumes. In general, it is more important to consider mass flux values, where possible, rather than concentration values because mass flux incorporates runoff flow rates and is indicative of the total mass of a constituent leaving the site. Concentration values do not incorporate runoff flow rates (which in general are significantly lower for compost plots). Therefore, high concentration values are not an accurate indication of total mass of a particular constituent leaving the site especially when runoff flow rates are low.

Total Runoff Volume

Fire-Damaged Plots: Both the compost blankets and incorporated compost treatments dramatically reduced volumetric runoff by 1.6 to 23 times the control. Runoff volumes associated with the compost treatments during the December storm were approximately half those from the controls. Subsequent storm event runoff rates were 3 to 23 times lower in the compost-treated plots than in the controls. Application methods did not affect runoff rates. Compost-biosolids infiltrated more water than compost-greenwaste.

Construction Plots: Runoff values from the compost-greenwaste plots were, on average, 4.6 times lower and runoff values from the compost-biosolids plots were 14 times lower than the control.

Conclusion: All compost treatments substantially reduced stormwater runoff compared to the control by an overall average of 7.5 times (1.6-23.4 times).

Turbidity

Fire-Damaged Plots: Runoff water leaving the compost treated plots was much clearer than water leaving the control plots by an order of 1.3 to 45.4 times. Turbidity associated with compost blankets was significantly less than that from the incorporated treatments, 11.0 and 4.0 times respectively.

Construction Plots: Turbidity was, on average; 4.3 times lower in the compost-greenwaste runoff than in the control runoff. Turbidity was, on average; 2.7 times lower in the compost-biosolids runoff value than the control runoff.

Conclusion: All compost treatments substantially reduced turbidity 1.3 to 45.4 times compared to the control values with an overall average reduction of 8.6 times.

pH

Fire-Damaged Plots: Measured pH values were generally neutral with an average of 7.0 from the compost treatments and differences when compared to the controls were not statistically significant. The controls averaged 7.2.

Construction Plots: Measured pH values from the compost treatments averaged 6.9 and the controls averaged 7.3. Measured pH values were slightly lower for compost treatments than the control plots. The resulting difference was statistically significant and was likely caused by the larger samples (n=9 rather than n=3 in the fire-damaged experiment).

Conclusion: Measured pH values from compost treatments averaged 7.0 with an overall range of 6.4 to 7.5.

Salinity

Fire-Damaged Plots: Compost treatments increased salinity by up to 7.6 times the control values. Compost-biosolids treatments presented the highest salinity concentrations, particularly the 5 cm applications. Concentrations were the highest following the initial December 2009 storm event. Subsequent storm event values were reduced as the salts were removed in runoff during previous storms.

Construction Plots: Compost treatments increased salinity by up to 11.8 times the control values. Compost-biosolids values were comparable to compost-greenwaste values.

Conclusion: Compost treatments had, on average, a 2-3 times increase in measured salinity compared to the control values. Compost treatments, however, had higher salinity concentrations during the first storm event and declined with each additional storm. Because salinity is measured indirectly using electrical conductivity, the measured values cannot be flow-adjusted and cannot be expressed in terms of mass export flux. This is important because while the salinity concentrations are higher for the compost treatments, the total runoff is lower. Total dissolved solid measurements can be flow-weighted and will therefore be more meaningful. Flow-weighted data can be expressed in terms of a mass export flux with units of g/m^2.

Although compost treatments resulted in higher salinity values than plots not containing compost, salts from compost are also considered nutrients to plants. When compost is used for erosion control, nutrients are important for developing and promoting the growth of vegetation which is paramount for stabilizing slopes in the long term. The applications of compost treatments will initially minimize erosion by greatly reducing the flow of water, but it is the roots and upper vegetation of the plants which will ultimately provide the long term benefit.

Total Dissolved Solids (TDS)

Fire-Damaged Plots: Compost treatments reduced the export of total dissolved solids (TDS) by an order of 1.2 to 10.6 times compared to the control on a mass flux basis. Compost-biosolids plot concentrations were generally higher than compost-greenwaste concentrations, but the mass flux values from the controls were greatly elevated demonstrating that more salts were lost from the controls than from any of the compost treatments.

Construction Plots: Compost treatments reduced TDS by up to 6.5 times (85 percent) compared to the control on a mass flux basis.

Conclusion: Compost treatments significantly reduced TDS from entering receiving waters by up to 10.6 times the control on a mass flux basis.

Total Suspended Solids (TSS)

Fire-Damaged Plots: Compost use dramatically reduced total suspended solids (TSS) relative to the controls. Mass flux losses were from 3.6 to 438 times lower from the compost treatments than from the controls. Losses were generally higher from the 5 cm blankets than the 2.5 cm blankets, but differences were not statistically significant.

Construction Plots: Mass flux values were, on average, 12.5 times lower from the compost-greenwaste and 41 times lower from the compost-biosolids compared to the control.

Conclusion: Compost use greatly reduced total suspended solids exports from the plots by an overall average of 39 times compared to the control on a mass flux basis.

Total Sediments

Fire-Damaged Plots: Compost treatments reduced total sediment by 8 to 536 times compared to the controls on a mass flux basis. The lowest loss rates were associated with the 2.5 cm compost blankets.

Construction Plots: Compost treatments reduced total sediments by 5 to 95 times compared to the control on a mass flux basis. The average reduction was more than 94 percent.

Conclusion: Compost treatments dramatically reduced total sediment losses with an overall average of 57 times the controls' flux values.

Total Phosphorus (P)

Fire-Damaged Plots: Total P was reduced by the compost treatments by up to 15 times compared to the control on a mass flux basis. Concentrations were highest in the compost-biosolids plots, though differences were statistically significant only for the last two storm events. The first storm values were highly variable for the compost-biosolids plots.

Construction Plots: Total P was increased by the compost-greenwaste 1 to 4.4 times and was decreased by the compost-biosolids 2.8 to 3.4 times compared to the control on a mass flux basis, but the results were not statistically different.

Conclusion: Compost treatments reduced mass flux total P values by 1 to 15 times compared to the controls with two specific exceptions. Compost-biosolids during the first rain event in the fire-damaged study and compost-greenwaste in the construction study increased total P mass flux values by 1.4 to 8.7 and 1 to 4.4 respectively.

Orthophosphate-P

Fire-Damaged Plots: Generally orthophosphate-P mass flux values were reduced by the compost treatments by up to 18 times the control values. Mass flux losses were significantly lower for the compost treated plots during rain events 2, 3, and 4. Losses were greater from the compost-biosolids than from the compost-greenwaste, but differences were usually not statistically significant.

Construction Plots: Mass flux values were elevated in the compost-greenwaste relative to the controls by up to 6.7 times. Compost-biosolids masses were lower than the controls for all events by an average of 2.4 times, but were not statistically different.

Conclusion: Compost treatments effectively reduced orthophosphate-P in most runoff samples by up to 18.3 times when compared to the control on a mass flux basis.

Nitrate-N:

Fire-Damaged Plots: Nitrate-N mass flux losses were up to 25 times lower from the compost treatments than the controls though statistically the control plot mass fluxes were comparable to the compost-biosolids plots due to variability. Mean concentrations were below the 10 mg/L drinking water standard for Nitrate-N, with one exception. Concentrations fell steadily during subsequent storms events.

Construction Plots: Mass flux values were 3 to 50 times lower for the compost treatments compared to the control for all three events and the difference increased with each storm. Concentrations for compost plots never exceeded 10 percent of the 10 mg/L regulatory standard for drinking water.

Conclusion: Compost treatments decreased mass flux losses for nitrate by up to 50 times compared to control plots, and nitrate concentrations in runoff from compost plots never exceeded regulatory drinking water standards.

Ammonium-N:

Fire-Damaged Plots: Ammonium-N mass flux values were 27 times lower for the compost-greenwaste compared to the control. But ammonium-N mass flux values were elevated in the compost-biosolids treatments by up to 132 times the control values following the first rain event, and averaged 6.6 times higher during subsequent events.

Construction Plots: Mass flux values were highest from the compost-biosolids by up to 3.6 times the control, though values were not statistically different. Compost-greenwaste values were up to 6.6 times lower than the control. Concentration averages were highest during the first event; 11.5 mg/L for compost-biosolids, 3.9 mg/L for compost-greenwaste, and 6.5 mg/L for the controls. Subsequent concentrations were greatly reduced.

Conclusion: Compost-greenwaste reduced mass flux ammonium-N values by up to 27 times and compost-biosolids increased mass flux values by up to 132 times compared to the control.

Metals

Arsenic: Arsenic concentration values are significantly lower from the runoff leaving the compost treated plots than the Freshwater Aquatic Life standard by an average of 28 times and 32 times from the fire-damaged land and construction plots respectively. The arsenic concentration values compared to the California/U.S. EPA Drinking standard were on average 1.3 times and 1.1 times greater from the fire-damaged land and construction plots respectively.

Cadmium: Cadmium concentration values were on average 8.2 times and 12 times lower than the California/U.S. EPA Drinking Water standard from the fire-damaged land and construction plots respectively. Concentration values are 1.5 times and 2.3 times lower than the Freshwater Aquatic Life standard from the fire-damaged land and construction plots respectively.

Chromium: Chromium concentration values are on average 3.7 times and 4.3 times lower than the California/U.S. EPA Drinking Water standard from the fire-damaged land and construction plots respectively.

Copper: From the fire-damaged land and the construction plots, copper concentration values are respectively on average 3.2 times and 3.3 times greater than the control values, 58 times and 50 times lower than the California/U.S. EPA Drinking Water standard, and 13 times and 10 times greater than the Freshwater Aquatic Life standard.

Nickel: From the fire-damaged land and construction plots, nickel concentration values are respectively 3.6 times and 2.1 times greater than the control, 36 times and 50 times lower than the

California/U.S. EPA Drinking Water standard, and 54 times and 74 times lower than the Freshwater Aquatic Life standard.

Lead: Lead was not detected during this study.

Selenium: Selenium concentration values are on average 2.0 times and 2.4 times lower than the California/U.S. EPA Drinking Water Standard from the Fire-Damaged Land and Construction plots respectively.

Zinc: Zinc concentration values are on average 2.2 times and 1.5 times greater than the controls, and 3.9 times and 2.0 times greater than the Freshwater Aquatic Life standard for the fire-damaged land and the construction plots, respectively.

Molybdenum: Molybdenum concentration values are on average 3.4 times and 2.9 times greater than the controls for the fire-damaged land and construction plots, respectively.

Compost Production Best Management Practices

The composting process converts organic waste materials into environmentally beneficial soil amendments, diverts wastes from landfills, and treats these wastes to control pathogens, whether human, animal, or plant. Finished composts are rich in nutrients that improve soils; however, during the composting process these nutrients may also degrade water quality if they are moved from the piles into groundwaters and surface waters. The accumulation of nutrients in groundwater can reduce the water's value as an irrigation resource. A well-run, open windrow composting operation will minimize nutrient losses to the environment by retaining those constituents on-site. The most attractive warehouse for compost nutrients is within the piles themselves.

The goal of this series of experiments is to give guidance to composters as to how they might manage their piles to reduce groundwater and surface water pollution. Since pollutants are carried in water, the strategy was to evaluate the potential for composters to use the water storage capacity of their piles (in their active phases of the composting process) to control the movement of water from the piles and into the environment.

Since this study was conducted for the purpose of assisting composters in managing leachate on-site as their compost piles mature, only partially composted materials from feedstocks of greenwaste and a mix of biosolids/greenwaste materials were used for this study. These partially composted materials may be referred to as: "material," "composting material," "partially composted material," "pile," or "composting pile." However, keep in mind that these materials were in various phases of the composting process but were not finished compost.

Management of pile moisture requires an understanding of how water enters, penetrates, and is held within the composting media. Water movement into and through a pile will be affected by the types of materials being composted and the extent to which decomposition has occurred within the pile. The amount of water that can be retained in a composting pile without draining is referred to as "*field capacity*." The amount of water that can be added to a composting pile should be a function of the difference between its maximum water holding capacity and the amount of water that is actually held within the pile or the "*as-received moisture content*." The difference between the field capacity and the as-received content is referred to as the *"storage capacity"* of the pile.

A column study was conducted to study how well an estimate of the potential storage capacity concept represents behavior of water in piles. Simulated rainfall was generated on columns that were one meter tall and filled with composting materials, until leachate was detected leaving the bottom of the column. The amount of water held in each column was then compared to the predicted potential storage capacity of the material. The study included both materials from a greenwaste feedstock (GWM) and materials from a feedstock mix of biosolids/greenwaste (BSM), that were in approximately Day-1, Day-7, and Day-14 of the composting process.

Because it is possible for precipitation to run off of the pile before it can be absorbed, different approaches for encouraging the infiltration of water into composting piles was studied. Once again, Day-1, Day-7, and Day-14 for both GWMs and BSMs were considered. Partially composted materials piled at angles consistent with typical windrows as well as windrows with flat tops were studied.

Finally, having verified that the potential storage capacity measures were reasonable compared to the performance of the columns, a simple computer program was developed for predicting the amount of precipitation a given amount of composting material can hold.

In summary:

- To minimize leaching, a simple procedure for estimating the *storage capacity* of composting material as the difference between its *field capacity* and *as-received* moisture contents was developed.
- To minimize runoff, strategies for encouraging the infiltration of water into composting piles were evaluated.
- To determine water holding potential, a computer program was developed to help composters reduce the amount of water exiting from their piles.

Objectives

The objectives of the study were to:

A. Develop a simple procedure for estimating the "*storage capacity*" of composting piles as the difference between its "*field capacity*" and "*as-received*" moisture content and incorporate into a guidance document for composters and regulators.

B. Verify that storage capacity estimates (determined in part "A" above) are meaningful by conducting a column study (medium intensity simulated rainfall) for evaluating the relationship between estimated storage capacity and the movement of water through a pile during a precipitation event.

C. Use constructed bins and intense simulated rainfall to test strategies for encouraging the infiltration of water into piles, including turning, emulsifying agents, and the use of flattened pile tops.

D. Develop a mathematical relationship, "Storage Potential Calculator," that could be used to help composters reduce water losses from their piles especially during rain events in order to reduce the potential of surface and groundwater pollution.

Moisture Content and Water Holding Capacity Determination

The goal was to make the assessment procedure for predicting the potential water-holding capacity of composting materials to be as simple and convenient as possible while maintaining accuracy. The approach uses mesh bags, which can be filled and handled easily. One bag is filled with partially composted material from the pile to measure the pile's "as-received" water content (as-received material). Another bag is filled with partially composted material, saturated with water, and then allowed to drain. This bag is used to measure the material’s field capacity. Each bag is then weighed prior to and after drying to measure their water content. The potential water holding content of the pile can then be estimated.

To test the approach, as-received materials representing 1-day, 7-days, and 14-days of the composting process were used for this study. Samples were collected from these materials and moderately packed in nylon fine-mesh bags, demonstrated in Figure 32 below, approximately 15.3 cm (6 in) wide, 11.4 cm (4.5 inches) tall, 2.5 cm (1 in) deep. These samples were used to determine the gravimetric water content of the as-received materials and at field capacity. All measurements were done in triplicate.

$$Wet\ basis\ moisture\ content = \frac{Bag\ mass\ \text{with}\ material\ as\ received\ (g) -\ Bag\ mass\ with\ dry\ material\ (g)}{Bag\ mass\ with\ material\ as\ received\ (g) - Empty\ bag\ mass\ (g)}$$

<u>As-received Moisture Content:</u> As-received samples were placed in hot air oven at 65°C for 24 hours for drying. Weights of the samples before and after drying were recorded to determine the gravimetric water content of the as-received material.

<u>Field Capacity Moisture Content:</u> Samples were completely immersed in water and periodically checked for saturation. Saturation was considered to have taken place when the bags stopped floating. The time taken to saturate the bags was approximately 2.5 hours for GWM and 1 hour for BSM. The time was recorded and the saturated sample bags were then placed vertically on a wire rack to allow free drainage. Samples were considered to be at field capacity when there was no weight change in the bag due to water loss. The time taken to achieve field capacity was recorded as 15 minutes for GWM and 35 minutes for BSM. Samples were then placed in an oven for drying at 65°c for 24 hours. Sample weights at field capacity and after drying were used to determine the gravimetric field capacity moisture content of the materials.

Figure 32. Nylon mesh sample bag. Ruler displays inches.

Column Study

Having developed a test for estimating the potential water holding capacity of composting material, it is necessary to verify that the measured potential water holding capacity values reasonably reflect the capacity of a pile to retain water. The purpose of this set of experiments was (1) to establish how much precipitating water can cumulatively enter a pile before it leaches to the soil below and (2) to compare measured amounts with predictions derived from the previously described water content measurements.

For this experiment six treatments were used:

- Day 1 composting material from a greenwaste feedstock;
- Day 7 composting material from a greenwaste feedstock;
- Day 14 composting material from a greenwaste feedstock;
- Day 1 composting material from a feedstock mix of biosolids/greenwaste ;
- Day 7 composting material from a feedstock mix of biosolids/greenwaste; and
- Day 14 composting material from a feedstock mix of biosolids/greenwaste.

Procedure

The approach was to predict the potential storage capacity of the composting material to the actual storage capacity as observed in columns. Measurements were designed to be simple so that they could be replicated in the field. Relationships were then derived to estimate the water holding capacity of composting piles.

Determining Storage Capacities

Plastic mesh bags were moderately packed with the sample materials representing Day 1, Day 7 and Day 14 of the composting process. Each was saturated and brought to field capacity, weighed and horizontally placed in buckets containing 1.75 kg of as-received material to represent the piles. In addition, at least 5 cm (2 inches) of partially composted material was placed over the sample bag. The buckets were covered with lids to avoid evaporation loss. Four replicates were established for each material type and maturity date. As-received partially composted material was allowed to equilibrate with the field capacity material for 24 hours. After 24 hours, the samples were removed from the buckets and weighed again. The samples were then placed back in the buckets and allowed to equilibrate to represent 48 and 72 hours from the start of the experiment. The initial and final weights were recorded after 48 and 72 hours and the samples were then placed in the oven for drying. The difference between the weights of the material at field capacity, after 24, 48, and 72 hours of equilibrium, and the dry weight of the material, indicate the gravimetric water holding capacity of the piles immediately after a rain event lasting 1, 2, and 3 days respectively.

The storage capacities of the materials were estimated as the difference between each material's measured field capacity and its actual water content. These were determined according to the procedure described previously. Available storage was estimated as a function of the difference between the water content at field capacity and the water content of the operating pile:

$$S = (1 - W_{FC})\left(\frac{W_{FC}}{W_{FC}+1} - \frac{W_P}{W_P+1}\right)E$$

where:

$S\ \left(\frac{\text{L}}{\text{kg ww}}\right)$ = Available water storage capacity of the partially composted material (moist basis)

$W_{FC}\ \left(\frac{\text{L}}{\text{kg ww}}\right)$ = Wet basis moisture content of the material at measured "field capacity"

$W_P\ \left(\frac{\text{L}}{\text{kg ww}}\right)$ = Wet basis moisture content of the pile

E = Efficiency term to account for preferential flow movement and losses

The efficiency term, E, will equal "1" when the water holding results from the columns study are precisely the same as the predicted value from the measured storage capacities test using the mesh bag. When efficiencies are found to exceed "1", measured storage capacities under predict the actual amount of water held within the column. When efficiencies are less than "1", the columns are holding less than predicted. Efficiencies that are significantly less than "1" may be attributed to preferential flow paths in the composting material. Preferential flow can occur when large pores in the material, channel water so that uniform wetting of the material does not occur.

POTENTIAL WATER STORAGE CAPACITY

Nine 1-meter columns were constructed from 0.305 m (12 inch) internal diameter single-wall corrugated PVC pipe. Corrugated pipe was selected to minimize preferential flow along the sides of the columns. Aluminum caps were fitted to the bottom of each column to hold the added material.

To pack the columns, approximately 4 cm of sandy loam soil was first added. Composting materials were then added gradually. During this loading process, the material was regularly tamped into place manually using a flat wooden disk attached to a wooden handle.

For each column, a double-wire transducer was then inserted through a small hole drilled into the PVC column just above the lip of the metal cap. The bare wires were then located within the soil just below the partially composted material. Leads from the transducers were connected through leads to an electronic bridge. One wire in each column received a 2.5 volt charge while the other was grounded. Any moisture moving from the material to the soil increased the conductivity between the transducer wires which resulted in a voltage measure. Changes were recorded using a Campbell Scientific CR10X data logger. Breakthrough times were saved on a laptop attached to the data logger.

To prevent leaks from prematurely activating the transducers, all seams were sealed with silicone caulk, and the columns were wrapped entirely with plastic cling film as demonstrated in Figure 33.

Precipitation was simulated using a Fulljet HH10W nozzle operating at 21 psi at a height of 3.2 m. Catch cup experiments showed that precipitation fell at an average rate of 3.3 cm/hr (1.3 in/hr).

The composting material was weighed prior to loading. The precipitation simulator was engaged and precipitation at a rate of 3.3 cm/hr was allowed to continue into each column until the transducers indicated that water had entered the columns. When a transducer in a particular column signaled a leachate breakthrough, that column was covered to prevent the entry of additional water. At the end of the experiment, each column was weighed again and the total water precipitated into that column until breakthrough was determined as the difference in weight after and prior to precipitation. Composting material from a feedstock mix of biosolids/greenwaste was run first and composting material from a greenwaste feedstock was run second.

Figure 33. Columns under rainfall simulator.

Figure 34. Composting material surface during rainfall experiment.

Results

Precipitation entered the material without pooling and there was no indication that there would be a problem with surface runoff, even with wet material. The run time, or the time required for the water to pass through the composting material and enter the soil below, ranged from 2 hours 37 minutes to 4 hours 45 minutes for the GWM and 2 hours 35 minutes to 4 hours 32 minutes for the BSM.

Initial moisture measures appear in Table 46. The moisture content of the GWM ranged from 45 to 48 percent, while the BSM was moister, ranging from 51 to 60 percent. The field capacities for the GWM were between 62 and 66 percent and increased with aging. By contrast, the BSM field capacity dropped from 73 to 65 percent during composting from Day 1 to Day 14.

Experiment results are given in

Table 47. It is evident from the table that the water-holding efficiencies within the columns were generally consistent with predictions. Excavations of the partially composted material following the experiment did not reveal obvious signs of concentrated flow down the sides of the column walls.

Efficiencies differed between the GWMs and the BSMs, shown in

Table 48 of Appendix B, when all values were considered simultaneously using a two-tailed t-test ($p<0.05$). Efficiency values therefore likely differ between the BSMs and the GWMs tested here. Efficiencies also drop during the composting process. For both material types, Day 7 efficiencies significantly differed ($p<0.05$) from the Day 1 materials. In both cases *E* values fell during the first week of composting. During the second week *E* values rose, but Day 14 terms did not differ significantly from Day 7 values.

It should be noted that this study revealed that partially-composted materials have a remarkable capacity to absorb water. It also found that preferential flow can occur, and the significance of this under commercial operating conditions has not been evaluated.

Storage Potential Calculator

The results from the Moisture Content & Water Holding Capacity Determination and the Column Study discussed above were used to develop a Storage Potential Calculator, shown in Figure 35, which is an interactive tool for estimating the amount of composting material that is needed to store a given amount of falling precipitation, as well as the gallons and inches of precipitation that a pile of a known size could hold. The calculator was designed to be a simple and easy to use computer program that conservatively assumes that all precipitation enters and is stored in a pile. To use the calculator, a user would need to complete the data entry fields shown in white. The first step for using the calculator is to collect representative samples from a pile and places them in the mesh bags as discussed above in the “Moisture Content & Water Holding Capacity Determination” section. To restate this process, one set is submerged, saturated, and drained to create a “field capacity” condition. The second represents the moist pile and is not modified. The masses of these sample bags are entered in the Field Capacity and Moisture wet weight cells. The bags are then placed in an oven for drying at 65°C until constant weight. Instead of using a drying oven, an apparatus such as the Koster Moisture Meter (http://www.kostercroptester.net) is an affordable on-site alternative that may also present results more quickly than a drying oven. Dry weights are then entered into their corresponding cells. The bulk density of the material, an easily obtained value that can be determined from a container with a known volume and a scale, is also entered.

The calculator returns the amount of composting material, as a depth in inches, required to hold an inch of precipitation as well as the gallons and inches of precipitation that a pile of a known size could hold. The results are listed in the Storage Potential Calculator in the light blue fields. Detailed directions for using the Storage Potential Calculator are included in Appendix A: Storage Capacity Calculator with Instructions.

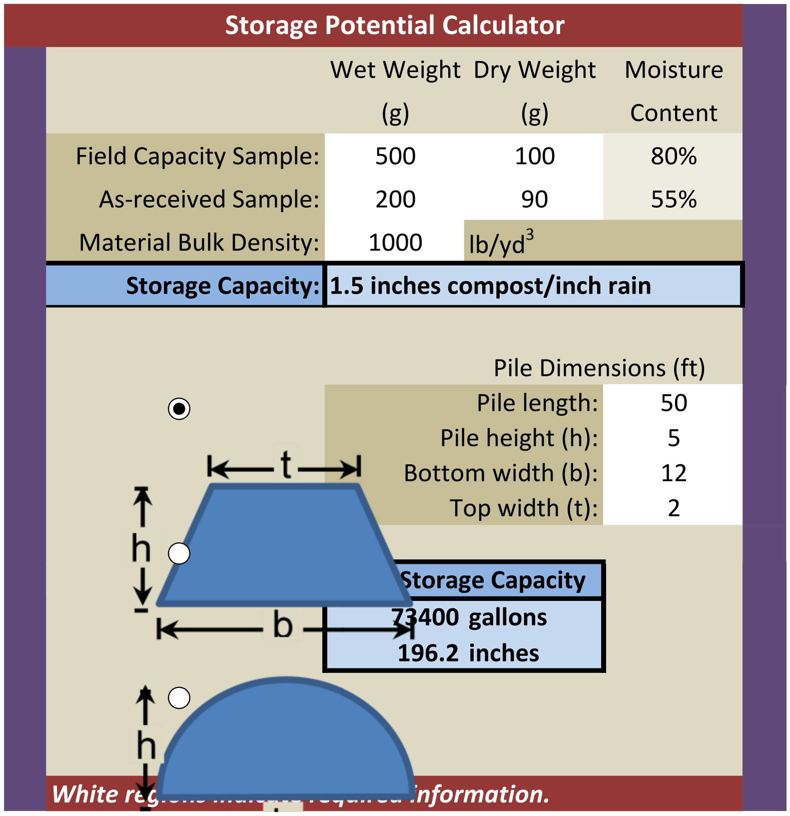


Figure 35. Storage capacity calculator. **Double clicking** the calculator activates the tool (in MS Word versions of this document formatted for Office 2007 or later).

Infiltration Study

The infiltration study considered several management practices likely to improve the infiltration of precipitation into composting piles. Without effective infiltration, rainfall will simply run off of the piles to pool on the soil surface. Considered treatments were:

- Sloped surface
- Flat surface
- Surfactant wetting agent
- Turned

Procedure

Twelve bins were constructed to compare the treatments. This allowed for the simultaneous consideration of Day 1, Day 7, and Day 14 materials. GWMs and BSMs were tested separately. Each bin was constructed to be 39 cm wide, 49 cm deep and 49 cm tall. Within the bins, the materials were placed on coarse (size 16) quartz sand to facilitate drainage. Figure 36 depicts how materials were installed to fill the bins for the sloped treatments, and to a depth of 17 cm for the flat treatments as shown in Figure 37. At the edge of the table, a wire mesh held the composting material above a collection system fabricated from PVC gutter materials. A galvanized steel plate was also installed to assure that water reaching the edge of the table was collected into the gutter. PVC flashing was used to protect the collection system from receiving precipitation directly. Downspouts conducted the flow to covered buckets. Precipitation was simulated using a FullJet HH-50W nozzle. The same procedure was used for both materials, except that no wetting agent was applied to the BSM. Each treatment was managed as follows:

<u>Sloped Side:</u>

Sloped pile: Fresh material was installed to fill the bin and then covered with 1 cm oven dry material to simulate solar drying and associated hydrophobicity.

Dry pile: Rain was simulated for 30 minutes at a pressure of 21 psi and runoff volumes were collected.

Moist pile: Rain was further simulated for 30 minutes at a pressure of 32 psi and runoff volumes were collected.

Wet pile: Rain was still further simulated for 30 minutes at a pressure of 21 psi and runoff volumes were collected.

Turned pile: Moist turned material was installed to fill the bin. Rain was simulated for 30 minutes at a pressure of 21 psi and runoff volumes were collected.

Flat Top:

Flat pile: Fresh material was installed to fill the bin to 17 cm and then covered with 1 cm oven dry material to simulate solar drying and associated hydrophobicity. The flat area was extended as far as the material's natural angle of repose would allow.

Dry pile: Rain was simulated for 30 minutes at a pressure of 21 psi and runoff volumes were collected.

Moist pile: Rain was further simulated for 30 minutes at a pressure of 32 psi and runoff volumes were collected**.**

Wet pile: Rain was still further simulated for 30 minutes at a pressure of 21 psi and runoff volumes were collected.

Turned pile: Moist turned material was installed to fill the bin and rain was simulated for 30 minutes at a pressure of 21 psi and runoff volumes were collected.

Surfactant:

- **Surfactant:** Fresh material was installed to fill the bin and then covered with 1 cm oven dry material to simulate solar drying and associated hydrophobicity. Fifteen milliliters (1 Tb) of *E*-Z Wet Soil Penetrant 26 was dissolved in 500 mL water and applied as a pressurized aerosol to each bin.
- **Dry pile:** Rain was simulated for 30 minutes at a pressure of 21 psi and runoff volumes were collected.
- **Moist pile:** Rain was further simulated for 30 minutes at a pressure of 32 psi and runoff volumes were collected.
- **Wet pile:** Rain was still further simulated for 30 minutes at a pressure of 21 psi and runoff volumes were collected.

Because there were modest differences in precipitation rates beneath the rainfall simulator, three replicate measures were taken of the precipitation incident on each bin at both 21 and 32 psi. The data was then averaged so that results could be reported as the fraction of the precipitation incident on each bin that was captured as runoff. Runoff results likely overestimate what would be observed in the field since the setup replicates the bottom edge of the pile. Precipitation falling near the edge of the pile could infiltrate, but nevertheless be captured as runoff. This would not be significant in a commercial scale pile, but likely skewed the results to overestimate runoff.

Figure 36. Sloped GWM arrangement.

Figure 37. Flat BSM arrangement.

Results

COMPOSTING MATERIALS FROM A GREENWASTE FEEDSTOCK (GWM)

Turning the piles had no significant effect ($p < 0.05$) on the fraction of rain water collected as runoff from the piles compared to the unturned moist piles. However, the turned piles had lower runoff volumes compared to the unturned piles at the three different dates. A decrease of up to 38.7, 27.3, and 8.99 percent in the fraction of rain water collected as runoff was observed for day 1, 7, and 14, respectively, and shown in Table 49. For both the turned and unturned piles, more runoff was collected from day 1 material followed by days 7 and 14, suggesting that the GWM at day 1 maturity is the most hydrophobic material and that the hydrophobicity of the material decreases with increasing composting time. As the material becomes less hydrophobic, it allows more rain water to penetrate through the piles, thereby resulting in less runoff as observed in days 7 and 14.

The surfactant improved infiltration into the dry material. With a 1 cm thick oven dry material on the surface of the pile, the treatment (sloped surface and flat top and surfactant application) had a significant effect ($p < 0.05$) on the fraction of applied rain water collected as runoff. In general, compared to the day 1 material, days 7 and 14 decreased the runoff fraction. Although a flat top did not significantly decrease the runoff ($p < 0.05$) compared to the sloped, a decrease of up to 45.6, 44.2, and 34.3 percent was observed for days 1, 7, and 14, respectively, with the use of flat surface compared to the sloped surface. Application of the surfactant resulted in a significant decrease in the runoff fraction ($p < 0.05$) from both the sloped and flat top pile configurations. Compared to the sloped top, application of the surfactant resulted in a reduction of up to 60.65, 58.79 and 31.64 percent in the runoff fraction for days 1, 7, and 14 maturity dates, respectively.

For the piles with semi-wet material on the surface, flat top decreased the runoff from day 1 GWM by 35.8 percent compared to the sloped top. However, flat top resulted in an increased runoff by 45.0 and 35.6 percent from days 7 and 14 GWM, respectively. Surfactant application did not have a significant decrease in runoff from the semi-wet piles.

With the moist GWM, treatments (sloped surface, flat top and surfactant application) there was no significant effect on the fraction of rain water collected as runoff. For the sloped top, days 7 and 14 decreased the runoff by 45.9 and 59.9 percent compared to the day 1 GWM. With a flat top, runoff was decreased by 4.9 and 33.3 percent from days 7 and 14 relative to the day 1 GWM. Surfactant application did not result in a significant decrease in the runoff from moist piles.

In the case of the turned pile, a flat top did not significantly decrease the runoff ($p < 0.05$) compared to a sloped top. However, regardless of the maturity date, sloped tops did reduce the runoff fraction compared to the flat tops. The percent decrease in runoff fraction was 30.7, 42.2 and 34.4 percent for day 1, 7, and 14 maturity dates, respectively.

The flat top configuration did not significantly decrease the total runoff ($p < 0.05$) compared to the sloped top. In the case of the day 1 maturity date, the flat top resulted in a 34.83 percent decrease in runoff fraction compared to the sloped surface. For the day 7 maturity, flat top decreased the total runoff fraction by 4.39 percent. However, compared to the sloped top, the flat top resulted in an increase in total runoff fraction of 3.4 percent for day 14 maturity. Use of surfactant resulted in a 47.5 and 19.6 percent decrease in the runoff from days 1 and 7 GWM but increased the runoff by 12.5 percent from the day 14 GWM as demonstrated by Table 49.

In summary, application of a surfactant and the use of a flat top resulted in a decrease in the runoff fraction of GWM at day 1, 7, and 14 maturity dates. Any significant decrease in runoff using a flat top compared to a sloped top configuration was not evident in this study. This may be due to the preferential flow pattern and infiltration of rain water through the piles which was noticed throughout this study. A turned pile decreased the runoff compared to unturned piles. For the turned piles, sloped tops had reduced runoff compared to the flat tops. In all cases, more runoff was observed from day 1 followed by day 7 and day 14 maturity dates, indicating that the hydrophobicity of GWM decreases with maturity.

COMPOSTING MATERIALS FROM A FEEDSTOCK MIX OF BIOSOLIDS/GREENWASTE (BSM)

In the case of the BSM, as seen in Table 50, with a 0.5 cm thick oven dry BSM on the surface, the flat surface did not significantly decrease runoff ($p < 0.05$) from day 1 and 14 BSM. However, runoff from day 7 BSM was significantly decreased with the flat top compared to the sloped top. A decrease of up to 11.99 and 24.81 percent were observed for day 1 and day 7 BSMs respectively with flat top compared to the sloped top. For the day 14 BSM, the flat top increased the runoff fraction by 7.44 percent compared to the sloped top. Also, the use of surfactants increased the runoff from day 1 and 7 BSMs by 17.47 and 19.00 percent respectively. For day 14 BSM, application of the surfactant reduced the runoff by 6.15 percent, as seen in Table 50.

With semi-wet material on the surface, the flat top did not significantly reduce the runoff ($p < 0.05$) from the piles. For day 1 and 7 BSMs, runoff was decreased by 10.71 and 26.92 percent, respectively, by flat top compared to the sloped top. However, for day 14 BSM, flat top resulted in an increased runoff by 7.53 percent relative to the sloped surface.

With the moist BSMs, the flat top did not result in a significant decrease in runoff ($p < 0.05$). However, the flat top decreased the runoff from days 1, 7, and 14 BSM by 9.74, 19.35 and 6.08 percent compared to the sloped top. Also, runoff from day 7 relative to day 1 BSM increased by 14.11 and 3.83 percent with sloped and flat tops (Table 50). However, runoff from day 14 relative to the day 1 BSM was decreased by 31.86 and 29.09 percent with sloped and flat tops, respectively.

The total runoff fraction was not significantly reduced with the use of a flat top compared to the sloped top. In general, day 14 BSM resulted in lower total runoff fractions followed by day 1 and 7 BSMs. Flat tops decreased the runoff fraction by 10.62 and 23.71 percent for day 1 and 7 maturity dates but slightly increased (2.89 percent) the runoff from day 14 material.

In summary, with an exception to the moist piles, flat tops decreased the runoff from day 1 and 7 BSMs but increased the runoff from day 14 BSM. In all cases, runoff from day 14 was the lowest relative to days 1 and 7 BSMs. Also, day 7 resulted in more runoff compared to day 1 BSM, suggesting that day 7 BSM may be more hydrophobic compared to day 1 BSM. This may have resulted due to the active decomposition of day 7 BSM from increased moisture content. Increased runoff from days 1 and 7 BSMs were observed after the application of the surfactant, indicating that there was a preferential flow pattern that may have resulted in more runoff.

Conclusions

The water-holding capacity test gave a reasonable result when used to estimate the water holding capacities of the materials in the columns. The exception was the day 7 BSM which transmitted water more quickly than predicted. It is not clear why this exception occurred, though it was likely due to natural variability that can occur in composting materials. The greenwaste material responded to the water more consistently. Emulsifying agents can be used to assist in infiltration into greenwaste materials if they are dry, but are not as useful when the materials are moist. These agents did not help with BSM. It should be noted that partially composted material was studied, curing compost will be denser. Curing compost will probably be hydrophilic and hold water well, but there may be a problem infiltrating water into curing compost if it is overly dense.

The approach outlined here will need to be verified under local conditions at different compost sites, and should be considered as one management tool available to composters. Over-reliance on active compost as a water holding structure will impede the movement of air into the active compost and should be avoided. In the case of excessive moisture, turning may help to even moisture in the pile and reopen blocked air passages.

Literature Review

Compost can be defined as an organic material which has undergone controlled biological degradation and transformed in to humus rich material (Alexander, 1996). It also has an earthy smell and a friable structure. Composting is a natural process that uses microbes to decompose and stabilize organic wastes from agriculture, industries, and municipal sources so that they can be used beneficially as soil amendments, mulches, and fertilizers. According to Millner et al. (1998), composting provides a superior environmentally friendly simple alternative to organic waste disposal.

Compost production and use are not at all new. Ancient Greeks, Romans, and Israelites are known to have been familiar with composting. The process was documented when a farmer from Italy, Marcus Cato (234-149 BC), described and extolled the benefits of using compost to improve soils. It is thought that the Chinese were the first to develop large composting operations for use in agriculture, but it was in India that modern composting was born. It was there early in the 20th century that Albert Howard, an English botanist, applied scientific principles to develop a composting technique known as the Indore method (Howard and Wad, 1931). Today's composters rely on the same principles to produce reliable composts to meet contemporary needs (Stoffella and Kahn, 2001).

Any uncontaminated organic material is at least a potential feedstock for composting. Some commonly used feedstock materials are greenwaste from farms and turf areas in urban landscapes, biosolids/greenwaste co-compost from municipal wastewater treatment plants, manures from animal husbandry activities, wood by-products, food residues, and other organic byproducts from manufacturing industries. Composting these materials provides a beneficial alternative to disposal by landfilling and incineration (Larcheveque et al., 2006).

Compost quality can be evaluated for a specific use in terms of its specific physical and chemical characteristics; but compost optimized for one use may be less suitable for other purposes. Factors that contribute to compost quality include its organic matter content, the presence or absence of contaminants, its maturity, pH, soluble salts, moisture, nutrient content, and particle size distributions, as well as the absence of phytotoxicity, weed seeds, disease causing organisms, or excessive heavy metals.

Compost Uses and Types of Applications

Compost Blankets

Compost blankets are unincorporated surface applications of composts or composted materials. Compost is applied as a blanket on the top of soil surface to depths typically ranging from 1.25 - 10 cm, depending on budgets and site-specific conditions. They may be vegetated or unvegetated. Vegetated compost blankets, when applied at a uniform depth, can give close to 100 percent cover (Faucette, 2004). Due to their fertility and water-holding properties, compost blankets should be more successful than wood mulches on steep hill slopes for vegetation establishment (Faucette et al., 2007). Compost blankets are generally used on construction sites, stream banks, mine areas, and other disturbed soils to achieve immediate runoff and erosion control. Compost blankets absorb the energy of rainfall which could have dislocated soil particles. They also help to absorb substantial amounts of moisture to reduce flow velocities which reduces scouring and improves water infiltration.

Soil Amendments

When incorporated into the soil as a soil amendment, compost helps to develop a superior environment for revegetation/vegetation establishment. It helps to increase plant productivity (Guerrero et al., 2001) by increasing soil organic matter content and fertility (Butler and Muir, 2006). Compost tilled into the topsoil helps improve soil structure and water penetration (Cogger, 2005), and provides essential macro- and micro-nutrients for plant nutrition (Martinez et al., 2003; Moreno et al., 1996). Compost can increase the water-holding capacity of the soil (Murray, 1981), improve tilth, and reduce the soil bulk density (Pengcheng et al., 2008). In some cases compost applied as a soil amendment can also serve as a disease suppressant (De Cuester and Holtink, 1999; Graham, 1998) by increasing the activity of soil’s beneficial organisms (Zibilske, 1998).

Compost Filter Socks and Berms

Compost filter berms and filter socks are used to remediate stormwater runoff by filtering the sediment and associated pollutants running off eroded slopes and are placed perpendicular to the flow. Filter berms are simply long piles of compost installed to intercept and filter concentrated flows. A filter sock provides a similar function, but consists of compost installed inside of a porous fabric tube. Main advantages of using compost filter berms or filter socks are that they are easy to install, they can effectively filter the sediments and pollutants from runoff, and they are biodegradable. Compost filter berms replace traditionally used silt fences, straw bales, and other perimeter sediment controls.

This literature review has been conducted to evaluate the benefits of compost applications with respect to specific environmental issues, and to identify areas needing further scientific investigation:

- Erosion control;
- Vegetation establishment;

- Stormwater quality;
- Water conservation;
- Reducing fertilizer and pesticide use; and
- Reducing greenhouse gas (GHG) emissions.

Soil Erosion and Erosion Control

Erosion is the physical removal of soil and its movement by water or wind. Water erosion occurs when precipitation or irrigation rates exceed the infiltration capacity of the soil, and carry away soil particles. Wind erosion occurs when moving air currents lift and remove soil constituents. Whether the cause is water or wind, soil erosion accounts for the majority of all damage to land resources and is a serious international threat to soil productivity (Coote et al., 1981; Hurni, 1994).

In the United States, a total cost of $27 billion per year has been associated with the loss of topsoil, nutrients, water quality, and production caused by water erosion (Brady and Weil, 1996). Billions more are lost due to resulting sedimentation. Compost can provide immediate protection against erosion damage. The extent to which soil loss is due to erosion is increased by poor soil structure, dense subsoils, frequent and high intensity rainfall, repeated freeze-thaw cycles, and human intrusions through agricultural or construction activities (Chow et al., 2003). Soil loss factors include soil type, rainfall intensity and amounts, slope length and steepness, land cover, and management practices (Wischmeier and Smith, 1978). Smaller and less dense soil particles tend to be removed first (Lal 1995). Building and highway construction sites are particularly prone to high erosion rates due to the absence of topsoil needed to support plant growth and to the increased water runoff rates associated with soil compaction that results from heavy equipment movement (Risse and Faucette, 2001).

An estimated 4×10^9 tons of soil are lost annually due to erosion from both agricultural and non-agricultural lands in United States (Brady and Weil, 1996). Soil loss processes have been grouped into two types; interrill and gully erosion. Interrill erosion is caused by the activity of rain drops where soil particles are dislodged with rain splash and removed with draining rainwater. Gully or rill erosion occurs when a concentrated flow of water cuts the soil and creates a small channel into the earth. These rills can widen into gullies if there is repeated erosion over time. Over time, soil erosion can significantly reduce the productivity of agricultural soils. On construction sites, erosion may significantly damage the terrain, increase site maintenance costs, and in severe cases make re-grading and reconstruction necessary (Persyn et al., 2005).

Soil erosion and stream water sedimentation have been shown to have a very significant effect on water quality (Binkley and Brown, 1993) and soil erosion is considered to be the single largest source of nonpoint source pollution in the United States (U.S. EPA, 1997). According to studies concluded as part of the National Pollution Discharge Elimination System, or NPDES, most urban nonpoint source pollution associated with erosion originates at building sites and on highway embankments. During construction there is a loss of fertile top soil to support plants slowing the development of protective vegetation. Construction activities increase erosion and stormwater runoff by one to two orders of magnitude and it is estimated that soil loss rates are 10 to 20 times greater in construction sites than compared to agricultural lands (U.S. EPA, 2000).

Effective erosion control practices are needed and are being adopted. Reducing soil loss and maintaining the stormwater quality are critical priorities. Environmental beneficial techniques, called “Best Management Practices” (BMPs), have evolved that represent effective and efficient alternatives for controlling soil erosion and reducing associated sediment losses into surface waters. BMPs for reducing erosion include the spreading of organic mulches (e.g. straw mulches, compost applications, and hydroseeding.) Once erosion has occurred, other BMPs, such as the use of filter strips, berms, socks, silt fences, straw wattles, and even K-rail, can be installed as an attempt to capture lost sediments before they enter surface waters. Although structures can reduce the damage imposed by erosion, optimal erosion control will result from supporting long-term vegetation establishment so that the pollutant source area is transformed and protected (Benik et al., 2003). The scientific literature now suggests that composts used as mulches (blankets) or soil amendments are particularly effective for both the establishment and long-term development of plants in damaged or otherwise unproductive soils. Bresson et al. (2001) reported that incorporated compost can aid in protecting the soil surface from rain drop impact, reduce surface crusting and thus reduce soil loss due to erosion.

Organic mulches are shown to offer better soil surface contact and resistance to wind and water movement than manufactured alternatives such as straw mats. Compost, when applied as a blanket, acts as organic mulch and in later stages of application can also serve as a soil amendment increasing soil organic matter. Organic matter restoration is increasingly appreciated for its role in slowing down erosion and rebuilding soils. Organic matter safeguards soil structure, a key factor in controlling the rate of erosion. By supplying organic matter, compost improves soil tilth and increases aggregate stability (Bradford and Foster, 1996; Piccolo and Mbagwu, 1990) which in turn helps soil particles resist rain drop impacts and reduces erosion even at elevated runoff rates. It also encourages infiltration which reduces the volume and intensity of runoff (Adams, 1966; Gilley and Risse, 2000).

Vegetation establishment on damaged soils is a critical strategy for achieving erosion control. Hydroseeding is another, more established, and common practice for controlling erosion on steeper slopes and highway embankments. Hydroseeding applies a thin layer of fibers and seeds, usually along with a tackifier, to the bare soil surface (GA, SWCC, 2002). Hydroseeding may develop vegetation more slowly and can encourage more weed growth than compost blankets. There is also a significant risk of phosphorus and nitrogen loading from the hydroseeded plots after storm events (Faucette et al., 2005). Compost applications, both as a blanket and soil amendments, have been shown to effectively control soil erosion, especially on highly disturbed sites like construction areas and highway embankments. Recent studies have also shown the effectiveness of compost to reduce runoff and sediment loss.

Compost Blankets for Erosion Control

Compost, when applied as a blanket on the soil surface, has the potential to reduce soil erosion (Persyn et al., 2004). Recent research conducted by several state transportation departments has emphasized the efficacy of compost use for erosion control on highway sites damaged by intense construction activities.

In an experiment conducted by the Connecticut Department of Transportation in Chaplin, Conn., composted yard waste, wood mulch, and straw reduced erosion about 10-fold compared to a bare soil treatment on a site with a 2:1 horizontal to vertical slope. Compost was applied in 3.8 and 7.6 cm blankets to each 35 by 10 ft plot. The plots were evaluated for soil erosion (sediment loss) after heavy rainfall events and runoff was collected to test for suspended solids, metals and nutrients. The compost and mulch treatments were found to perform equally well or better than the conventional hay and seeded treatments. However, the thickness of the compost and mulch blankets did not have a significant effect on sediment loss since the 3.8 cm blanket produced the same sediment load as that of a 7.6 cm blanket (Block, 2000). Similar results were reported by Portland Metro (1994), where yard waste compost blankets used in residential construction sites in Portland, Oregon, enhanced the erosion control and also improved the water quality when compared to a traditional erosion and sediment control practice of straw mulching.

Glanville et al. (2003) reported that when three different composts (biosolids/greenwaste co-compost, yard waste and bio-industrial) were applied as 5 and 10 cm blankets, there was no significant difference observed between the two different depths with respect to soil erosion rates when rainfall was simulated to achieve an intensity of 95 mm/hr. The 5 cm layer performed as well the 10 cm blanket with respect to erosion control, water quality, and vegetation benefits. In this experiment, conducted on a highway construction site in Iowa, three composts along with an incorporated topsoil treatment and a control (conventional treatments) were tested for associated runoff rates, rill and interrill erosion rates, and the dissolved and absorbed metal and nutrient concentrations in runoff. During the first 30 minutes of high intensity rainfall, all plots treated with composts produced 0.5 mm of runoff while conventionally treated plots produced 15 mm of runoff. The total mass of eroded material carried by runoff from compost treated plots was less than 0.02 percent of that of material coming from conventional treatments. The eroded solids in the runoff from composted plots ranged from 0.02 mg/L to 7.84 mg/L than 40,000 to 43,000mg/L in both top soil and bare soil plots. Of the three compost treatments, the yard waste compost was most effective in controlling interrill erosion rate and reducing the time to initiate runoff (Persyn et al., 2004).

Research initiated by the Texas Transportation Institute's Hydraulics and Erosion Control Field Laboratory compared the effectiveness of a mixed yard trimmings and biosolids/greenwaste co-compost with a shredded wood and tackifier mulch. Erosion control (sediment loss) and vegetation establishment were considered on clay and sandy loam soils with 3:1 horizontal to vertical slopes. Rain was simulated to produce 1, 2, and 5 year return period storms. Results indicated that compost materials produced less sediment in sandy loam soils and had more vegetation on both clay and sandy loam soils than did the shredded wood plus tackifier treatment. Sediment loss from the compost treated plots was 0.034 kg/m^2 on the clay soil and 0.39 kg/m^2 on the sandy loam soil plots. The tackified shredded wood treatments produced sediments at rates of 0.030kg/m^2 on clay soil and 1.1 kg/m^2 on sandy loam soil (Storey et al., 1996).

Researchers at the Department of Biological and Agricultural Engineering at the University of Georgia developed a multi-phase project to investigate the impacts of compost use for erosion and sediment control. As a part of the project a small-scale research study was constructed using different types of composts and mulches. A total of 11 treatments, including poultry litter composts, uncomposted aged poultry litter, yard waste compost, food waste compost, a biosolids/greenwaste co-compost, finely screened wood mulch, wood waste mulch, and a control treatment with bare soil were included. These treatments were placed on a 1 m^2 plot frame at a depth of 5 cm. Each frame was filled with soil and compost and mulch treatments were surface applied on the soil with a 10 percent slope. Rainfall was simulated at a rate of 3.5 in/hr for one hour. Results showed that all the composted and mulch treatments, except aged poultry litter, presented significantly less runoff and erosion. There were no statistically significant differences among the compost and mulch treatments with respect to runoff volumes and solids losses (Faucette and Risse, 2002; Faucette et al., 2004).

A study conducted by Ettlin and Stewart (1993), in conjunction with Portland Metro Water District in Portland, Oregon, reported that three different composts (coarse yard waste compost, medium textured compost material, and leaf compost) applied in 7.6 cm blankets on slopes of 34 and 42 percent, were more successful in erosion control than sediment fences and wood fiber hydromulch treatments.

Pengcheng et al. (2008) conducted an experiment on a highway embankment of Xihuang highway in China with a 2:1 slope. Their goal was to treat a clay loam soil with poor structure and low fertility, which made it prone to erosion during rain events. For their experiment, biosolids/greenwaste co-compost was applied to the soil surface at rates of 15, 30, 60, and 120 dry tons per hectare (ha) along with a control without compost and the results showed that compost treatments with increasing application rates significantly reduced the runoff and reduced sediment losses from the embankment when compared to control.

An experiment in Willington, Conn., with a 2:1 slope using composted wood waste material applied in depths ranging from 2 to 7.6 cm was found to effectively control erosion, surface runoff and sediment losses when compared to bare soil treatments over 11 rainfall events with varying magnitude and intensity (Demars et al., 2000). There was a significant difference among the mulched treatments and controls with respect to total runoff volume at low rainfall intensities. With a high rainfall intensity of 47.1 mm/hr, even though mulched treatments reduced the runoff volume, runoff differences were not statistically significant when compared to control due to statistical variability in the data. Sediment export was significantly reduced in the mulch treatments with controls producing about 50 times more sediment than the composted wood waste mulches.

Reinsch et al. (2007) conducted an experiment in Lincoln, Neb., on a 3:1 slope for evaluating the effectiveness of yard waste compost for improving the quality of stormwater runoff. The treatments included incorporated yard waste compost, compost applied as a 5 cm blanket, incorporated compost along with a filter berm, straw mat, straw mat with silt fence, and a control. A total of 21 natural rainfall events and three simulated rain events were used over two seasons. Results showed that the compost blanket reduced runoff by 96 percent compared to the control. Other differences included 74 percent by the incorporated compost with filter berm, 69 percent by the incorporated compost alone, 52 percent by the straw mat with silt fence, and 29 percent by the straw mat alone in reducing runoff compared to the control during the first season. Both the incorporated and blanket compost treatments eliminated runoff altogether by the end of second season.

In an effort to test the effectiveness of compost blankets in reducing soil erosion in a vineyard in Champagne area of France, it was found that compost treatments decreased the amount of eroded material by two orders of magnitude when compared with the no compost treatments (Baliff and Herre, 1988). Results from an experiment conducted by Michaud (1995), have shown that 10 cm mulch applications of compost significantly controlled erosion on slopes up to 45 percent (~1:1). It was found that compost mulch applications reduced soil erosion 10-fold on a 2:1 slope compared to control in a study conducted by the Connecticut Department of Transportation (Demars and Long, 1998).

Composts are clearly effective for reducing erosion when applied as blankets. These products can also be incorporated into soils for use as amendments to improve soil properties and enhance vegetative cover.

Compost as a Soil Amendment for Erosion Control

Many authors mention the importance of organic matter content in the soil and its relation to susceptibility of a soil for erosion and have demonstrated that increasing organic matter content decreases the rate of soil loss (Barthes et al., 1999; Auerswald et al., 2003; Tejeda and Gonzalez, 2007). The organic matter content in compost can range from 25 to 75 percent but average values fall in the range of 35 and 45 percent. Increasing organic matter through compost applications in soils can help to stabilize the soil surface and improve its structure after damage due to various human activities. Better soil structure helps to prevent the loss of fertile top soil through erosion and also helps to infiltrate and retain water. An increase in organic matter in the soil surface layer can help to absorb the energy of raindrop impacts and facilitate water movement into the soil reducing both surface runoff and erosion (Jordan, 1998). Compost use also helps with vegetation efforts. Densely covered vegetation offers a greater resistance and helps to reduce the runoff rates and pollutant sediment loading.

A study conducted in Sevilla, Spain, on a 2 percent slope incorporated 28.09 tons/ha crushed cotton gin compost as one of its treatments. This decreased the soil losses by 32 percent compared to untreated controls when rainfall was simulated at a rate of 140 mm/hr (Tejada and Gonzalez, 2008).

A research study was completed in France that tested the effectiveness of biosolids/greenwaste co-compost for reducing runoff and soil erosion. The compost was incorporated into a highly unstable silt loam soil representative of a north Paris basin. The experiment was conducted under laboratory conditions (repacked seedbeds) using simulated rainfall. Compost was hand mixed with the soil and placed in 50-by-50-cm runoff trays at a rate equivalent to 50 tons/ha mixing into a 25 cm plow layer. Results indicated that compost was successful in reducing the surface crusting and sealing. Sediment concentration in the incipient runoff also was very low in compost amended trays with 11 g/L compared 36.4 g/L in control trays. Soil loss was significantly less from the compost amended trays (18.3 g) compared to the control trays (54.6 g). This study concluded that compost as a soil amendment improved soil structure, reduced soil crusting, and increased soil aggregate stability which significantly helped to reduce the soil loss and sediment transport (Bresson et al., 2001).

Vegetation Establishment

It is not unusual for construction to damage the capacity of soils to support vegetative growth. Construction can remove or displace organic matter needed to maintain soil structure, structure that is also typically destroyed by the mechanical activities associated with installing pavement and buildings. Vegetation development on highly disturbed sites is hampered when fertile topsoil is lost and the medium required for good plant growth is restricted (Mitsch and Wilson 1996). Under these conditions reestablishment native species can be challenging (Lindig-Cisneros and Zedler 2002). Wildfires also remove vegetation, exposing soils to the actions of precipitating and draining water.

Revegetation problems are further intensified in areas when construction or fire damage is followed by accelerated soil erosion. Whether exposed by construction or wildfire, damaged soils are likely to erode; discharging sediments and associated pollutants to local surface water. The most important factor influencing long-term erosion control is the level of cover crop establishment (Pritchett and Fischer, 1987; Morgan 1997; Block 2000). There are a number of approaches for developing vegetation on damaged sites. The most popular and affordable approach commonly followed is hydroseeding or seeding alone along with fertilizers and sometimes herbicides. However these alternatives may have short-term risks associated with their applications due to increased sediment and stormwater runoff, fertilizer and herbicide runoff (Faucette et al., 2005). Compost blankets, by contrast, provide immediate cover to soils reducing these losses. Also, where soils are severely damaged, compost use, as blankets or soil amendments, supplies significant organic matter and organic nutrients to sustain plants for many years.

Topography is an important factor in revegetation efforts. Revegetation is often most difficult on steep, particularly north-facing, slopes, and steep slopes are also most likely to suffer erosion (Meyer et al., 1971). Re-vegetating plants also need water, and compost, whether used as a blanket or incorporated, has been shown to assist in water infiltration and retention (Singer et al., 2006). Compost blankets also moderate soil temperatures further reducing water losses and conserving soil water (He et al., 2002; Sikora and Szmidt, 2002). Water needed by plants and their seeds is less likely to infiltrate steep slopes. In the Northern Hemisphere, north-facing slopes also receive less of the light needed for photosynthesis. In California, revegetation efforts are commonly limited by precipitation which typically falls during the late fall, winter, and early spring when daylight hours are short and solar radiation is less intense. Once installed, composts on steep slopes can work well, but planners should be aware that installation to inaccessible steep surfaces can pose a challenge. The availability of local application equipment should be investigated as part of the revegetation strategy development process.

Composts contain nutrients, but these are mostly in organic forms released more slowly than the inorganic fertilizers added with hydromulch. Application of compost increases the soil's organic matter content, and releases its nutrients slowly, which assures their long-term availability to the plants. Increasing soil organic matter content has a positive effect on the establishment and persistence of the plant communities on a long-term basis (Classen and Hogan 2002; Reeder and Sabey 1987). Once cover develops, soil conditions improve and erosion is reduced. Vegetation slows water movement and encourages infiltration (De Ona 2006). Soil particles are held in place by roots and root activity and soil textures improve. Cover crop establishment also helps prevent weathering and encourages slope stabilization. In most cases, vegetation can be established by adding organic material to the surface of the damaged sites.

Some soils are prone to the development of low permeable crusts that prevent seed emergence, limit infiltration, and facilitate erosion. Incorporated composts have proven to help control this problem (Bresson et al., 2001). Decomposed granite soils may resist water infiltration by crust formation due to the rain drop's splash impact. Soils derived from decomposed granite (DG) are also prone to severe erosion due to various disturbance activities (Gonsior and Gardner, 1971). Most highways in Northern California pass through regions where granite is significant in the local geology. Curtis and Claassen (2007) concluded after a study on a 2:1 slope with DG parent material located on California Highway 299, that unscreened yard waste compost used as an organic amendment can facilitate rapid plant growth and increase water infiltration. They found that incorporated compost can help prevent surface sealing. Compost was incorporated at rates of 135, 270, and 540 dry tons/ha. A control which received no compost treatment was used as a reference site. During the first year of the experiment there was no strong trend observed between the treatments with respect to plant biomass, however during year two, the plant cover was significantly improved with increasing compost application rates. The 540 tons/ha treatment had a biomass of 354 g/m2 while the control averaged 290 g/m2 of biomass. Norland and Veith (1995) reported that municipal solid waste compost amendments increased plant cover in a taconite iron ore tailing site. After four years of compost applications ranging from 10-90 tons/ha, plant cover improved from zero (before amendment application) to 90 percent.

In the landscape, weeds commonly displace more desired species. Mulches are widely used to reduce weed emergence (Altieri and Liebman, 1988). In a revegetation effort intended to establish native grasses that included an untreated control, straw mulch, bonded-fiber matrix, straw/coconut blanket, and wood-fiber blanket treatments, Benik et al. (2003a; 2003b) found that there was no native grass establishment for the first three years due to the dominance of the weed species. Compost blankets can be an affordable alternative compared to synthetic weed control alternatives (Feldman et al., 2000). Composting eliminates most weed species and fine textured or fine/coarse compost blankets can provide an effective germination environment as long as the material is mature. Uncomposted materials, such as ground greenwaste for example, will contain more viable weed seeds. It should be noted that immature compost can act as effective natural herbicides due to their phytotoxic compounds (Niggli et al., 1990; Ozores-Hampton et al., 2002a) and should be avoided where swift revegetation is a project objective.

In an Iowa experiment, Persyn et al. (2007) compared the revegetation success of three composts (biosolids/greenwaste co-compost, yard waste and bio-industrial) with incorporated topsoil and compacted subsoil treatments on a 3:1 slope. Treatments were seeded with oats, annual ryegrass, red clover, and timothy. All treatments improved the vegetative stand both during the first and second years and differences between the treatments were not statistically significant. The mean dry masses of the planted species were 230 g/m^2¸ 339 g/m^2 and 366 g/m^2 for the biosolids/greenwaste co-compost, yard waste, and bio-industrial composts, respectively, 294 g/m^2 for the topsoil treatment, and 354 g/m^2 for the subsoil treatment. These composts did significantly control weed emergence, however. The mean weed dry mass after two years was 34, 75 and 94 g/m^2 for the biosolids/greenwaste co-compost, yard waste and bio-industrial treatments compared to 353 g/m^2 and 260 g/m^2 for the subsoil and topsoil treatments, respectively. Although these compost treatments were applied at depths of 5 and 10 cm, there was no significant difference between the depths. Both depths also proved effective for controlling erosion (Persyn et al., 2004). Another Iowa study evaluating the vegetation effectiveness of incorporated and surface applied yard waste composts on a highway slope project found that the mean shoot biomass was more than twice as great in compost treated plots as in control plots. There were no significant differences among the compost treatments with respect to the shoot biomass (Singer et al., 2006). Both compost treatments increased soil moisture.

Stormwater Quality

Runoff is the water remaining from a precipitation event after discounting what is infiltrated into the soil, taken up by plants or evaporated in to the atmosphere. In urban areas, stormwater is generated after precipitation from runoff draining from construction sites, buildings, roads and other impervious soil surfaces (Barrett et al., 1998; Sansalone and Buchberger, 1997; Wu et al., 1998). Stormwater quality is often very poor, due to its removal of accumulations of sediments, nutrients, oil and grease, and heavy metals. Sediment in the runoff is considered to be the greatest single nonpoint source of pollution with respect to the quality of surface water (Ermine and Ligon, 1988). Road and building construction sites are said to be mainly responsible for the development of sediment in the stormwater runoff. About 10-20 times sediment runoff rates have been reported from the construction sites when compared to agricultural lands and 1000-2000 times from that of forest lands and 200 times that of the rate from grass lands (Wark and Keller 1963). Gray and Sotir (1996) estimated that about 2 billion tons of eroded sediment in total is produced every year in the U.S. Of this total, around one-third reaches oceans and the remaining goes in to fresh waterways, lakes, river channels, and reservoirs, causing water quality deterioration. Excess sediments in runoff have the potential of carrying adsorbed contaminants like fertilizers, pesticides, oils, etc. to clean waterways. Turbidity is one negative result associated with sediment in runoff. High turbidity inhibits light penetration interfering with aquatic life. Sediment can also interfere with benthic fauna and fish eggs (Barrett et al., 1995). Nutrients, whether dissolved or associated with sediments in solid form, are also of great concern. Grace (2004) reported that an estimated 1 million metric tons of nitrogen was carried annually by sediment in the stormwater to fresh water resources. Phosphorus can lead to eutrophication and toxic anaerobic conditions. Sediments have the capacity to transport heavy metals and harmful soil bacteria to contaminate the receiving waters (Sallaway, 2006). Also excessive sediment accumulation in water reservoirs would reduce their storage capacity over a period of time, decrease the aesthetic and recreational value of water resources, increase costs of cleaning the water, and also may lead to clogging of irrigation systems (Risse and Faucette, 2001).

Stormwater Quality Management

Controlling the impact of erosion on stormwater quality has been a national regulatory priority for some time (Goldman et al., 1986). In 1987, amendments made to the Federal Clean Water Act (CWA) mandated the control of soil erosion, and sediment accumulation in stormwater near construction sites (Glanville et al., 2004). The U.S. EPA requires strict stormwater management practices on construction sites and administers its requirements as part of the National Pollution Discharge Elimination System (NPDES) program (Reinsch et al., 2007). Best Management Practices, including detention ponds, bio-retention system, swales, filter berms and other infiltration techniques must be applied to reduce and improve stormwater runoff (Ellis et al., 1986; Schueler 1987; Urbonas and Stahre 1993).

Role of Compost in Maintaining Stormwater Quality

Research has shown that compost and composted products can be successfully used to prevent water pollution. Many of the most effective BMPs developed to improve stormwater runoff quality take advantage of the ability of compost to filter water or to improve soils. By either directly protecting (as with the compost blankets), by improving (as with the use of soil amendments), or by assisting in the vegetative development of soils, compost use reduces the intensity of runoff events. The sediment load associated with the runoff is also reduced. The organic carbon in the compost may absorb heavy metals and organic contaminants while maintaining a soil structure suitable for filtering sediments (Koob and Barber, 1999). Compost blankets have been found to be particularly effective for controlling erosion, stormwater runoff and water pollution from construction sites (Glanville et al., 2003). Compost filter berms and filter socks are an increasingly popular option for removing sediments through filtration in areas with concentrated flows at high rainfall intensities and steeper slopes. The filter berms, when placed at the top or at the bottom of the steep slopes, would provide protection by reducing runoff flow rates and filtering sediments thus preventing the contamination of receiving waters in the downstream (Goldstein, 2002).

Compost blankets are mulches used to reduce stormwater pollution. Glanville et al. (2004) in an experiment using three different composts (Biosolids/greenwaste co-compost, yard waste and Bio-industrial) and two conventional treatments (compacted subsoil or bare soil and top soil), tested the effects of compost blankets on runoff water quality when simulated with a high rainfall intensity of 100 mm/hr. The soluble and adsorbed mass of pollutants (which included nutrients and metals) from the compost treatments during the first 30 minutes of rainfall ranged from 0.01 mg to 1.08 mg when compared to the range of 1.38 mg to 104 mg in bare soil treatment and 0.16 mg to 206 mg in top soil treatment. This is almost 100 times less in compost treatments. There were significant differences in the concentrations of nutrients within the compost treatments; however the levels were well below the EPA minimum threshold levels.

Faucette et al., (2004) conducted research comparing different types of composts used as blankets, including poultry litter compost, municipal solid waste compost, biosolids/greenwaste co-compost, food waste compost, yard waste compost, three different types of wood mulch, and a control. Results indicated that, compared to bare soil treatment, compost and mulch treatments reduced the total solids loss significantly. The total solids loss was in the range of 74-550 gm for the compost treatments, compared to the bare control which had a solids loss of 646 gm. Even though nitrogen and phosphorus loss rates were higher in some compost treatments, especially in poultry litter compost, it was not significant enough to cause an environmental concern because of the low runoff volumes produced when compared to the control.

Compost filter socks are a down slope alternative for treating concentrated flows. Compost filter socks treated with a polymer have been shown to outperform silt fences. Sediment removal efficiencies ranged from 90-99 percent for the compost filter socks. The removal efficiencies of compost for total suspended solids (TSS) concentrations ranged from 62-87 percent, TSS load 68-90 percent and turbidity 53-78 percent (Faucette et al., 2008). In 2005, the U.S. EPA approved the use of compost filter socks as a BMP under NPDES phase-2 for encouraging sediment deposition and as a means of improving the quality of runoff water (U.S. EPA, 2006).

Research initiated in Georgia compared the peak flow rates and sediment removal efficiencies of straw bales, mulch filter berms, compost filter socks and compost filter socks + polymer as perimeter sediment control devices. Rainfall was simulated to represent a 24 hr 5-yr return period storm on a 10 percent slope. Results showed that all the sediment control treatments significantly reduced the peak flow rates compared to bare soil control. All treatments produced significantly less total solids both in terms of concentration and mass. Compost filter sock treatments had less total solids than mulch filter berms and straw bales. Total solids load removal efficiency ranged from 63 to 88 percent. All treatments significantly reduced total suspended solids compared to the control and compost filter socks produced lower concentration and mass of suspended solids than filter berms and straw bales. The removal efficiency of total suspended solid load ranged from 60 to 90 percent. All compost filter socks treatments had significantly lower turbidity values. Those filter socks with polymer had significantly lower turbidity than those without polymer. The percent turbidity reduction ranged from 8 to 49 percent (Faucette et al., 2009). Similar results were found in a study conducted by Faucette and Tyler (2006) where compost filter socks had significant removal efficiencies of concentrations of nitrate-N and total P. The total solids and hydrocarbon removal efficiency of the compost filter socks averaged 95 percent. The motor oil removal efficiencies from stormwater runoff ranged from 85 to 99 percent.

Reinsch et al. (2007) conducted an experiment in Lincoln, Neb., on a 3:1 slope for evaluating the effectiveness of yard waste compost for improving the quality of stormwater runoff. The treatments included incorporated yard waste compost, compost applied as a 5 cm blanket, incorporated compost with filter berm, straw mat, straw mat with silt fence, and a control. A total of 21 natural rainfall events and three simulated rain events were used over two seasons. Results showed that compost blankets reduced 96 percent of total reactive Phosphorus (mg-PO4/season) loading when compared to control. Total Kjeldahl Nitrogen loading was also monitored and it was observed that compost blankets did not increase nutrient loading in stormwater runoff when compared to conventional straw mats and silt fences. The total sediment load in the runoff from compost blanket was 0.56 kg/season in the first season and zero in the second season, with corresponding 180 kg and 83.8 kg per season sediment load in the runoff from control plots.

In an experiment conducted at Environmental Quality Laboratory, USDA Agricultural Research Service, Maryland, the sediment and nutrient removal efficiencies of compost filter socks and silt fence was evaluated with respect to control. Three compost filter sock treatments, one silt fence treatment, and a control (bare soil) were established using 10 percent slope soil chambers. Each received simulated rainfall at a rate of 7.45 cm/hr 30 minutes. It was observed that compost filter socks reduced water turbidity by 78 percent. Other removal rates for compost filter socks included 87 percent for TSS, 65 percent for Total P, and 28 percent for soluble P. Corresponding silt fence removal efficiencies were 76 percent, 87 percent, 63 percent (Faucette et al., 2008).

Bio-retention is one of the most effective management approaches for protecting stormwater quality. Bio-retention structures are essentially soil, mulch, and plant-based low impact treatment and filtration systems. Soils used for bio-retention structures are commonly amended with substantial amounts of compost. They are most often used in urban and suburban areas for treating the stormwater runoff from construction sites, roads, and parking areas (Kim et al., 2003;

Davis et al., 2003). Bio-retention systems work by encouraging infiltration, evapotranspiration, soil filtering, adsorption, and biotransformation of the pollutants. Research conducted by Davis et al. (2001) reported that this system efficiently reduced exported metal (copper and zinc) concentrations by 92 percent, phosphorus by 80 percent and total Kjeldahl nitrogen by 75 percent from the urban storm waters. Bio-retention can be less effective in controlling nitrate emissions. However, one precisely engineered bio-retention systems has been shown to successfully remove up to 80 percent of the nitrate and nitrite in stormwater (Kim et al., 2003). The system uses leaf mulch compost as an organic media for denitrifying microorganisms. Bio-retention systems typically maintain vegetation perpendicular to the flow path of the stormwater. This further assists in the adsorption and filtration of nutrients and metals (Harper et al., 1984; New Berry and Yonge 1996). Ecology ditches are related to bio-retention structures. Ecology ditches are modified infiltration trench that are used to reduce pollutant levels in stormwater runoff. Compost can also be used in ecology ditches as a filtration agent and pollutant adsorbent (Yonge, 2003).

Water Conservation

More than 40 percent of the world's food production is from irrigated areas and demand for water is likely to increase as population pressure increases (Fereres and Connor, 2004). Jury and Vaux (2005) concluded that "the single biggest water problem worldwide is water scarcity." Of all water use sectors, agriculture has the highest rate of consumption. According to Shiklomonav (1999), agricultural demand accounts for 65 percent of the total water usage, while 30 percent goes to urban uses and the remaining 5 percent is lost to the atmosphere through evaporation from surface waters. In California, most agricultural water is delivered through irrigation because precipitation does not meet the crop requirements. Most of the fresh water that is used for urban water supply is derived from the melting mountain snow packs. Population pressure and global warming are likely to increase the need to conserve water in the future. With increasing urban water use, allocations of fresh water to agriculture are expected to decrease, forcing growers to further conserve water. In water-pressed agricultural areas, future irrigation management strategies may shift from production per unit area toward increasing the production per unit of water consumed, thus maximizing the water productivity (Fereres and Soriano, 2007).

Mulching and Water Conservation

It is well established that mulch use can conserve water. Mulch is any material that is spread on the soil surface to conserve soil moisture, reduce soil temperature, prevent soil erosion, moderate runoff, or to suppress weed growth. Mulches may be biological in origin (compost, straw, wood chips) or not (gravel, plastic). Organic mulches can be made from many natural materials including leaves, stubbles, straw, tree trimmings, wood chips, compost, etc. Plastic mulches are widely used in inorganic mulching in addition to pea gravel and crushed volcanic rocks; however these do not provide organic matter or nutrients to the soil. Research has established that the use of organic residues as mulches can increase water use efficiency in both horticulture and agriculture by (1) improving water infiltration and storage in the soil and by (2) reducing evaporative losses from soil surface (Gardner, 1959; Bennett et al., 1966; Mahrer et al., 1984). Evaporative water losses from the soil can lead to depletion of soil water levels, which may require more frequent water applications. Mulch insulates and protects soil from drying caused by evaporation of water from soil due to high temperatures (Todd et al., 1991). Mulched soils are therefore cooler than non-mulched soils and have fewer fluctuations in soil temperature. Over a period of time organic mulches also become part of the soil, helping to increase soil organic matter content and build soil structure, ultimately helping soil conserve moisture (Clatterbuck, 2003).

In greenhouse experiments at the University of Jordan, Abu Awwad (1999) estimated that mulching reduced the irrigation water requirements of onion plants by 70 percent, and decreased the soil temperatures by an average of 3°C. Abdullah et al. (2004) found in a lettuce crop greenhouse study that mulching reduced the crop irrigation water requirements by 60 percent. Similar, but less dramatic, results were reported for pepper plants where irrigation requirements were reduced from 761 mm in open soil treatment to 670 mm in a mulched treatment for a 12 percent reduction in irrigation requirements (Abu Awwad, 1998). Other studies with organic residues as mulches have also been shown to conserve soil moisture (Adetunji, 1990; Carter et al., 1992 Gajri et al., 1994) and also to decrease the soil temperature (Bristow and Abrecht, 1989), helping to reduce evaporation losses.

Mulches need not be plant-derived. Plastic mulches can also conserve water (Stapleton et al., 1988; Stapleton et al., 1989). Peters and Johnson (1962) reported an approximately 50 percent rate of water savings when a soil was mulched using plastic. Plastic mulches must be collected and disposed after they are used, however. Because plastic mulches do not improve soil properties, they may be less effective for maintaining moisture in soils (Cook et al., 2006).

Most research into the mulching properties of compost blankets has emphasized runoff control and water quality conservation. Reductions in runoff imply at least some conservation of water within the soil, however. Composts applied as mulch also reduce evaporation and increase the soil water storage. A research study in Willunga basin, South of Adelaide, Australia, composted green organics when applied as surface mulches to vineyards and found a significant increase in soil moisture levels after compost mulch applications. Compost mulch depths ranged from 1 to 15 cm and a 20 cm straw mulch treatment was used for comparison. A 100 percent increase in soil moisture observed occurred for the 1 cm depth compost mulch treatment, along with a 300 percent increase for the 5 cm treatment, and a 400 percent increase for the 15 cm treatment. The soil moisture content at 5 cm depth of compost mulch equaled that of 20 cm straw mulch, indicating that compost can be a better alternative for water conservation (Anonymous, 1998). Israeli investigators considered the use of composted municipal solid waste as dry-land wheat mulch and found that compost treatments did conserve water. By reducing evaporation, yields were almost doubled. The mulch treatments also supplied nutrients sufficient to support the crops, however, the authors expressed concern that at the highest application rate groundwater pollution might occur due to the excessive release of nitrate-nitrogen (Agassi et al., 2004; Hadas et al., 2004).

Mulching may be more effective at water conservation than soil amendment use. Unger et al., (1968) reported that, compared to controls, cumulative evaporation rates decreased by 57 percent when straw was applied as mulch on the surface of the soil and by 19 percent and mixed with the soil. Nevertheless, soil amendments can conserve water, and because there has been considerable research into the use of composts as soil amendments there is more information available in the literature on this topic.

Soil Amendments and Water Conservation

Organic amendments, such as compost, can conserve water by improving soil water infiltration and storage. Pagliai et al. (1981) suggested that an increase in water holding capacity of soil can also be attributed to improvement in pore size distributions with compost incorporation. Pore sizes in the range of 0.5-50µm most effectively maintain water that is freely available for plant uptake. Incorporating compost, or even surface applications, can encourage the development of pores in this range (Hernando et al., 1989). In both horticultural and agricultural settings, compost has been shown to improve soil physical properties such as bulk density, total porosity, saturated hydraulic conductivity and soil water holding capacity that are associated with water conservation (Edwards et al., 2000; Rosen et al., 1993).

Water Infiltration

Compost assists water infiltration into finer textured soils. In an experiment conducted by Butler and Muir (2006), composted dairy manure, applied at various rates, improved soil organic matter content by 54 percent and water infiltration rate by 55 percent. The infiltration rate increased with increasing rates of compost applications. Mays et al. (1973) reported that the incorporation of municipal sludge compost at various rates for production of forage sorghum, Bermuda grass and corn at Johnson City, Tenn., enhanced both the infiltration capacity and water holding capacity of the soil. This increase in water movement into the soil profile was explained as a result of increase in organic matter content and decrease in bulk density. Studies conducted using biosolids/greenwaste co-compost at different rates (0, 40, 80, 120 and 240 tons/acre) reported an increase in water content and water retention in a silt loam soil (Epstein et al., 1976). Similar findings were made when biosolids and composted biosolids applications increased the soil aggregate stability and water retention in silt loam soils (Epstein, 1975). Singer et al., (2006) suggested that the use of yard waste compost at a rate of 64 tons/acre on construction embankments in Altoona, Iowa, helped to increase infiltration and water storage capacity after rainfall and also improved plant growth when surface applied or mixed into the soil. They found that incorporation of the compost had increased water storage to 5.6 cm in the top 5 cm layer than the surface application which had 4.8 cm of water. Similar results were reported by Gallaher and McSorley (1994) in an experiment conducted with yard waste compost to test the effects on soil properties and sweet corn yields in Alachua county of Florida. Compost treatments at planting time increased the water storage capacity by 70-150 percent. Martens and Frankenberger (1992) also concluded that water infiltration rates were increased in soils amended with composted organic materials. Weindorf et al. (2006), in a 10 site Dallas County, Texas, study, however, found that infiltration rates were determined more by site-specific soil conditions than by incorporation of compost derived from greenwaste at three rates (2.5, 5.0, and 7.5 cm). Compost soil amendments did appear to increase the water storage of the Austin, Eddy, and Brackett soils.

Water Storage

Composts also can improve the capacity of soils to hold water, making irrigation more efficient (McDaneil and Munn, 1985; Busschiazzo et al., 1991). Compost can rapidly improve the water-holding capacity of coarse-textured soils (Kreft, 1987; Rynk 2002). Clark et al. (2000) reported that application of municipal solid waste compost increased the soil water in drip irrigated sandy soils, reducing the number of irrigation cycles for a given crop period. In another experiment in a young slash pine plantations planted in a sandy soil in central Florida, composted municipal waste applied at 44 tons/acre increased the soil moisture and reduced the number of irrigation events needed during the drought period (Bengtson and Cornette, 1973). This was attributed to the modest increase in soil organic matter content after disking, which incorporated the compost treatment into the soil.

Compost encourages soil aggregate stability and reduces bulk density which helps to improve a soil's water holding capacity (Murray, 1981). In a research study reported by Maynard and Hill (1994), compost applications reduced the bulk density from 1.21g/cm^3 to 0.91g/cm^3, increased the organic matter content of the soil from 7 to 12.5 percent, and as a result, increased the water storage in the plow layer from 3.3 cm to 4.8 cm. Similar examples of increased plant-available water were reported by Flavio (1998) when two types of compost were applied as 5 mm depth mulches over a sandy soil in a grape vineyard. A mixture of biosolids-poplar bark co-compost and municipal solid waste compost was applied along with plastic mulch and were compared with a control which received no treatment. The plant available water for the compost treatments ranged from 13.1 to 13.5 percent, while that of control treatments was 12 percent. A two-year study by Foley and Cooperband (2002) revealed that composted paper mill residuals increased both the soil water holding capacity and plant available water in a potato crop in Wisconsin's central sandy soils.

Compost applications can reduce the number of irrigations in arid and semi-arid regions while maintaining the crop productivity. A New South Wales, Australia, agriculture study concluded that compost use increased soil water holding capacities by 3-10 percent, reducing irrigation water requirements. It was estimated that about 14,000 to 100,000 gallons/acre were saved annually (Sharma and Campbell, 2003). The treatments were raw paper mill residuals, composted paper mill residuals, paper mill residuals composted with bark, peat, and an unamended control. All the treatments were incorporated into the soil to a depth of 15 cm. Compost treatments showed an increase in plant-available water by 5-45 percent relative to non-amended control. Also a positive correlation was observed with soil organic matter. Increased soil carbon increased the plant-available water. Subsequently, the compost treatments reduced irrigation water requirements by 4 to 30 percent and the number of irrigation events by 10 to 90 percent. A study conducted in both Taiwan and Chad, found that 10 tons/ha compost application rates could reduce water needs by between 15 and 35 percent in semi-arid lands and by 15 and 55 percent in humid environments supplemented by rainfall. Compost effectively reduced the number of irrigations needed to sustain production (Ngoundo et al., 2007).

Finer textured soils can also benefit from compost applications, though improvement may require some persistence. Giusquiani et al. (1995) reported that continuous applications of compost for 5 years increased the available water linearly with increasing compost rates in a low organic matter clay loam soil. Anabayan and Palaniappan (1991) found that incorporating 10 tons/ha coir compost into a fine-textured soil improved water infiltration and elevated the soil moisture content measured at field capacity. A study conducted in Iran showed that compost when applied either as mulch or as a soil amendment can improve water storage and plant-available water. Compost used as mulch reduced evaporative water losses more than a soil amendment (Taban and Naeini, 2006). The water management improvements composts provide are also complemented by their nutritional properties to promote plant growth and development.

Fertilizer and Pesticide Reduction

Increased productivity is needed to meet the demands of a growing population for food, fiber, and energy. At the same time, growing urban and suburban populations demand healthy vegetation to temper and beautify their environment. Both will require attention to soil fertility and plant health. Soil fertility refers to the nutrient status of the soil and plant health refers to the conditions free of any harmful organism to the plant. Chemical strategies are available to improve plant fertility and health. Improved fertility can be achieved by adding synthetic fertilizers. Plant health can be maintained with pesticides; herbicides, fungicides, insecticides, nematicides, and bactericides are all available. The expense of overusing these tools can reduce farm profits, however. Overuse also has the potential to increase soil degradation and may pose severe environmental concerns, such as elevated pollution and the development of resistant pests (Tisdale et al., 1985).

Excessive use of these chemical inputs could not only reduce the profit margin for the farmers but also poses a potential threat to sustainability of natural ecosystems. Excess use of pesticides in agriculture may harm non-target organisms, increases the resistance within the target organisms for a particular control chemical, and creates imbalances in local population ecologies. Fertilizers and pesticide are indiscriminate when applied and excessive amounts can move offsite with air and water currents where they may impose both foreseeable and unforeseeable impacts on sensitive species or individuals. Dangers are particularly acute for workers. According to the World Health Organization, every year about 3 million people worldwide suffer severe pesticide poisoning. Others manifest severe allergic symptoms after exposure to pesticides. In response to some negative environmental effects from excessive use of fertilizer and pesticides, the U.S. and several European countries have restricted or banned some of these chemicals. Composts contain nutrients that can reduce the need to apply other fertilizers. Under some circumstances, they can also reduce the need for pesticides.

Compost as a Nutrient Management Tool

Organic materials have been used since ancient times to provide plant nutrients (Ibrahim et al., 2008). Research shows that compost can reduce the need for synthetic chemicals when used as a soil amendment. Composts are particularly useful as fertilizers in landscapes where sustained low release rates are desirable (Bruneau et al., 2005).

Nitrogen (N), phosphorus (P) and potassium (K) are the three major nutrients required by plants for growth and development. Trace elements are also required by crops as micronutrients. Many types of composted organic wastes can be effective fertilizer supplements (Maynard, 2003) reducing the expense of synthetic fertilizers. Compost is nutrient-rich (Candinas et al., 1999) and frequent compost applications increase the soil organic matter which, besides improving the physiochemical conditions of soil (Ahmad et al., 2008), releases nutrients as it decomposes (Bevacqua and Mellano, 1993; McConnel et al., 1993; Smith, 1995).

Compost, when incorporated into the soil, can serve as a natural resource for nutrients (Dick and McCoy, 1993). The release of nutrients from compost is facilitated by soil microbes which decompose the organic compost material and release the nutrients in quantities that are adequate for proper plant growth and establishment (U.S. EPA, 1999). However, the release of nutrients from any organic material is a relatively slow process (Diener et al., 1993) and compost applications cannot meet the intense short-term plant nutrient requirements, especially nitrogen, due to low mineralization rates (Benitez et al., 2003). Nutrient release rates cannot be predicted with precision, being a function of difficult compost chemistry, as well as variable soil moisture and temperature conditions (Valenzuela-Solano and Crohn, 2006). On an annual basis, N availability from stable composts has been estimated to range from 6-20 percent of their organic N content (Eghball and Power, 1999; Wolkowski, 2003).

Many studies have confirmed the fertility benefits of incorporating different types of composts into soils. Substantial applications are often involved to show immediate benefits. Maynard (1997) found that incorporated leaf waste compost amended plots had higher concentrations of soil nitrate, and the concentrations of micro nutrients Ca and Mg were also higher in compost amended plots than unamended plots. Tambone et al. (2007) reported on a study conducted using food waste compost in North Italy which showed that total organic carbon (TOC), N, P and exchangeable K of soil all increased with compost applications at 50 and 85 tons/ha, with increased nutrient status further increasing at higher application rates. Research conducted using biosolids/greenwaste co-compost and spent mushroom compost showed an increase in soil nitrogen and phosphorus levels when incorporated in to the soil (Courtney and Mullen, 2008). Compost application rates of 25, 50, and 100 tons/ha were used with significant increases observed at the 50 and 100 tons/ha application rates. Also, in this study, the total and exchangeable K was higher in plots that received 50 and 100 tons/ha of mushroom compost. Stewart et al. (1998) also reported that, applying spent mushroom compost at 100 tons/ha increased the plant available phosphorus to 63.5 mg/L when compared to the control's 13.8 mg/L concentration, measured as Olsen's extractable P. Similar results were reported by Evanylo et al. (2008), when poultry litter/yard waste compost applied to organic vegetables at rates of 144 tons/ha increased the soil organic C, total N and available P by 60 percent, 68 percent, and 225 percent. At 31 tons/ha no significant improvement was noted, however. Helton (2004) reported dairy manure compost could support the growth of Bermuda grass, but supplemental N and K were also needed. Research conducted by Naeini and Cook (2000) showed that compost when applied at 50 and 100 tons/ha increased the soil's mineral nitrogen and also the concentrations of K, P, Ca, and Mg in medium textured soils planted with forage maize.

Many of the rates reported in the above studies are not economically feasible, at least for most agricultural applications. At more economically feasible application rates, composts supplement conventional or organic fertilizer needs. A study conducted by Nevens and Rheul (2003) on silage maize grown in a sandy loam soil concluded that vegetable, fruit, and garden waste mix compost incorporated at 22.5 tons/ha in conjunction with cattle slurry at 44 tons/ha, significantly reduced the inorganic N fertilizer requirements while producing an economically optimum output. Mineral N fertilizer savings of 52, 92, 142, and 134 Kg N/ha was reported during the four respective years of compost + slurry applications. Maynard (2000) found that the fertilizer requirements of vegetables can also be supplemented by the application of chicken manure compost. Leaf waste compost applied at 50 tons/acre in a sand and loamy soil for two consecutive years, increased the yields of tomato plants same as that of application of 0.65 tons/acre 10-10-0 inorganic fertilizer. This study concluded that compost can be successfully used as a substitute for inorganic fertilizers in the production of vegetables. Also, Hill (1984) reported higher yields of vegetable crops when amended with leaf compost and inorganic fertilizer requirements were reduced by one-third to two-thirds.

In some cases, a blend of mineral fertilizers and compost materials are added to meet the short-term and long-term nutrient requirements of a crop. For example, Sikora and Enkiri (2000) reported that 33 percent of fertilizer N, when substituted with compost N resulted in same yield in tall fescue when compared to a control which received only inorganic nitrogen fertilizer. Similar results were determined by Mamo et al. (1999) which showed that a mixture of compost and fertilizer would result in the same yield as that of fertilizer applied alone. Nitrogen-enriched compost has been used in Pakistan to mitigate the excess use of synthetics and high compost application rates. Ahmad et al. (2008) reported that this technology can reduce the fertilizer use by 25 percent while still sustaining the crop yields even with low rates of compost applications. They concluded that this approach can be environmentally and economically sound, and farmer-friendly with adequate compost applications and with a possible reduction in the amount of synthetic fertilizers used as inputs.

Fertility also improves when compost is used as mulch. Flavio (1998) showed that both sewage sludge/bark co-compost and MSW compost mulches increased the total N (0.181, 0.177 percent), plant available P (38.6, 40.1 mg/L Olsen's P) and exchangeable K (215, 206 mg/kg) when compared to a control which had 0.16 percent N, 30.7mg/L of Olsen's P and 176 mg/kg of exchangeable K. Similar results were found in a study conducted by McIntyre et al. (2000) which showed that mulch applications increased the soil exchangeable P, K and Mg. Application of composted municipal solid waste to dry-land wheat in Israel at rates of 100 and 300 m^3/ha increased soil total N and available P after 2 years of application as mulch replacing the need for inorganic fertilizers. However, the 300 m^3/ha rate of compost increased the nitrates in the soil and had a potential for leaching and contaminating the ground water (Hadas et al., 2004).

Compost use clearly benefits soil fertility. Because of the expense of composts and because compost N is only released slowly, additional fertilizers will usually be needed to meet plant needs.

Compost as a Pest Management Tool

Pest control is at least as important to growers as is nutrient management. Weeds can be unsightly and rob desired plants of their nutrients, water, and solar energy. Unchecked, soil-borne diseases have the potential to cause catastrophic damages to crops, orchards, and landscapes. Control of some soil-borne pathogens can be assisted by the application of different composts to soil (Hoitink et al., 1997). Application of compost for weed and disease control has been studied for many years and suppression is most often attributed to the increased antagonistic biological activity within the soil after compost application.

Biological control factors like increased beneficial micro-organisms (Pascual et al., 2002), predation of these beneficial organisms (*Bacillus* spp, *Trichoderma* spp, *Psuedomonas* spp) on disease causing organisms (antagonism) (Wittling et al., 1996), antibiotic production by these beneficial organisms, induction of pathogen resistance in plants helping for the disease suppression (Hoitink and Fahy, 1986; Nelson, 1992; Hoitink et al., 1993) can all be encouraged by composts.

One approach to disease control is the intentional cultivation of beneficial microbes that either displace or feed on pathogens. Research conducted by Bulluck et al. (2002) in Virginia, showed that application of organic amendments (cotton gin compost, yard waste compost, or cattle manure) increased the beneficial organisms (*Trichoderma* sp) in soil when compared to synthetic fertilizer amendments applied in 1996 and 1997. Improvements in soil quality, soil pH, organic matter content, soil nutrient levels, and moisture status can reduce disease severity and pathogen control (Whipps, 1997).

Nematode control can sometimes be assisted by the use of compost. Marull et al. (1997) reported that the population of root-knot nematode (*Meloidogyne javanica*) decreased more in municipal compost amended soils than in unamended soils in green pepper and tomato plantations. Similar results were reported when yard waste compost was applied to soils in Florida, reducing the populations of plant parasitic nematodes belonging to several species including *Pratylenchus* spp. and *Criconomella* spp. (McSorley and Gallaher, 1995). Composts may also increase the soil's nutrient status encouraging the growth of organisms which can compete or destroy the nematodes. In this case, the ability of a compost material to suppress a nematode or soil pathogen also depends on the feedstock materials. A study conducted by Chen et al. (2000) reported that brewery compost reduced the severity and incidence of root galls and reduced the egg production and hatching of *M. hapla* nematodes. Lettuce yields were increased by 13 percent in fumigated soil and by 22 percent in unfumigated soil.

Fungi and oomycetes can cause tremendous damage to crops, orchards, and landscapes. Disease management in the turf grass industry by the application of composts has shown to be promising and reduced the pesticide use, especially for the Dollar spot disease of turf grass. An experiment conducted by Boulter et al. (2002) showed that several applications of five different types of compost at the rate of 12.2, 24.4, and 48.8 kg/m^2 (dry weight) as top dressing reduced the disease incidence and suppressed the dollar spots same as that of a commercial fungicide. Some of the several examples which reported that compost can be successfully used in place of pesticides for the control of soil-borne pathogens include; control of *Rhizoctonia* by tree bark compost (Kwok et al., 1987), pine bark compost for *Pythium ultimum* suppression (Zhang et al., 1996), and control of *Phytophthora* by hard wood bark compost (Nelson and Hoitink, 1982). In a laboratory experiment, olive mill waste compost was shown to reduce root rot pathogens *Pythium* and *Botrytis* spp. (Cayuela et al., 2008). Compost mulches have proven effective in helping California avocado orchards infected with *Phytophthora*, and may also help with citrus (Downer et al., 2001; Widmer et al., 1997).

There has been some research supporting the use of compost extracts popularly known as "compost tea" for a variety of purposes. One such product inhibited the seed germination of several weed species along with the hatching of the common root-knot nematode, *Meloidogyne incognita* (Cayuela et al., 2008). Cronin et al. (1996) have found that the spent mushroom compost extracts, when sprayed, reduced the incidence and severity of the apple scab pathogen, *Venturia inaequalis*. The pest control benefits of compost have been widely reviewed (Hoitink et al., 2001; van Elsas and Postma, 2007).

Weeds: Compost mulches are widely used to suppress the weed development. Their use predates the development of synthetic herbicides (Altieri and Liebman, 1988). Mulches act as a physical barrier for the germination of the weed seeds (Richard et al., 2002). In some cases the phytotoxic properties of immature composts developed during the composting process can also be used to suppress the weed germination (Niggli et al., 1990). Care must be taken to protect desired plants, however. Thicker compost layers offer better weed control. Khan et al. (2007) reported that rice bran compost when applied at 22 tons/ha controlled broad leaved weeds in organic spinach. In California, research conducted by Swezey et al. (1998) and Smith et al. (2000) showed that weeds in pecan trees and apple orchards can be controlled by application of wood chip waste and composted poultry manure. A compost mulch (mixture of turkey and chicken litter and hard wood chips) applied at 12 cm depth also reduced weed growth in an apple orchard (Brown and Tworkoski, 2004).

(Persyn et al., 2007) conducted a study on highway slopes in Iowa using three different types of compost at two depths of 5cm and 10cm. Control and a top soil treatment were also used to compare with compost amended plots. Results showed that the three compost types (Biosolids/greenwaste co-compost, Bio-industrial and yard waste) significantly reduced the weed biomass when compared to the control and top soil treatments irrespective of the depth. Similar results were found in a study conducted by Ozores-Hampton et al. (2001), where irrespective of depth, complete inhibition of weed germination was observed when compost differing in maturity levels was applied. The results were explained as a result of the phytotoxic compounds present in the immature composts. So, weed control by composts depends on their maturity at the time of their application. Weed suppression with compost applications was also extensively reviewed by (Ozores-Hampton et al., 2002).

Greenhouse Gas Reduction

To date, limited information exists on the role and net result of compost use and production in reducing greenhouse gas emissions (GHG). Composting commonly diverts organic materials from methane-producing environments such as landfills and lagoons and the benefits of this diversion have been shown to outweigh emissions associated with the composting process itself, which is managed so that the material remains aerobic (Brown et al., 2008). Methane is predominately generated under anaerobic conditions.

In California, agriculture is a contributor of GHG emissions by releasing 28.06 million tons of CO_2 equivalent greenhouse gases during 2008 (AB 32 Scoping Plan, 2010). This primarily includes emissions of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) from soils into the atmosphere (Cole et al., 1997; Paustian et al., 2004).

Though CO_2, CH_4, and N_2O are all greenhouse gases, N_2O is 298 times more potent than CO_2 and CH_4 is 25 times more potent than CO_2 (IPCC 4th Assessment Report 2007, GWP 100-yr). Carbon dioxide is released through microbial degradation of soil organic matter (Janzen, 2004). Methane is released directly from livestock, from manure management facilities, from rice fields, and from the soil (Mosier et al., 1998). Nitrous oxide is released due to soil microbial degradation of nitrogen rich compounds like manures and organic materials under wet conditions (Oenema et al., 2005).

Agriculture, on the other hand, can also be an emissions sink through soil carbon sequestration. However, compost can help to increase the soil organic matter, improve vegetation, and sequester carbon into soils. Compost nutrients supplement soil fertility, which can reduce the need for synthetic fertilizers. Synthetic nitrogen is manufactured using natural gas and accounts for 1 percent of all international energy consumption (Smith, 2002). Less energy is also required to till quality soils, and compost use improves soil structure (Favoino and Hogg, 2008).

U.S. landfills are considered to be the third largest source of CH_4 emissions (Fung et al., 1997; U.S. EPA, 2001) due to their naturally occurring anaerobic conditions. Methane collection systems are generally in place, but the efficiency is less than 100 percent and some methane inevitable escapes to the atmosphere. Landfill covers can assist in the elimination of these fugitive emissions by methane oxidation. Historically, soils are the most commonly used landfill covers for oxidation of CH_4 (Scheutz et al., 2003). However, research has also shown that the use of compost as a biofilter over a landfill would significantly reduce methane emission by oxidation. In a laboratory study using CH_4 fed columns and covering them with biosolid/greenwaste co-compost, researchers showed that the compost oxidized CH_4 more effectively than a conventional soil (Humer and Lechner, 1999). This was confirmed in subsequent field studies as well. When a mixture of wood chips, biosolid/greenwaste co-compost, and municipal greenwaste compost were used, these compost materials oxidize the CH_4 gas significantly faster than soil (Humer and Lechner, 2001). In another study, a 10 cm layer of mulch and soil had doubled the oxidation efficiency of CH_4 relative to a clay cover (Chanton and Liptay, 2000).

Barlez et al. 2004 conducted a study at a local landfill in Louisville, Ky., using yard waste compost as a landfill biocover to test its effectives in reducing the CH_4 emissions when compared to soil cover. The results showed that the soil cover was able to oxidize 21 percent of the gas while the compost filter oxidized 55 percent of the CH_4 gas. It was found that organic materials when used as covers on these landfills increased the aerobic biological activity and helped oxidize emerging CH_4. Composts are known to increase the biological activity of methanotrophic bacteria which help to oxidize CH_4 in landfill gas (Hanson and Hanson, 1996). Oxidation of CH_4 gas produces CO_2 and water. CO_2 is also a greenhouse gas as well, but contributes much less on a molecular basis to global warming than methane (Melse and Wanderwarf, 2005).

Research Gaps/Future Studies

There has been considerable research to address the agricultural and horticultural benefits of compost. Additional research has been conducted in response to emerging concerns regarding compost use in areas where construction activities can erode soils and pollute water. Other studies indicate that compost can be used to improve soil fertility and to assist with pathogen control. Although there has been considerable research on compost and its uses, more comprehensive analysis is needed to further understanding of the processes by which composting works and to clarify the economic issues regarding compost use.

Erosion Control

Compost is increasingly placed among Best Management Practices available for erosion control. Research has shown that compost can be successfully used for the remediation of disturbed sites and to avoid erosion. Most of these findings are based on small experimental studies with artificial rainfall simulations calibrated to produce design storms. Small-scale research and lab findings may not be sufficient to quantify the benefits of compost and may not replicate field conditions with high spatial variability or the hydrologic accumulation of flows over a landscape. Larger scale studies are also needed.

There are various characteristics of compost that determine its effectiveness in controlling erosion, but little research has been reported on the mechanisms by which these properties contribute to success or failure. For example, compost installations are most likely to fail when concentrated waters float material off a location. Little is known about how to work with the hydraulic conductivity of compost so that this is avoided. The relationship between compost hydraulic properties, slope, run length, and design storms constraints need study to establish more sophisticated design procedures.

There has been considerable research on hill-slope hydrology, but this soil science theory has not been tested for use with compost. Hill-slope hydrology theory could be use to predict both runoff and pollutants from areas treated with compost blankets. Soil science models should be tested to see how well they predict compost behavior and performance.

Research is also needed to develop more sophisticated procedures for determining when additional stabilization measures are needed to supplement the protection afforded by compost blankets. Technologies such as straw wattles and jute fiber nets are often installed along with compost blankets, but there is no theory to support decisions as to when such measures are needed, or even the extent to which they are helpful.

In Southern California, wildfires also damage the environment. After a fire, the erosion potential of an area is significantly increased. Resulting pollutants can dramatically impair the quality of the receiving waters. Hydrophobicity resulting from fire damage can increase in soils. Researchers have found that organic materials can be used in conjunction with surfactants to overcome the hydrophobicity of the soils, but composts should be specifically studied as an alternative. There has been no scientific research, other than what is included in the body of this report where hydrophobicity was not observed, focusing on fire-damaged soils and their remediation using compost materials. A study comparing the chemistry and microbiology associated with the weathering of hydrophobic layers, with and without compost, would be enlightening.

Wind losses are another common reason why erosion control efforts fail and research is needed as to how to best avoid such losses. In Southern California, during late summer and early fall seasons, powerful Santa Ana winds are of major concern in fueling and spreading the wildfires. These winds can continue into the late fall season. Compost materials used for erosion control can also be removed by high winds. There has not been rigorous scientific study of wind effects on different composts and application methods. Studies evaluating the impact different wind speeds and compost particle characteristics that can withstand these high wind speeds would be useful.

Vegetation Establishment

Scientists have found that incorporating compost can help in the long term revegetation of disturbed sites. It is challenging to incorporate huge quantities of compost on steep slopes, however. Methods for economically applying compost to steep slopes are needed, and the benefits of incorporation verses blanket development should be scientifically assessed.

There has been some limited research on the use of compost in vegetation establishment, but this work has been largely conducted in environments that differ from those in California. Research has shown that compost can be successfully used for vegetating disturbed sites as a long-term approach to deal with effective erosion control. More work is needed to compare the use of compost to other techniques, such as hydroseeding, in arid and semi-arid environments. Both short- and long-term studies are needed.

Research is needed on the best timing and strategies for incorporating seeds of different species into revegetation efforts.

There is also some concern in the scientific community that nutrient rich soils may advantage invasive grasses rather than native species. The degree to which this is true for revegetation of damaged soils merits investigation.

The role of compost in the establishment of more elaborate irrigated landscape plantings also merits work. The economic value of compost as a measure for assisting in the long-term survival and beauty of desired plants should be quantified for varieties commonly used in California.

Stormwater Management

Compost berms, filters and compost socks can reduce runoff and improve stormwater quality. Research for stormwater management and stormwater quality improvement using compost has concentrated mainly on construction sites as these can be the potential sites for high sediment loads in stormwater runoff due to their frequent soil disturbances and high soil compaction.

There are findings which conclude that composted organics can be used to remediate these soils and help reduce the stormwater runoff, but the mechanisms involved in the remediation process have not been studied. For example, compost blankets and incorporated compost modify the soil surface and improve infiltration, but the chemical and biological alterations contributing to changes in runoff rates have not been well characterized.

Composts blankets tend to absorb water and result in producing less stormwater runoff. However, depending on the feedstocks used for composting, concentrations of some undesirable materials can be elevated in runoff even though mass export rates may be considerably lower. Appropriate ways to interpret observed losses from compost are needed to provide evidence and guidance as to when mass export verses concentration values should be used for environmental decision making. In addition, although guidance is now available to assist farmers in compost salt management, there is insufficient information as to the development and fate of compost salts in the literature to guide the decisions of regulators.

Water Conservation

Whether applied as soil amendments or mulches, composts can increase soil moisture retention and conserve water. Compost applications directly and indirectly improve soil physical and hydraulic properties such as soil bulk density, water holding capacity, moisture retention capacity, infiltration rates, and hydraulic conductivity. Incorporation of compost improves infiltration rates and water retention. Mulches can also increase moisture availability by reducing evaporative losses. Generous compost use has been shown to reduce the need for frequent irrigations, especially in soils of semi-arid and arid regions with limited water availability.

Unfortunately, most of the research has been done in agricultural crops amended at high rates and only very limited literature is available on water conservation techniques in landscape horticulture using compost. Future research should be more focused on compost appropriate role in water conservation strategies located in commercial and residential areas with varying slopes.

It is likely that composts will also conserve water indirectly by improving plant health. Landscape managers and homeowners typically respond to signs of plant stress by supplying more water. Use of compost improves infiltration, water holding capacity, and both soil micro- and macro-nutrient content.

The forces controlling water movement at the interface of compost blankets and the soil surface merit study. This would assist in the design of compost blankets as well as retention structures.

Finally, research is needed into the economic benefits of compost use with respect to water conservation. Compost use has been shown to reduce the need to irrigate, but the degree that this is true has yet to be quantified. The application rates required to save significant water in agriculture are likely unaffordable unless compost is applied repeatedly for several years. Compost is likely to be economically compelling in landscapes, however, because urban water is more costly and the high compost application rates necessary to realize immediate water savings are more realistic as a component of landscape budgets.

Fertilizer and Pesticide Reduction

Research has shown that compost use can reduce the need for fertilizer and pesticide applications by altering soil physical, chemical and biological properties. While use of compost and mulches usually cannot completely replace the synthetic or certified organic fertilizers for nutrient and pest management, regular use can reduce their requirement. Compost use improves the fertility of soils. Compost can be used as a preventive measure help to suppress or control certain pathogens or to reduce the severity symptoms so pesticide use can be reduced or eliminated, though results are variable and expectations should be kept reasonable. This is particularly important for certified organic agricultural operations that cannot apply synthetic pesticides. To assist in market development, the economic value of compost use should be quantified in terms of avoided pesticide and fertilizer costs.

The most significant plant fertilizer is often N, but N is only plant-available after microbes have converted it to mineral forms. The rate at which nutrients are converted is difficult to predict, but is a function of time, soil temperature, soil moisture, and compost chemistry. Though mineralization rates cannot be predicted with precision, growers would benefit from an educational tool that could give them at least some insight into what they can expect in terms of fertility improvement from the use of composts. Better advice could then be given as to possible adjustments in their overall nutrient management plans.

Composts can also be used for revegetation on the road slopes and disturbed sites with optimum weed control. Weed control with compost is fairly straight-forward, although a study quantifying the role of particle size and compost nutrient status on weed suppression would be welcome.

The role of compost in suppressing plant infections varies from pest to pest and will continue to need attention as new pests emerge. Although claims are made that composts improve soils by increasing their microbial activity and diversity, little has been done to precisely characterize these changes and their benefits with respect to plant disease. Such studies will be challenging because the case-by-case nature of infections can make knowledge transfer to other situations difficult or even inappropriate.

When new pests or pest vectors, such as Asian citrus psyllid, appear in or nearby a given area, regulatory programs are often put into place to minimize the threat. Proper composting eliminates both pests and their vectors from landscape trimmings. Untreated trimmings may spread pests and their vectors. Risk-assessment research is needed to assist decision makers. When uninformed, decision makers may confuse compost with materials that have not been biologically sanitized, imposing undue restriction on their production and use. Properly managed composting should be considered a landscape health activity, just as water treatment and solid waste management protect public health. Research is also needed to verify the time-temperature exposure required to completely eliminate particular undesired organisms (Crohn et al., 2008; Downer et al., 2008).

Greenhouse Gas Reduction and Air Quality

The direct role of compost use in reducing the greenhouse gas emissions has not been specifically evaluated in the referenced literature and research is needed to confirm and explain the mechanism on how this occurs. Additionally, research is needed that shows how composts, when applied as bio-filtration covers over landfills, effectively reduces CH_4 emissions. Further research on landfill cover design and maintenance using composts is needed as well.

Nitrous oxide emissions are a significant global warming concern and these emissions are increased when nitrogen (N) is added to the soil. Nitrous oxide is generated both when ammonium is oxidized to nitrate and when nitrate is reduced to nitrogen (N_2) gas. The addition of compost may increase N_2O losses by adding N to the soil—or it may decrease losses by supplying the C needed by soil microbes to completely reduce nitrate. There is strong preliminary evidence that compost use in soils facilitates the elimination of greenhouse gases, including CO_2, when compared to urea, a common synthetic fertilizer (Alluvione et al., 2010).

Other air quality issues also warrant investigation. Regions experiencing high winds are prone to substantial wind erosion releasing dust into the air. Composting should be investigated as a means for reducing fugitive dust emissions.

It should also be noted that composting is one of many waste management alternatives for organic residuals. Other alternatives, such as landfilling, energy conversion, or simple grinding, also impact the environment and any research into alternatives will clarify the relative advantages and disadvantages of the compost option.

Glossary of Terms

Field Capacity: The amount of water that is retained in compost after it is saturated and allowed to draining.

Mass Flux: The mass flow across a unit area (mg/m2)

Preferential Flow: The uneven movement of water and solutes through soil as it travels through finger-like pathways such as wormholes, root holes, cracks, etc. These pathways also allow for transport of contaminants, including pesticides, nutrients, trace metals, etc.

Active Compost: Per Title 14 of the California Code of Regulations, Section 17852(a)(1) – Active compost means compost feedstock that is in the process of being rapidly decomposed and is unstable. Active compost is generating temperatures of at least 50 degrees Celsius (122 degrees Fahrenheit) during decomposition; or is releasing carbon dioxide at a rate of at least 15 milligrams per gram of compost per day, or the equivalent of oxygen uptake.

Feedstock: Any compostable material used in the production of compost or chipped and ground material including, but not limited to, agricultural material, green material, food material, biosolids, and mixed solid waste. Feedstock materials serve as food for compost microbes.

Compostable Material: Any organic material that when accumulated and supplied with adequate moisture and air will become active compost.

Abbreviations and Acronyms

Compost-greenwaste—Compost from a greenwaste feedstock

Compost-biosolids —Co-composts from a mix of greenwaste and biosolids feedstocks

GWF1—1 inch of finished compost from greenwaste feedstocks (compost-greenwaste) fines

GWF2—2 inches of finished compost from greenwaste feedstocks (compost-greenwaste) fines

GWFInc—2 inches of finished compost from greenwaste feedstocks (compost-greenwaste) incorporated

GWC1—1 inch of finished compost from greenwaste feedstocks (compost-greenwaste) overs

GWC2—2 inches of finished compost from greenwaste feedstocks (compost-greenwaste) overs

GWCInc—2 inches of finished compost from greenwaste feedstocks (compost-greenwaste) overs

BS1—1 inch of finished compost from a mix of biosolids and greenwaste feedstocks (compost-biosolids)

BS2—2 inches of finished compost from a mix of biosolids and greenwaste feedstocks (compost-biosolids)

BSInc—2 inches of finished compost from a mix of biosolids and greenwaste feedstocks (compost-biosolids) incorporated

GWM—Partially composted materials from a greenwaste feedstock

BSM—Partially composted materials from a feedstock mix of biosolids/greenwaste

BMP—Best Management Practices

TDS—Total Dissolved Solids

TSS—Total Suspended Solids

L—Liter

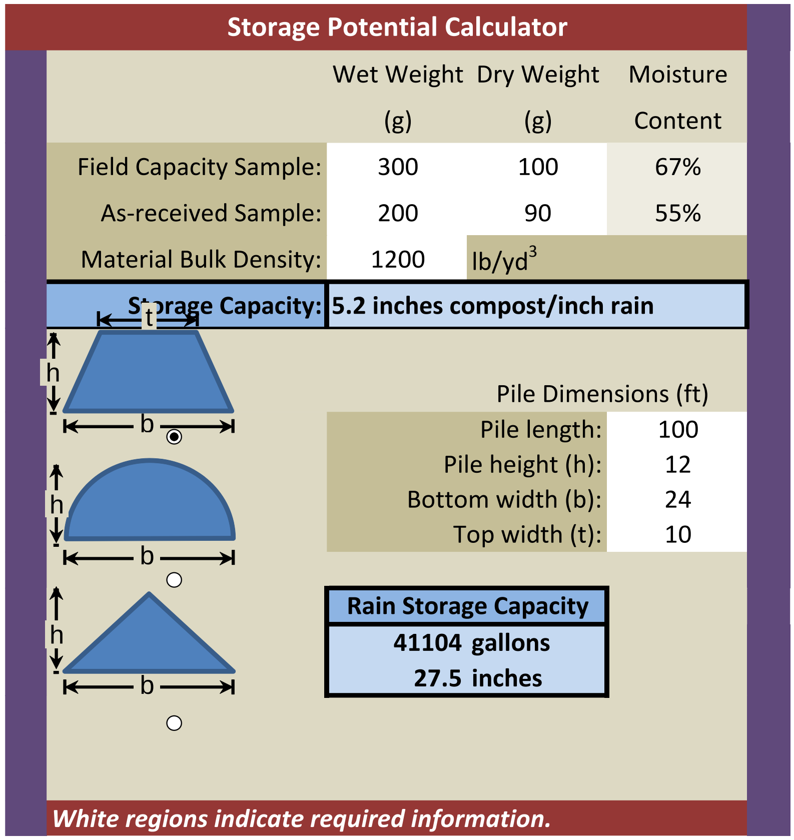
EC—Electrical Conductivity

P—Phosphorous

Appendix A: Storage Capacity Calculator with Instructions

Determining Gravimetric Water Content and Water Holding Capacity

The Storage Potential Calculator is an interactive tool for estimating the amount of partially composted material or active compost that is needed to store a given amount of falling precipitation. The Calculator was designed to be a simple and easy-to-use program that conservatively assumes that all precipitation enters and is stored in a compost pile. The experimental approach uses mesh bags, which can be filled and handled easily. One bag is filled with material from the pile in question to measure the pile's as-received water content. Another is filled with the same material, saturated with water, and allowed to drain. This bag is used to measure the material's field capacity. Each bag is then weighed prior to and after drying to measure their water content. The potential water holding capacity of the pile will then be estimated and automatically provided by the Calculator in both gallons of water and inches of rain water storing capacity. This is a planning tool. Its estimates assume that water falls directly down on the pile and infiltrate. The tool does not consider high winds blowing rain onto the sides of the pile. Because the calculator assumes that the pile absorbs water uniformly, shallow areas along the edges of the pile may begin to lose water earlier than this model predicts. Composters must understand that introducing too much water into compost piles will slow the movement on oxygen into the material leading to the creation of anaerobic zones. Anaerobic areas may not heat sufficiently and can emit odors.



Instructions

Complete all fields that are shown in white in the Storage Capacity Calculator:

1. Wet Weight of the Field Capacity

   a. Moderately pack a nylon fine-mesh bag (6"×12"×1") with partially composted material.

   b. Weigh (grams) the bag of material in grams.

   c. Gently saturate the full bag in a bucket of water until the bag stops floating. Expected time for saturation is between 1-3 hours.

   d. Remove the bag and place vertically on a wire rack until the water completely stops draining out. Sample is considered to be at field capacity when there is no weight change in the bag due to water loss. Expect time is about 15 – 45 minutes.

   e. The material is now at Field Capacity. Weigh (grams) the bag and record the weight in the Field Capacity – Wet Weight field of the Storage Capacity Calculator.

2. Dry Weight of the Field Capacity sample

    a. Dry the bag of partially composted material used to determine the "Field Capacity – Wet Weight" above in an oven at 65°C for 24 hours and the weight stabilizes, or use a Koster Moister Tester or similar type apparatus to completely dry the material.

    b. Weigh (grams) the full bag and record the weight in the Field Capacity – Dry Weight field of the Storage Capacity Calculator

3. Wet Weight of the As-received sample

    a. Moderately pack a nylon fine-mesh bag with partially composted material

    b. Weigh (grams) the full bag and record the weight in the "As-received – Wet" field of the Storage Capacity Calculator.

4. Dry Weight of the Field Capacity sample

    a. Dry the bag of partially composted material used to determine the "As-received – Wet" above in an oven at 65°C for 24 hours and the weight stabilizes, or use a Koster Moisture Tester or similar type apparatus.

    b. Weigh (grams) the full bag and record the weight in the "As-received – Dry" field of the Storage Capacity Calculator

5. Material Bulk Density (moist basis)

    a. Fill a 5 gallon bucket with exactly 5 gallons of water and make the level of the water on the bucket with a permanent marker.
    b. Measure the height from the bottom of inside of bucket to the 5 gallon line, divide this number by 3, and mark 1/3rd and 2/3rd of the bucket
    c. Fill bucket to the 1/3rd line with as-received composted material. This material should not be dried. The material used should be representative of the whole pile. Take small samples from several locations and avoid the dried-out outer layer.
    d. Drop bucket squarely from about 1 foot high to the ground 10 times.
    e. Fill bucket to the 2/3 line. Drop bucket squarely from approximately 1 foot high to the ground 10 more times.
    f. Fill bucket to just above the 5 gallon line. Mound the material if necessary. Drop bucket squarely from approximately 1 foot high to the ground 10 more times. Remove any material above the 5 gallon line.
    g. Weigh the bucket in pounds.
    h. Multiply the weight of material in pounds (excluding bucket weight) by 40. This is your bulk density, in pounds per cubic yard.

6. The storage capacity of the composting material is determined to be the difference between the measured field capacity and its actual water content.

    a. Once all fields have been completed the Calculator will automatically estimate the water storage capacity of the material in both gallons and inches of rain.

Appendix B: Complete Data Tables

Fire-affected Soil Runoff Statistics

Table 23. Fire-affected soil runoff concentration statistics. Common letters indicate no significant difference (n<0.5).

Treatment	*Precipitation Event*							
	12/14/2009		*1/19/2010*		*1/21/2010*		*1/23/2010*	
	Total Runoff Volume (L)							
Control	1.90±0.51	b	44.83±5.04	b	33.25±3.57	b	27.08±1.73	b
GWC1	1.07±0.19	ab	6.40±1.10	a	3.50±1.26	a	7.91±1.59	a
GWC2	1.19±0.18	ab	4.51±1.14	a	4.20±1.51	a	9.73±0.72	a
GWCInc	0.83±0.13	a	6.58±1.18	a	2.50±0.58	a	3.98±1.51	a
GWF1	1.03±0.06	ab	7.17±2.67	a	3.08±0.74	a	10.17±2.39	a
GWF2	0.92±0.16	ab	11.00±0.76	a	3.03±0.58	a	6.17±1.01	a
GWFInc	1.17±0.11	ab	14.38±1.13	a	3.58±1.40	a	7.17±1.30	a
BS1	0.67±0.08	a	4.28±1.07	a	1.42±0.33	a	4.33±1.64	a
BS2	0.69±0.13	a	6.00±0.00	a	3.00±0.58	a	8.83±2.59	a
BSInc	0.33±0.04	a	7.08±1.20	a	1.58±0.58	a	6.08±0.79	a
	Turbidity (NTU)							
Control	568±25	b	708±10	b	848±31	b	771±42	b
GWC1	118±45	a	536±60	ab	143±44	a	32±4	a
GWC2	100±33	a	149±8	a	78±14	a	38±3	a
GWCInc	167±35	a	379±55	ab	253±88	a	103±29	a
GWF1	102±65	a	310±122	ab	87±51	a	142±120	a
GWF2	127±54	a	197±83	a	236±134	a	31±10	a
GWFInc	172±37	a	341±134	ab	223±61	a	69±20	a
BS1	112±54	a	133±73	a	65±22	a	17±3	a
BS2	86±43	a	211±135	a	59±23	a	24±6	a
BSInc	130±56	a	443±19	ab	257±117	a	291±106	a

	pH							
Control	6.87±0.09	a	7.30±0.12	a	7.23±0.22	a	7.33±0.20	a
GWC1	6.74±0.20	a	7.10±0.20	a	7.23±0.22	a	7.03±0.17	a
GWC2	6.81±0.25	a	6.73±0.37	a	7.47±0.12	a	7.00±0.10	a
GWCInc	6.77±0.16	a	6.90±0.15	a	7.27±0.07	a	7.03±0.15	a
GWF1	6.80±0.14	a	7.03±0.23	a	7.17±0.12	a	7.07±0.09	a
GWF2	6.63±0.07	a	7.13±0.03	a	7.30±0.10	a	7.13±0.03	a
GWFInc	7.00±0.20	a	6.85±0.15	a	7.27±0.03	a	7.03±0.15	a
BS1	6.57±0.13	a	7.07±0.13	a	7.17±0.15	a	7.00±0.10	a
BS2	6.40±0.11	a	7.00±0.20	a	7.10±0.15	a	6.70±0.12	a
BSInc	6.87±0.14	a	7.03±0.13	a	7.10±0.00	a	7.17±0.15	a

Table 24. Fire-affected soil runoff statistics

	Precipitation Event							
	12/14/2009		***1/19/2010***		***1/21/2010***		***1/23/2010***	
Treatment	***Salinity (dS/m)***							
Control	0.31±0.01	a	0.06±0.00	a	0.03±0.00	a	0.03±0.00	a
GWC1	0.19±0.06	a	0.10±0.01	ab	0.05±0.02	a	0.03±0.00	a
GWC2	0.20±0.01	a	0.08±0.01	a	0.04±0.01	a	0.03±0.00	a
GWCInc	0.26±0.02	a	0.09±0.01	a	0.05±0.00	a	0.04±0.00	a
GWF1	0.32±0.02	a	0.09±0.00	a	0.06±0.00	a	0.04±0.00	a
GWF2	0.36±0.14	a	0.06±0.01	a	0.04±0.01	a	0.04±0.00	a
GWFInc	0.25±0.05	a	0.08±0.00	a	0.05±0.00	a	0.05±0.01	a
BS1	1.64±0.89	ab	0.17±0.01	b	0.15±0.01	b	0.10±0.01	b
BS2	2.26±0.59	b	0.40±0.04	c	0.23±0.03	c	0.13±0.02	b
BSInc	0.87±0.13	ab	0.12±0.02	ab	0.13±0.02	b	0.10±0.01	b
	Total Dissolved Solids (mg/L)							
Control	717±86	b	89±20	a	70±1	a	51±1	ab
GWC1	169±24	a	134±6	ab	78±17	ab	41±5	a
GWC2	133±48	a	110±14	ab	77±4	ab	45±8	a
GWCInc	225±3	a	121±17	ab	96±3	ab	50±4	ab
GWF1	145±78	a	118±12	ab	101±10	ab	35±15	a
GWF2	184±87	a	97±30	a	72±2	ab	51±3	ab
GWFInc	442±59	ab	133±10	ab	95±4	ab	61±4	ab
BS1	606±113	b	227±31	ab	235±22	c	101±8	bc
BS2	509±116	ab	548±38	c	357±50	d	119±24	c
BSInc	629±24	b	142±12	ab	192±44	bc	103±11	bc
	Total Suspended Solids (mg/L)							
Control	43.6±2.6	c	56.9±9.6	c	51.9±4.6	b	34.8±0.6	b
GWC1	13.7±10.6	ab	10.0±4.0	a	8.5±3.8	a	4.4±2.1	ab
GWC2	7.0±2.1	a	3.9±1.3	a	7.6±4.0	a	13.2±11.6	ab
GWCInc	12.1±4.2	a	16.9±6.5	a	12.7±2.5	a	10.9±6.3	ab
GWF1	8.6±3.7	a	11.7±7.6	a	5.3±3.6	a	3.2±1.2	a
GWF2	9.7±3.5	a	18.7±11.0	ab	8.5±5.2	a	11.3±6.3	ab
GWFInc	8.2±1.6	a	17.2±13.6	a	16.8±3.0	a	9.3±4.5	ab
BS1	14.3±1.8	ab	5.1±1.4	a	3.6±1.8	a	8.1±1.9	a
BS2	33.3±3.4	c	17.0±6.2	a	6.1±1.5	a	4.1±0.7	a
BSInc	29.8±1.8	bc	22.8±3.6	ab	18.7±7.4	a	4.4±1.2	a

Table 25. Fire-affected soil runoff statistics

	Precipitation Event							
	12/14/2009		***1/19/2010***		***1/21/2010***		***1/23/2010***	
Treatment	***Total Sediments (gm/L)***							
Control	42.6±2.2	b	52.1±11.1	b	52.6±5.4	b	44.8±0.9	b
GWC1	4.7±2.0	a	9.1±4.8	a	3.4±0.6	a	1.8±0.9	a
GWC2	6.2±1.1	a	7.0±1.0	a	13.3±10.8	a	8.9±6.7	a
GWCInc	8.9±2.0	a	12.2±3.2	a	5.7±2.2	a	5.3±2.5	a
GWF1	8.2±5.1	a	11.1±1.6	a	2.2±0.9	a	4.4±3.2	a
GWF2	10.6±5.3	a	15.1±4.8	a	7.7±5.5	a	7.4±4.1	a
GWFInc	9.2±2.9	a	15.9±6.4	a	6.7±3.2	a	3.3±1.2	a
BS1	8.0±4.0	a	7.1±1.7	a	2.0±1.1	a	1.1±0.2	a
BS2	4.9±0.5	a	4.9±0.7	a	8.6±6.6	a	3.1±0.9	a
BSInc	3.9±1.0	a	13.2±1.9	a	7.5±4.5	a	8.8±3.0	a
	Total Phosphorus (mg/L)							
Control	1.88±0.05	a	1.46±0.41	a	0.68±0.12	a	0.42±0.05	a
GWC1	1.45±0.48	a	1.29±0.45	a	0.49±0.19	a	0.26±0.14	a
GWC2	2.05±0.19	a	1.12±0.22	a	0.46±0.06	a	0.24±0.07	a
GWCInc	1.98±0.53	a	1.32±0.23	a	0.58±0.06	a	0.23±0.06	a
GWF1	2.17±0.37	a	1.30±0.31	a	0.65±0.22	a	0.29±0.09	a
GWF2	1.96±0.71	a	1.65±0.85	a	0.83±0.07	a	0.38±0.05	a
GWFInc	2.81±0.33	a	2.21±0.13	a	0.81±0.07	a	0.36±0.03	a
BS1	14.62±12.79	a	1.42±0.37	a	1.20±0.06	ab	0.87±0.05	ab
BS2	52.82±49.22	a	2.53±0.95	a	2.06±0.12	b	1.12±0.21	b
BSInc	15.75±13.07	a	1.73±0.54	a	1.42±0.54	ab	0.83±0.34	ab
	Orthophosphate (mg/L)							
Control	1.15±0.58	a	1.25±0.40	a	0.59±0.11	a	0.36±0.05	ab
GWC1	1.28±0.49	a	1.01±0.34	a	0.37±0.16	a	0.23±0.13	a
GWC2	1.70±0.27	a	0.77±0.19	a	0.33±0.07	a	0.21±0.07	a
GWCInc	1.73±0.32	a	1.08±0.20	a	0.42±0.03	a	0.18±0.04	a
GWF1	2.08±0.21	a	0.97±0.26	a	0.49±0.19	a	0.23±0.07	a
GWF2	2.20±0.07	a	1.17±0.59	a	0.64±0.05	ab	0.30±0.04	ab
GWFInc	2.42±0.25	a	1.75±0.08	a	0.60±0.05	a	0.30±0.03	ab
BS1	1.56±0.41	a	1.10±0.32	a	0.98±0.06	ab	0.68±0.07	ab
BS2	2.50±0.36	a	1.86±0.77	a	1.48±0.15	b	0.88±0.14	b
BSInc	1.97±0.47	A	1.38±0.49	a	1.12±0.45	ab	0.72±0.32	ab

Table 26. Fire-affected soil runoff statistics

	Precipitation Event							
	12/14/2009		*1/19/2010*		*1/21/2010*		*1/23/2010*	
Treatment	***Nitrate-N (mg/L)***							
Control	7.97±4.13	a	0.46±0.09	a	0.23±0.03	a	0.15±0.04	ab
GWC1	1.10±0.13	a	1.68±0.06	ab	0.82±0.68	a	0.11±0.04	ab
GWC2	1.92±0.75	a	1.04±0.31	ab	0.21±0.08	a	0.11±0.07	ab
GWCInc	2.49±1.21	a	1.35±0.36	ab	0.41±0.34	a	0.09±0.05	ab
GWF1	3.81±1.05	a	1.16±0.13	ab	0.22±0.11	a	0.03±0.02	a
GWF2	2.40±1.66	a	0.88±0.43	ab	0.21±0.07	a	0.10±0.06	a
GWFInc	1.54±0.37	a	0.76±0.27	ab	0.07±0.05	a	0.02±0.02	ab
BS1	7.08±2.35	a	2.12±0.26	b	1.75±0.57	a	0.35±0.05	b
BS2	6.07±1.99	a	2.01±0.10	b	1.12±0.59	a	0.33±0.11	b
BSInc	11.17±4.46	a	1.01±0.42	ab	0.94±0.23	a	0.29±0.07	ab
	Ammonium-N (mg/L)							
Control	0.47±0.20	a	0.47±0.06	a	0.11±0.06	a	0.12±0.02	a
GWC1	5.91±5.29	a	1.56±1.15	a	0.25±0.19	ab	0.15±0.03	a
GWC2	0.52±0.13	a	0.54±0.20	a	0.08±0.02	a	0.16±0.06	a
GWCInc	0.30±0.06	a	0.70±0.32	a	0.06±0.01	a	0.16±0.01	a
GWF1	0.42±0.14	a	0.71±0.06	a	0.09±0.02	a	0.10±0.01	a
GWF2	0.41±0.15	a	0.49±0.17	a	0.07±0.03	a	0.15±0.01	a
GWFInc	0.32±0.16	a	0.41±0.14	a	0.06±0.03	a	0.11±0.02	a
BS1	11.17±5.76	a	11.42±1.88	b	5.32±2.19	b	3.98±0.87	b
BS2	142.1±36.5	b	35.00±4.00	c	19.75±2.27	c	7.80±1.44	c
BSInc	26.24±9.99	a	4.51±1.84	ab	4.46±0.85	ab	2.07±0.45	ab

Table 27. Fire-affected soil runoff mass flux statistics. Common letters indicate no significant difference (n<0.5).

	Precipitation Event							
	12/14/2009		***1/19/2010***		***1/21/2010***		***1/23/2010***	
Treatments	***Total Dissolved Solids (mg/m^2)***							
Control	247.6±38.7	b	743.2±130.7	b	445.5±45.0	c	267.6±19.3	c
GWC1	33.8±4.9	a	166.5±35.7	a	49.9±17.0	a	63.9±18.3	a
GWC2	29.0±9.4	a	101.2±38.6	a	62.1±23.6	a	86.3±22.4	ab
GWCInc	35.9±5.1	a	160.7±45.4	a	45.7±9.9	a	39.5±16.9	a
GWF1	27.1±13.1	a	174.3±81.8	a	61.1±19.2	a	80.8±43.9	ab
GWF2	33.7±15.2	a	202.9±67.4	a	41.9±7.8	a	61.1±13.5	a
GWFInc	99.0±14.2	a	366.0±2.4	ab	63.8±22.4	a	81.7±9.7	ab
BS1	81.1±22.8	a	176.2±27.3	a	64.9±17.9	a	78.8±23.1	ab
BS2	72.1±27.7	a	631.6±43.3	b	211.1±64.8	b	178.1±7.8	bc
BSInc	40.7±6.0	a	194.9±42.9	a	50.9±9.4	a	119.7±16.7	ab
	Total Suspended Solids (mg/m^2)							
Control	15.68±3.83	b	478.6±53.9	b	329.1±38.4	b	181.5±14.1	b
GWC1	2.29±1.52	a	13.15±7.03	a	6.11±2.93	a	7.73±4.27	a
GWC2	1.62±0.56	a	2.95±0.49	a	8.04±6.36	a	27.52±24.72	a
GWCInc	2.12±0.85	a	23.58±10.48	a	6.01±1.56	a	7.44±3.26	a
GWF1	1.74±0.81	a	23.93±19.61	a	4.15±3.30	a	7.28±3.59	a
GWF2	1.66±0.60	a	36.43±19.12	a	5.27±3.12	a	12.02±5.37	a
GWFInc	1.90±0.53	a	44.58±33.86	a	13.15±6.89	a	14.49±7.08	a
BS1	1.86±0.41	a	4.54±2.28	a	0.75±0.15	a	5.72±1.12	a
BS2	4.32±0.61	a	19.61±7.15	a	3.23±0.49	a	7.75±3.67	a
BSInc	1.89±0.14	a	31.35±8.60	a	4.04±0.97	a	4.79±0.70	a
	Total Sediments (gm/m^2)							
Control	15.98±5.15	b	435.2±77.1	b	338.7±56.54	b	233.7±18.2	b
GWC1	1.11±0.63	a	12.22±7.86	a	2.15±0.57	a	2.25±0.89	a
GWC2	1.47±0.47	a	6.47±2.41	a	16.75±15.48	a	18.37±14.38	a
GWCInc	1.52±0.48	a	15.98±5.73	a	2.24±0.42	a	3.54±1.25	a
GWF1	1.70±1.09	a	16.51±8.30	a	1.55±0.97	a	11.26±9.33	a
GWF2	1.84±0.90	a	32.21±11.61	a	4.77±3.26	a	7.87±3.49	a
GWFInc	2.11±0.79	a	45.26±21.17	a	4.08±1.86	a	4.03±0.80	a
BS1	1.15±0.69	a	6.30±3.00	a	0.63±0.39	a	1.02±0.54	a
BS2	0.66±0.17	a	5.68±0.78	a	3.66±2.38	a	5.37±2.01	a
BSInc	0.25±0.08	a	18.16±4.77	a	1.65±0.75	a	9.55±2.06	a

Table 28. Fire-affected soil runoff statistics

	Precipitation Event							
	12/14/2009		***1/19/2010***		***1/21/2010***		***1/23/2010***	
Treatment	***Total Phosphorus (mg/m²)***							
Control	0.695±0.207	a	12.00±2.387	b	4.201±0.246	b	2.172±0.290	c
GWC1	0.275±0.060	a	1.682±0.826	a	0.418±0.291	a	0.472±0.337	a
GWC2	0.481±0.115	a	1.054±0.427	a	0.402±0.179	a	0.462±0.172	a
GWCInc	0.334±0.115	a	1.775±0.532	a	0.280±0.066	a	0.174±0.065	a
GWF1	0.422±0.046	a	2.098±1.242	a	0.420±0.222	a	0.588±0.289	ab
GWF2	0.308±0.101	a	3.617±2.043	a	0.500±0.125	a	0.449±0.101	a
GWFInc	0.632±0.090	a	6.134±0.837	ab	0.524±0.171	a	0.484±0.081	a
BS1	1.587±1.331	a	1.026±0.181	a	0.321±0.069	a	0.696±0.230	ab
BS2	6.074±5.569	a	2.918±1.096	a	1.214±0.301	a	1.723±0.214	bc
BSInc	0.993±0.809	a	2.540±0.953	a	0.391±0.129	a	0.894±0.258	ab
	Orthophosphate (mg/m²)							
Control	0.310±0.157	a	10.26±2.37	b	3.622±0.253	b	1.884±0.280	c
GWC1	0.240±0.060	a	1.314±0.632	a	0.329±0.239	a	0.420±0.308	ab
GWC2	0.405±0.119	a	0.746±0.357	a	0.306±0.163	a	0.411±0.165	ab
GWCInc	0.285±0.079	a	1.448±0.456	a	0.198±0.043	a	0.125±0.038	a
GWF1	0.407±0.018	a	1.584±0.973	a	0.319±0.178	a	0.466±0.217	ab
GWF2	0.328±0.051	a	2.568±1.419	a	0.384±0.097	a	0.346±0.067	a
GWFInc	0.545±0.073	a	4.853±0.599	ab	0.391±0.131	a	0.404±0.063	a
BS1	0.189±0.030	a	0.793±0.179	a	0.260±0.053	a	0.519±0.139	ab
BS2	0.342±0.097	a	2.144±0.888	a	0.880±0.230	a	1.386±0.229	bc
BSInc	0.130±0.036	a	2.019±0.824	a	0.318±0.116	a	0.768±0.251	ab

Table 29. Fire-affected soil runoff statistics

	Precipitation Event							
	12/14/2009		*1/19/2010*		*1/21/2010*		*1/23/2010*	
Treatment	***Nitrate-N (mg/m^2)***							
Control	3.70±2.67	a	4.06±1.10	b	1.44±0.24	b	0.77±0.22	b
GWC1	0.22±0.03	a	2.05±0.29	ab	0.35±0.24	a	0.15±0.03	a
GWC2	0.39±0.11	a	0.80±0.12	a	0.22±0.14	a	0.21±0.15	a
GWCInc	0.34±0.11	a	1.57±0.27	ab	0.13±0.09	a	0.07±0.03	a
GWF1	0.77±0.24	a	1.48±0.39	ab	0.12±0.06	a	0.04±0.02	a
GWF2	0.39±0.29	a	1.73±0.72	ab	0.13±0.06	a	0.14±0.09	a
GWFInc	0.36±0.11	a	2.14±0.90	ab	0.07±0.06	a	0.03±0.03	a
BS1	0.89±0.28	a	1.68±0.31	ab	0.50±0.24	ab	0.32±0.16	ab
BS2	0.71±0.18	a	2.32±0.11	ab	0.77±0.50	ab	0.47±0.08	ab
BSInc	0.68±0.27	a	1.20±0.30	a	0.24±0.02	ab	0.32±0.06	ab
	Ammonium-N (mg/m^2)							
Control	0.13±0.04	a	4.11±0.93	a	0.81±0.41	a	0.61±0.10	a
GWC1	0.93±0.78	a	1.67±1.08	a	0.12±0.06	a	0.24±0.10	a
GWC2	0.11±0.02	a	0.49±0.19	a	0.08±0.04	a	0.31±0.13	a
GWCInc	0.05±0.01	a	0.93±0.54	a	0.03±0.00	a	0.12±0.05	a
GWF1	0.08±0.03	a	0.92±0.26	a	0.06±0.02	a	0.21±0.08	a
GWF2	0.07±0.02	a	0.99±0.27	a	0.04±0.01	a	0.18±0.04	a
GWFInc	0.08±0.04	a	1.10±0.30	a	0.05±0.04	a	0.14±0.02	a
BS1	1.60±0.89	a	8.77±1.40	a	1.34±0.69	a	2.81±0.52	b
BS2	17.14±2.66	b	40.36±4.61	b	11.60±3.23	b	11.81±0.77	c
BSInc	1.79±0.74	a	6.50±3.49	a	1.46±0.70	a	2.43±0.65	b

Table 30. Metal concetrations from the 12.5 mm event on December 15, 2009. Fire-affected soil runoff statistics

	Metal concentrations in mg/L (mean±standard error)				
Treatment	As	Cd	Cr	Cu	Mo
Control	Non-detect	Non-detect	≤0.0011±≥0.0001	0.074±0.028	0.0078±0.0004
GWC1	≤0.011±≥0.001	≤0.00078±≥0.00038	≤0.0016±≥0.0006	0.065±0.046	0.0189±0.0109
GWC2	Non-detect	Non-detect	≤0.0011±≥0.0001	0.026±0.004	0.0065±0.0019
GWCInc	Non-detect	Non-detect	Non-detect	0.041±0.007	0.0054±0.0003
GWF1	≤0.012±≥0.002	Non-detect	Non-detect	0.042±0.011	0.0122±0.0039
GWF2	≤0.012±≥0.001	≤0.00060±≥0.00010	≤0.0014±≥0.0004	0.031±0.007	0.0066±0.0011
GWFInc	≤0.011±≥0.001	≤0.00041±≥0.00001	Non-detect	0.036±0.015	0.0071±0.0012
BS1	≤0.011±≥0.001	0.00171±0.00096	0.0033±0.0006	0.134±0.012	0.0417±0.0091
BS2	0.021±0.003	0.00259±0.00066	0.0089±0.0016	0.342±0.075	0.1058±0.0165
BSInc	≤0.011±≥0.001	0.00199±0.00110	0.0036±0.0013	0.120±0.019	0.0388±0.0134
Detection limit*	0.01	0.0004	0.001	0.002	0.001
Treatment	Ni	Pb	Se	Zn	Hg
Control	0.0094±0.0045	Non-detect	Non-detect	0.165±0.082	Non-detect
GWC1	0.0085±0.0058	Non-detect	≤0.020±≥0.000	0.143±0.080	Non-detect
GWC2	0.0045±0.0011	Non-detect	Non-detect	0.129±0.006	Non-detect
GWCInc	0.0055±0.0008	Non-detect	Non-detect	0.119±0.020	Non-detect
GWF1	0.0063±0.0014	Non-detect	Non-detect	0.129±0.006	Non-detect
GWF2	0.0080±0.0016	Non-detect	Non-detect	0.210±0.016	Non-detect
GWFInc	0.0285±0.0242	Non-detect	Non-detect	0.223±0.096	Non-detect

* Statistics conservatively assume the detection limit as a lower bound on all measures. n=3.

BS1	0.0221±0.0021	Non-detect	0.024±0.002	0.592±0.299	Non-detect
BS2	0.0643±0.0104	Non-detect	0.062±0.019	0.610±0.141	Non-detect
BSInc	0.0282±0.0089	Non-detect	0.032±0.004	0.538±0.264	Non-detect
Detection limit	0.001	0.02	0.02	0.003	0.001

Table 31. Metal mass flux losses from the 12.5 mm event on Dec.15, 2009.

	Metal concentrations in mg/m² (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	≤0.0004±≥0.0001	0.0236±0.0065	0.0029±0.0009
GWC1	≤0.0022±≥0.0003	≤0.00014±≥0.00005	≤0.0003±≥0.0001	0.0108±0.0065	0.0033±0.0014
GWC2	Non-detect	Non-detect	≤0.0003±≥0.0000	0.0059±0.0007	0.0014±0.0003
GWCInc	Non-detect	Non-detect	Non-detect	0.0069±0.0019	0.0009±0.0001
GWF1	≤0.0023±≥0.0002	Non-detect	Non-detect	0.0080±0.0017	0.0024±0.0008
GWF2	≤0.0022±≥0.0006	≤0.00010±≥0.00002	≤0.0002±≥0.0001	0.0055±0.0014	0.0011±0.0002
GWFInc	≤0.0025±≥0.0004	≤0.00009±≥0.00001	Non-detect	0.0081±0.0036	0.0016±0.0004
BS1	≤0.0014±≥0.0001	0.00025±0.00016	0.0004±0.0000	0.0169±0.0007	0.0051±0.0006
BS2	0.0026±0.0004	0.00032±0.00006	0.0011±0.0001	0.0435±0.0081	0.0137±0.0024
BSInc	≤0.0007±≥0.0001	0.00014±0.00009	0.0002±0.0001	0.0078±0.0016	0.0026±0.0009

Treatment	***Ni***	***Pb***	***Se***	***Zn***	***Hg***
Control	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²
GWC1	0.0014±0.0008	Non-detect	≤0.0042±≥0.0007	0.025±0.011	Non-detect
GWC2	0.0011±0.0004	Non-detect	Non-detect	0.030±0.005	Non-detect
GWCInc	0.0009±0.0002	Non-detect	Non-detect	0.020±0.005	Non-detect
GWF1	0.0012±0.0002	Non-detect	Non-detect	0.026±0.002	Non-detect
GWF2	0.0014±0.0004	Non-detect	Non-detect	0.037±0.008	Non-detect
GWFInc	0.0066±0.0057	Non-detect	Non-detect	0.051±0.023	Non-detect
BS1	0.0028±0.0001	Non-detect	0.0030±0.0001	0.086±0.052	Non-detect
BS2	0.0080±0.0006	Non-detect	0.0074±0.0016	0.077±0.014	Non-detect
BSInc	0.0019±0.0006	Non-detect	0.0021±0.0004	0.038±0.022	Non-detect

Table 32. Metal concetrations from the cm event 32 mm on Jan. 19, 2010.

	Metal concentrations in mg/L (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	≤0.0011±≥0.0001	0.0127±0.0026	Non-detect
GWC1	Non-detect	≤0.00040±≥0.00000	≤0.0010±≥0.0000	≤0.0213±≥0.0107	≤0.0027±≥0.0008
GWC2	Non-detect	≤0.00042±≥0.00002	≤0.0011±≥0.0001	0.0250±0.0083	0.0036±0.0005
GWCInc	Non-detect	≤0.00055±≥0.00015	≤0.0012±≥0.0002	0.0296±0.0021	0.0029±0.0005
GWF1	Non-detect	Non-detect	≤0.0012±≥0.0001	0.0287±0.0071	0.0042±0.0009
GWF2	Non-detect	≤0.00075±≥0.00035	≤0.0012±≥0.0001	0.0776±0.0416	0.0021±0.0008
GWFInc	Non-detect	≤0.00071±≥0.00031	Non-detect	0.0307±0.0166	0.0037±0.0009
BS1	Non-detect	0.00068±0.00024	≤0.0020±≥0.0006	0.0982±0.0267	0.0215±0.0062
BS2	Non-detect	0.00091±0.00004	0.0039±0.0010	0.1540±0.0069	0.0549±0.0123
BSInc	Non-detect	≤0.00051±≥0.00009	0.0014±0.0000	0.0457±0.0137	0.0083±0.0050
Detection limit[†]	0.01	0.0004	0.001	0.002	0.001

[†] Statistics conservatively assume the detection limit as a lower bound on all measures. n=3.

Treatment	*Ni*	*Pb*	*Se*	*Zn*
Control	0.0019±0.0002	Non-detect	Non-detect	0.046±0.007
GWC1	≤0.0027±≥0.0009	Non-detect	≤0.020±≥0.000	≤0.043±≥0.022
GWC2	0.0045±0.0023	Non-detect	Non-detect	0.095±0.042
GWCInc	0.0021±0.0004	Non-detect	Non-detect	0.108±0.021
GWF1	0.0024±0.0007	Non-detect	Non-detect	0.071±0.012
GWF2	0.0369±0.0353	Non-detect	Non-detect	0.545±0.470
GWFInc	0.0040±0.0010	Non-detect	Non-detect	0.115±0.014
BS1	0.0094±0.0030	Non-detect	Non-detect	0.186±0.037
BS2	0.0198±0.0029	Non-detect	≤0.023±≥0.003	0.227±0.002
BSInc	0.0041±0.0012	Non-detect	Non-detect	0.083±0.020
Detection limit	0.001	0.02	0.02	0.003

Table 33. Metal mass flux losses from the 32 mm event on Jan. 19, 2010.

	Metal concentrations in mg/m^2 (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	≤0.0090±≥0.0010	0.105±0.012	Non-detect
GWC1	Non-detect	≤0.00050±≥0.00009	≤0.0013±≥0.0001	≤0.040±≥0.017	≤0.0043±≥0.0007
GWC2	Non-detect	≤0.00018±≥0.00009	≤0.0005±≥0.0002	0.010±0.006	0.0016±0.0009
GWCInc	Non-detect	≤0.00074±≥0.00030	≤0.0016±≥0.0004	0.038±0.009	0.0038±0.0012
GWF1	Non-detect	Non-detect	≤0.0016±≥0.0006	0.046±0.025	0.0057±0.0019
GWF2	Non-detect	≤0.00149±≥0.00059	≤0.0025±≥0.0002	0.152±0.071	0.0047±0.0020
GWFInc	Non-detect	≤0.00203±≥0.00101	Non-detect	0.089±0.052	0.0105±0.0034
BS1	Non-detect	0.00047±0.00006	≤0.0015±≥0.0004	0.072±0.017	0.0158±0.0041
BS2	Non-detect	0.00105±0.00004	0.0045±0.0012	0.178±0.008	0.0633±0.0141
BSInc	Non-detect	≤0.00065±≥0.00004	0.0019±0.0003	0.062±0.024	0.0127±0.0089

Treatment	***Ni***	***Pb***	***Se***	***Zn***
Control	mg/m^2	mg/m^2	mg/m^2	mg/m^2
GWC1	≤0.0044±≥0.0011	Non-detect	≤0.025±≥0.004	≤0.080±≥0.034
GWC2	0.0018±0.0011	Non-detect	Non-detect	0.039±0.023
GWCInc	0.0028±0.0009	Non-detect	Non-detect	0.128±0.005
GWF1	0.0040±0.0025	Non-detect	Non-detect	0.110±0.057
GWF2	0.0678±0.0642	Non-detect	Non-detect	1.016±0.847
GWFInc	0.0112±0.0036	Non-detect	Non-detect	0.321±0.063
BS1	0.0071±0.0022	Non-detect	Non-detect	0.162±0.055
BS2	0.0229±0.0034	Non-detect	≤0.026±≥0.003	0.261±0.002
BSInc	0.0058±0.0025	Non-detect	Non-detect	0.114±0.038

Table 34. Metal concetrations from the 39 mm event on Jan. 21, 2010.

	Metal concentrations in mg/L (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	Non-detect	0.0071±0.0012	Non-detect
GWC1	Non-detect	Non-detect	Non-detect	0.0146±0.0025	≤0.0013±≥0.0003
GWC2	Non-detect	Non-detect	≤0.0011±≥0.0001	0.0107±0.0018	≤0.0015±≥0.0005
GWCInc	Non-detect	Non-detect	Non-detect	0.0123±0.0032	≤0.0011±≥0.0001
GWF1	Non-detect	Non-detect	Non-detect	0.0120±0.0029	≤0.0016±≥0.0003
GWF2	Non-detect	Non-detect	Non-detect	0.0236±0.0122	≤0.0012±≥0.0001
GWFInc	Non-detect	Non-detect	Non-detect	0.0102±0.0010	≤0.0018±≥0.0004
BS1	Non-detect	Non-detect	≤0.0010±≥0.0000	0.0646±0.0058	0.0245±0.0015
BS2	Non-detect	0.00053±0.00002	0.0024±0.0003	0.1153±0.0269	0.0588±0.0109
BSInc	≤0.0105±≥0.0005	Non-detect	≤0.0011±≥0.0001	0.0348±0.0066	0.0122±0.0050
Detection limit‡	0.01	0.0004	0.001	0.002	0.001

‡ Statistics conservatively assume the detection limit as a lower bound on all measures. n=3.

Treatment	*Ni*	*Pb*	*Se*	*Zn*
Control	≤0.0011±≥0.0001	Non-detect	Non-detect	0.037±0.001
GWC1	≤0.0015±≥0.0005	Non-detect	Non-detect	0.049±0.002
GWC2	≤0.0012±≥0.0002	Non-detect	Non-detect	0.049±0.002
GWCInc	≤0.0012±≥0.0001	Non-detect	Non-detect	0.049±0.001
GWF1	≤0.0013±≥0.0002	Non-detect	Non-detect	0.051±0.004
GWF2	0.0197±0.0184	Non-detect	Non-detect	0.178±0.119
GWFInc	0.0035±0.0022	Non-detect	Non-detect	0.058±0.003
BS1	0.0068±0.0012	Non-detect	Non-detect	0.093±0.012
BS2	0.0143±0.0030	Non-detect	Non-detect	0.121±0.025
BSInc	0.0042±0.0014	Non-detect	Non-detect	0.055±0.001
Detection limit	0.001	0.02	0.02	0.003

Table 35. Metal mass flux losses from the 39 mm event on Jan. 21, 2010.

	Metal concentrations in mg/m^2 (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	Non-detect	0.0446±0.0065	Non-detect
GWC1	Non-detect	Non-detect	Non-detect	0.0089±0.0021	≤0.0008±≥0.0002
GWC2	Non-detect	Non-detect	≤0.0009±≥0.0004	0.0082±0.0024	≤0.0011±≥0.0004
GWCInc	Non-detect	Non-detect	Non-detect	0.0053±0.0004	≤0.0005±≥0.0001
GWF1	Non-detect	Non-detect	Non-detect	0.0074±0.0030	≤0.0010±≥0.0003
GWF2	Non-detect	Non-detect	Non-detect	0.0161±0.0105	≤0.0007±≥0.0001
GWFInc	Non-detect	Non-detect	Non-detect	0.0065±0.0019	≤0.0010±≥0.0002
BS1	Non-detect	Non-detect	≤0.0003±≥0.0001	0.0182±0.0053	0.0065±0.0014
BS2	Non-detect	0.00031±0.00007	0.0014±0.0004	0.0713±0.0295	0.0360±0.0133
BSInc	≤0.0031±≥0.0011	Non-detect	≤0.0003±≥0.0001	0.0102±0.0034	0.0033±0.0011

Treatment	***Ni***	***Pb***	***Se***	***Zn***
Control	mg/m^2	mg/m^2	mg/m^2	mg/m^2
GWC1	≤0.0009±≥0.0002	Non-detect	Non-detect	0.034±0.013
GWC2	≤0.0009±≥0.0003	Non-detect	Non-detect	0.039±0.013
GWCInc	≤0.0006±≥0.0001	Non-detect	Non-detect	0.024±0.006
GWF1	≤0.0008±≥0.0004	Non-detect	Non-detect	0.031±0.010
GWF2	0.0149±0.0143	Non-detect	Non-detect	0.126±0.097
GWFInc	0.0036±0.0030	Non-detect	Non-detect	0.041±0.018
BS1	0.0019±0.0006	Non-detect	Non-detect	0.027±0.008
BS2	0.0087±0.0034	Non-detect	Non-detect	0.075±0.029
BSInc	0.0012±0.0004	Non-detect	Non-detect	0.017±0.006

Table 36. Metal concetrations from the 49 mm event on Jan. 23, 2010.

	Metal concentrations in mg/L (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	Non-detect	0.0082±0.0014	≤0.0011±≥0.0001
GWC1	Non-detect	Non-detect	Non-detect	0.0113±0.0019	≤0.0010±≥0.0000
GWC2	Non-detect	Non-detect	≤0.0010±≥0.0000	0.0095±0.0005	≤0.0023±≥0.0008
GWCInc	Non-detect	Non-detect	≤0.0011±≥0.0001	0.0111±0.0004	≤0.0012±≥0.0002
GWF1	Non-detect	Non-detect	Non-detect	0.0106±0.0014	≤0.0011±≥0.0000
GWF2	Non-detect	Non-detect	Non-detect	0.0094±0.0014	≤0.0020±≥0.0006
GWFInc	Non-detect	Non-detect	Non-detect	0.0124±0.0020	≤0.0013±≥0.0003
BS1	Non-detect	Non-detect	Non-detect	0.0368±0.0009	0.0067±0.0017
BS2	Non-detect	≤0.00042±≥0.00002	Non-detect	0.0495±0.0122	0.0144±0.0029
BSInc	Non-detect	Non-detect	Non-detect	0.0219±0.0043	0.0024±0.0004
Detection limit[§]	0.01	0.0004	0.001	0.002	0.001

[§] Statistics conservatively assume the detection limit as a lower bound on all measures. n=3.

Treatment	***Ni***	***Pb***	***Se***	***Zn***
Control	≤0.0010±≥0.0000	Non-detect	Non-detect	0.029±0.001
GWC1	Non-detect	Non-detect	Non-detect	0.035±0.004
GWC2	≤0.0012±≥0.0002	Non-detect	Non-detect	0.033±0.001
GWCInc	≤0.0012±≥0.0002	Non-detect	Non-detect	0.038±0.003
GWF1	Non-detect	Non-detect	Non-detect	0.034±0.002
GWF2	Non-detect	Non-detect	Non-detect	0.038±0.002
GWFInc	≤0.0011±≥0.0001	Non-detect	Non-detect	0.039±0.003
BS1	0.0020±0.0002	Non-detect	Non-detect	0.053±0.003
BS2	0.0035±0.0006	Non-detect	Non-detect	0.055±0.008
BSInc	≤0.0017±≥0.0003	Non-detect	Non-detect	0.042±0.002
Detection limit	0.001	0.02	0.02	0.003

Table 37. Metal mass flux losses from the 49 mm event on Jan. 23, 2010.

	Metal concentrations in mg/m^2 (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	Non-detect	0.043±0.008	≤0.0056±≥0.0002
GWC1	Non-detect	Non-detect	Non-detect	0.018±0.007	≤0.0016±≥0.0003
GWC2	Non-detect	Non-detect	≤0.0020±≥0.0002	0.018±0.001	≤0.0045±≥0.0019
GWCInc	Non-detect	Non-detect	≤0.0008±≥0.0003	0.009±0.003	≤0.0008±≥0.0003
GWF1	Non-detect	Non-detect	Non-detect	0.021±0.006	≤0.0021±≥0.0005
GWF2	Non-detect	Non-detect	Non-detect	0.011±0.002	≤0.0022±≥0.0003
GWFInc	Non-detect	Non-detect	Non-detect	0.016±0.002	≤0.0018±≥0.0007
BS1	Non-detect	Non-detect	Non-detect	0.030±0.011	0.0045±0.0007
BS2	Non-detect	≤0.00072±≥0.00024	Non-detect	0.073±0.007	0.0217±0.0010
BSInc	Non-detect	Non-detect	Non-detect	0.026±0.006	0.0027±0.0002

Treatment	***Ni***	***Pb***	***Se***	***Zn***
Control	mg/m^2	mg/m^2	mg/m^2	mg/m^2
GWC1	Non-detect	Non-detect	Non-detect	0.056±0.018
GWC2	≤0.0023±≥0.0005	Non-detect	Non-detect	0.062±0.005
GWCInc	≤0.0008±≥0.0003	Non-detect	Non-detect	0.029±0.010
GWF1	Non-detect	Non-detect	Non-detect	0.066±0.017
GWF2	Non-detect	Non-detect	Non-detect	0.044±0.007
GWFInc	≤0.0015±≥0.0002	Non-detect	Non-detect	0.053±0.009
BS1	0.0015±0.0004	Non-detect	Non-detect	0.043±0.015
BS2	0.0054±0.0005	Non-detect	Non-detect	0.088±0.019
BSInc	≤0.0020±≥0.0005	Non-detect	Non-detect	0.050±0.009

Table 38. Metal concetrations including all four events.

Treatment	As	Cd	Cr	Cu	Mo
	Metal concentrations in mg/L (mean±standard error)				
Control	Non-detect	Non-detect	≤0.0010±≥0.0000	0.011±0.001	≤0.0011±≥0.0001
GWC1	≤0.0101±≥0.0001	≤0.00042±≥0.00002	≤0.0010±≥0.0000	0.019±0.004	0.0028±0.0007
GWC2	Non-detect	≤0.00036±≥0.00005	0.0009±0.0001	0.012±0.002	0.0022±0.0005
GWCInc	Non-detect	≤0.00046±≥0.00006	≤0.0011±≥0.0001	0.022±0.001	0.0022±0.0002
GWF1	≤0.0100±≥0.0000	Non-detect	≤0.0011±≥0.0000	0.018±0.003	0.0026±0.0004
GWF2	≤0.0101±≥0.0001	≤0.00056±≥0.00015	≤0.0011±≥0.0001	0.044±0.019	0.0022±0.0006
GWFInc	≤0.0102±≥0.0002	≤0.00053±≥0.00013	Non-detect	0.022±0.007	0.0027±0.0004
BS1	≤0.0101±≥0.0001	≤0.00059±≥0.00009	≤0.0016±≥0.0003	0.073±0.014	0.0179±0.0045
BS2	≤0.0105±≥0.0001	0.00064±0.00005	≤0.0022±≥0.0002	0.096±0.021	0.0352±0.0055
BSInc	≤0.0101±≥0.0000	≤0.00048±≥0.00003	≤0.0012±≥0.0001	0.035±0.006	0.0067±0.0023
Detection limit[**]	0.01	0.0004	0.001	0.002	0.001

[**] Statistics conservatively assume the detection limit as a lower bound on all measures. n=3.

Treatment	*Ni*	*Pb*	*Se*	*Zn*
Control	0.0016±0.0001	Non-detect	Non-detect	0.040±0.004
GWC1	≤0.0021±≥0.0006	Non-detect	≤0.020±≥0.000	0.050±0.005
GWC2	0.0017±0.0003	Non-detect	Non-detect	0.046±0.008
GWCInc	0.0019±0.0003	Non-detect	Non-detect	0.078±0.009
GWF1	≤0.0018±≥0.0003	Non-detect	Non-detect	0.054±0.005
GWF2	≤0.0199±≥0.0183	Non-detect	Non-detect	0.289±0.218
GWFInc	0.0059±0.0023	Non-detect	Non-detect	0.088±0.008
BS1	0.0072±0.0018	Non-detect	≤0.020±≥0.000	0.143±0.022
BS2	0.0117±0.0019	Non-detect	≤0.023±≥0.001	0.126±0.028
BSInc	0.0035±0.0007	Non-detect	≤0.020±≥0.000	0.072±0.014
Detection limit	0.001	0.02	0.02	0.003

Table 39. Metal mass flux losses including all four events.

Treatment	As	Cd	Cr	Cu	Mo
	Metal concentrations in mg/m^2 (mean±standard error)				
Control	Non-detect	Non-detect	≤0.0210±≥0.0018	0.216±0.009	≤0.0235±≥0.0021
GWC1	≤0.032±≥0.009	≤0.0013±≥0.0004	≤0.0034±≥0.0009	0.064±0.024	0.0086±0.0023
GWC2	Non-detect	≤0.0013±≥0.0002	0.0036±0.0008	0.042±0.005	0.0086±0.0029
GWCInc	Non-detect	≤0.0013±≥0.0005	≤0.0030±≥0.0007	0.059±0.013	0.0061±0.0015
GWF1	≤0.042±≥0.011	Non-detect	≤0.0044±≥0.0012	0.082±0.034	0.0111±0.0033
GWF2	≤0.041±≥0.001	≤0.0023±≥0.0007	≤0.0045±≥0.0003	0.185±0.083	0.0087±0.0022
GWFInc	≤0.042±≥0.012	≤0.0023±≥0.0009	Non-detect	0.090±0.040	0.0115±0.0038
BS1	≤0.021±≥0.006	≤0.0012±≥0.0003	≤0.0030±≥0.0006	0.137±0.023	0.0320±0.0055
BS2	≤0.033±≥0.008	0.0021±0.0006	≤0.0072±≥0.0022	0.307±0.094	0.1136±0.0323
BSInc	≤0.029±≥0.004	≤0.0014±≥0.0002	≤0.0036±≥0.0006	0.105±0.032	0.0213±0.0101

Treatment	Ni	Pb	Se	Zn
Control	mg/m^2	mg/m^2	mg/m^2	mg/m^2
GWC1	≤0.0067±≥0.0023	Non-detect	≤0.064±≥0.018	0.17±0.06
GWC2	0.0062±0.0007	Non-detect	Non-detect	0.17±0.02
GWCInc	0.0051±0.0015	Non-detect	Non-detect	0.20±0.03
GWF1	≤0.0080±≥0.0034	Non-detect	Non-detect	0.23±0.08
GWF2	≤0.0854±≥0.0789	Non-detect	Non-detect	1.22±0.95
GWFInc	0.0191±0.0007	Non-detect	Non-detect	0.36±0.10
BS1	0.0133±0.0029	Non-detect	≤0.042±≥0.011	0.32±0.12
BS2	0.0374±0.0105	Non-detect	≤0.070±≥0.016	0.41±0.13
BSInc	0.0108±0.0037	Non-detect	≤0.059±≥0.009	0.22±0.08

Construction-Affected Soil Runoff Statistics

Table 40. Construction site runoff concentration statistics. Common letters indicate no significant difference (n<0.5).

Treatment	1/19/2010		1/21/2010		1/23/2010	
	Total Runoff Volume (L)					
Control	77.0±10.1	a	86.9±10.6	a	86.0±11.5	a
GWC	24.3±7.9	b	15.8±3.4	b	16.9±4.0	b
BS	5.5±0.9	b	5.1±1.5	b	7.7±2.2	b
Treatment	**Turbidity (NTU)**					
Control	954±40	a	975±36	a	859±56	a
GWC	494±62	b	203±12	b	139±14	b
BS	467±110	b	368±91	b	248±76	b
Treatment	**pH**					
Control	7.13±0.18	a	7.46±0.13	a	7.33±0.09	a
GWC	6.63±0.07	b	7.13±0.07	b	7.21±0.05	ab
BS	6.53±0.09	b	6.90±0.03	b	7.09±0.04	b
Treatment	**Salinity (dS/m)**					
Control	0.020±0.001	a	0.010±0.000	a	0.015±0.001	a
GWC	0.232±0.029	b	0.079±0.008	b	0.066±0.007	a
BS	0.190±0.050	b	0.118±0.029	b	0.128±0.027	b
Treatment	**Total Dissolved Solids (mg/L)**					
Control	71±22	a	46±4	a	38±2	a
GWC	232±36	b	114±12	b	87±8	b
BS	195±49	ab	131±22	b	92±14	b
Treatment	**Total Suspended Solids (mg/L)**					
Control	55.3±8.7	a	53.5±3.1	a	57.1±2.1	a
GWC	19.2±2.4	b	22.7±8.1	b	18.6±1.9	b
BS	26.8±5.6	b	13.4±1.7	b	28.1±14.2	ab
Treatment	**Total Sediments (gm/L)**					
Control	71.3±8.0	a	38.2±5.2	a	50.5±5.7	a
GWC	50.7±8.2	a	5.8±1.3	b	3.8±0.7	b
BS	40.1±9.3	a	12.9±3.3	b	5.1±0.8	b
Treatment	**Total Phosphorus (mg/L)**					
Control	0.27±0.01	a	0.17±0.01	a	0.15±0.01	a
GWC	3.51±0.43	b	1.61±0.19	b	0.79±0.10	b
BS	1.38±0.21	c	0.93±0.15	c	0.56±0.09	b

Note: the column headers 1/19/2010, 1/21/2010 and 1/23/2010 are printed under a spanning header "Precipitation Event".

Table 41. Construction site runoff concentration statistics (cont'd).

	Precipitation Event					
	1/19/2010		***1/21/2010***		***1/23/2010***	
Treatment	***Orthophosphate (mg/L)***					
Control	0.17±0.01	a	0.05±0.01	a	0.12±0.01	a
GWC	3.10±0.43	b	1.37±0.20	b	0.69±0.09	b
BS	0.92±0.13	a	0.65±0.12	c	0.47±0.09	b
Treatment	***Nitrate-N (mg/L)***					
Control	0.43±0.04	a	0.21±0.01	ab	0.17±0.03	a
GWC	0.36±0.07	a	0.11±0.02	a	0.03±0.02	a
BS	1.00±0.17	b	0.38±0.10	b	0.33±0.16	a
Treatment	***Ammonium-N (mg/L)***					
Control	0.45±0.03	a	0.09±0.01	a	0.17±0.02	a
GWC	0.79±0.07	a	0.16±0.05	a	0.13±0.02	a
BS	11.96±3.76	b	6.90±1.77	b	3.34±0.68	b

Table 42. Construction site runoff mass flux loss statistics. Common letters indicate no significant difference (n<0.5).

Treatment	Precipitation Event					
	1/19/2010		1/21/2010		1/23/2010	
	Total Dissolved Solids (mg/m^2)					
Control	1,004±347	a	758±111	a	637±103	a
GWC	1,238±451	a	327±67	b	273±75	b
BS	229±76	b	116±33	b	116±25	b
	Total Suspended Solids (mg/m^2)					
Control	834±187	a	879±117	a	972±155	a
GWC	102.4±38.2	b	59.3±15.0	b	67±18	b
BS	27.6±6.4	b	15±5	b	29±11	b
	Total Sediments (gm/m^2)					
Control	1,030±184	a	617±112	a	882±168	a
GWC	218.1±84.7	b	22.7±10.1	b	14.8±5.3	b
BS	42.3±11.1	b	16.7±7.1	b	9.3±4.0	b
	Total Phosphorus (mg/m^2)					
Control	3.99±0.57	a	2.91±0.38	ab	2.53±0.49	a
GWC	17.73±6.29	b	5.45±1.50	b	2.62±0.77	a
BS	1.42±0.28	a	0.84±0.25	a	0.75±0.21	b
	Orthophosphate (mg/m^2)					
Control	2.60±0.39	a	0.70±0.22	a	2.05±0.37	ab
GWC	15.20±5.35	b	4.74±1.42	b	2.35±0.73	b
BS	0.96±0.20	a	0.58±0.16	a	0.61±0.16	a
	Nitrate-N (mg/m^2)					
Control	6.42±1.00	a	3.52±0.51	a	3.04±0.77	a
GWC	1.91±0.70	b	0.31±0.10	b	0.06±0.03	b
BS	1.11±0.25	b	0.43±0.16	b	0.35±0.11	b
	Ammonium-N (mg/m^2)					
Control	6.53±0.84	a	1.55±0.27	ab	2.85±0.61	a
GWC	3.86±1.21	a	0.40±0.13	a	0.43±0.14	b
BS	11.51±3.22	a	5.64±1.49	b	4.25±1.11	a

Table 43. Construction site selected metal concentrations and mass flux losses from the 32 mm event on Jan. 19, 2010.

	Metal concentrations in mg/L (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	≤0.0012±≥0.0001	0.0212±0.0063	Non-detect
GWC	≤0.0118±≥0.0009	≤0.00041±≥0.00001	≤0.0011±≥0.0000	0.0252±0.0071	≤0.0023±≥0.0003
BS	≤0.0101±≥0.0001	≤0.00046±≥0.00004	0.0020±0.0002	0.0759±0.0141	0.0211±0.0066
Detection limit††	0.01	0.0004	0.001	0.002	0.001
Treatment	***Ni***	***Pb***	***Se***	***Zn***	
Control	0.0023±0.0003	Non-detect	Non-detect	0.070±0.006	
GWC	0.0045±0.0009	Non-detect	Non-detect	0.120±0.009	
BS	0.0092±0.0018	Non-detect	≤0.021±≥0.001	0.133±0.019	
Detection limit	0.001	0.02	0.02	0.003	

	Metal concentrations in mg/m^2 (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	≤0.0175±≥0.0031	0.240±0.039	Non-detect
GWC	≤0.0531±≥0.0167	≤0.00187±≥0.00060	≤0.0049±≥0.0015	0.108±0.033	≤0.0093±≥0.0024
BS	≤0.0107±≥0.0017	≤0.00048±≥0.00008	0.0021±0.0004	0.071±0.012	0.0193±0.0063
Treatment	***Ni***	***Pb***	***Se***	***Zn***	
Control	0.0362±0.0076	Non-detect	Non-detect	1.068±0.195	
GWC	0.0256±0.0099	Non-detect	Non-detect	0.615±0.223	
BS	0.0089±0.0016	Non-detect	≤0.022±≥0.004	0.128±0.018	

†† Statistics conservatively assume the detection limit as a lower bound on all measures. n=9.

Table 44. Construction site selected metal concentrations and mass flux losses from the 39 mm event on Jan. 21, 2010.

	Metal concentrations in mg/L (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	≤0.0016±≥0.0003	0.0072±0.0009	Non-detect
GWC	≤0.0101±≥0.0001	Non-detect	Non-detect	0.0106±0.0007	≤0.0021±≥0.0003
BS	Non-detect	≤0.00040±≥0.00000	≤0.0011±≥0.0001	0.0449±0.0101	0.0137±0.0041
Detection limit‡‡	0.01	0.0004	0.001	0.002	0.001
Treatment	***Ni***	***Pb***	***Se***	***Zn***	
Control	≤0.0013±≥0.0001	Non-detect	Non-detect	0.040±0.001	
GWC	≤0.0012±≥0.0001	Non-detect	Non-detect	0.056±0.003	
BS	0.0040±0.0009	Non-detect	Non-detect	0.059±0.005	
Detection limit	0.001	0.02	0.02	0.003	

	Metal concentrations in mg/m^2 (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	≤0.0299±≥0.0074	0.1149±0.0197	Non-detect
GWC	≤0.0307±≥0.0066	Non-detect	Non-detect	0.0304±0.0058	≤0.0069±≥0.0023
BS	Non-detect	≤0.00040±≥0.00012	≤0.0012±≥0.0004	0.0463±0.0204	0.0145±0.0075
Treatment	***Ni***	***Pb***	***Se***	***Zn***	
Control	≤0.0223±≥0.0039	Non-detect	Non-detect	0.670±0.086	
GWC	≤0.0037±≥0.0011	Non-detect	Non-detect	0.181±0.045	
BS	0.0042±0.0019	Non-detect	Non-detect	0.056±0.016	

‡‡ Statistics conservatively assume the detection limit as a lower bound on all measures. n=9.

Table 45. Construction site selected metal concentrations and mass flux losses from the 49 mm event on Jan. 23, 2010.

	Metal concentrations in mg/L (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	≤0.0011±≥0.0001	0.0102±0.0010	≤0.0011±≥0.0001
GWC	Non-detect	Non-detect	≤0.0010±≥0.0000	0.0267±0.0054	≤0.0016±≥0.0002
BS	Non-detect	Non-detect	≤0.0010±≥0.0000	0.0458±0.0069	≤0.0048±≥0.0015
Detection limit[§§]	0.01	0.0004	0.001	0.002	0.001
Treatment	***Ni***	***Pb***	***Se***	***Zn***	
Control	≤0.0010±≥0.0000	Non-detect	Non-detect	0.040±0.003	
GWC	≤0.0010±≥0.0000	Non-detect	Non-detect	0.047±0.003	
BS	≤0.0018±≥0.0003	Non-detect	≤0.0208±≥0.0007	0.043±0.004	
Detection limit	0.001	0.02	0.02	0.003	

	Metal concentrations in mg/m² (mean±standard error)				
Treatment	***As***	***Cd***	***Cr***	***Cu***	***Mo***
Control	Non-detect	Non-detect	≤0.0194±≥0.0037	0.163±0.023	≤0.0175±≥0.0022
GWC	Non-detect	Non-detect	≤0.0033±≥0.0008	0.091±0.027	≤0.0045±≥0.0010
BS	Non-detect	Non-detect	≤0.0015±≥0.0004	0.054±0.009	≤0.0055±≥0.0019
Treatment	***Ni***	***Pb***	***Se***	***Zn***	
Control	≤0.0169±≥0.0023	Non-detect	Non-detect	0.672±0.101	
GWC	≤0.0033±≥0.0008	Non-detect	Non-detect	0.165±0.049	

[§§] Statistics conservatively assume the detection limit as a lower bound on all measures. n=9.

BS	≤0.0025±≥0.0006	Non-detect	≤0.0300±≥0.0082	0.058±0.014

Compost Production Best Management Practices Statistics

Table 46. Initial compost mean moisture contents and field capacities

	GWM		BSM	
Treatment	***W_P, Initial Moisture Content (L/kg ww)***	***W_{FC}, Measured Field Capacity (L/kg ww)***	***W_P, Initial Moisture Content (L/kg ww)***	***W_{FC}, Measured Field Capacity (L/kg ww)***
Day 1	0.48	0.63	0.60	0.73
Day 7	0.45	0.62	0.56	0.68
Day 14	0.48	0.66	0.51	0.65

Table 47. Column experiment results.

Treatment	***Wet Compost Initial Wet Weight (kg)***	***Initial Compost Dry Weight (kg)***	***Initial Water Content (L)***	***Predicted Storage Capacity (L)***	***Actual Storage Capacity (L)***	***E Actual to Predicted Storage Capacity Ratio***
			Compost-greenwaste			
Day 1, Rep 1	27.1	12.6	14.5	7.6	10.8	1.42
Day 1, Rep 2	24.0	11.2	12.8	6.7	7.9	1.18
Day 1, Rep 3	24.4	11.4	13.0	6.8	8.1	1.19
Day 7, Rep 1	32.1	14.9	17.2	9.3	4.8	0.51
Day 7, Rep 2	29.2	13.5	15.7	8.5	8.7	1.03
Day 7, Rep 3	27.9	12.9	15.0	8.1	10.0	1.23
Day 14, Rep 1	30.5	14.0	16.5	9.1	9.6	1.05
Day 14, Rep 2	35.2	16.2	19.0	10.5	6.7	0.64
Day 14, Rep 3	31.9	14.7	17.2	9.5	7.4	0.78
		mean±standard error:				1.00±0.10

BSM						
Day 1, Rep 1	30.8	12.3	18.5	8.0	9.2	1.14
Day 1, Rep 2	31.6	12.6	19.0	8.2	8.4	1.02
Day 1, Rep 3	31.0	12.4	18.6	8.1	6.1	0.75
Day 7, Rep 1	33.1	18.3	14.8	9.5	2.5	0.26
Day 7, Rep 2	31.3	17.3	14.0	9.0	3.8	0.42
Day 7, Rep 3	32.8	18.1	14.7	9.5	4.5	0.48
Day 14, Rep 1	28.2	15.6	12.6	4.4	6.0	1.36
Day 14, Rep 2	29.0	16.1	12.9	4.5	4.5	0.99
Day 14, Rep 3	29.5	16.3	13.2	4.6	5.0	1.08
mean±standard error:						0.83±0.13

Table 48. Measured storage efficiency (*E*) statistics.
Statistics sharing letters do not differ (t-test, $p<0.05$)

	GWM	BSM
Treatment	mean±std.error	mean±std.error
Day 1	1.26±0.08 a	0.97±0.12 a
Day 7	0.93±0.21 ab	0.39±0.06 b
Day 14	0.82±0.12 b	1.14±0.11 a

Table 49. Fraction of rain water collected as runoff from sloped, flat surface and surfactant application at three maturity dates for greenwaste compost.

	Slope Surface	Flat Surface	Surfactant
Maturity		Dry Material on top	
Control	0.109±0.006a	0.115±0.001a	0.122±0.014a
Day 1	0.254±0.050a	0.138±0.009a	0.100 ± 0.023b
Day 7	0.247±0.044a	0.138±0.019ab	0.102 ± 0.037b
Day 14	0.123±0.029a	0.080±0.002a	0.084 ± 0.063a
		Semi-wet Material on top	
Control	0.115±0.011a	0.121±0.005a	0.126±0.016a
Day 1	0.203±0.056a	0.130±0.021a	0.115 ± 0.039a
Day 7	0.092±0.004a	0.134±0.019a	0.117 ± 0.039a
Day 14	0.064±0.031a	0.087±0.019a	0.089 ± 0.077a
		Moist Pile	
Control	0.117±0.006a	0.104±0.004a	0.106±0.008a
Day 1	0.151±0.079a	0.126±0.007a	0.101 ± 0.042a
Day 7	0.082±0.008a	0.120±0.035a	0.110 ± 0.051a
Day 14	0.060±0.032a	0.084±0.032a	0.101 ± 0.118a
		Total	
Control	0.114±0.008a	0.114±0.001a	0.119±0.013a
Day 1	0.202±0.057a	0.132±0.012a	0.106±0.020a
Day 7	0.137±0.016a	0.131±0.024a	0.110±0.023a
Day 14	0.081±0.028a	0.084±0.017a	0.091±0.050a
	Turned Pile		
Control	0.113±0.098a	0.101±0.004a	
Day 1	0.092±0.029a	0.133±0.004a	
Day 7	0.059±0.046a	0.103±0.026a	
Day 14	0.055±0.050a	0.084±0.054a	

Note: Values reported as mean ± standard error.

Table 50. Fraction of rain water collected as runoff from sloped, flat surface and surfactant application at three maturity dates for biosolid/greenwaste co-composts.

	Slope Surface	Flat Surface	Surfactant
Maturity	Dry Material on top		
Control	0.158±0.013a	0.132±0.016a	0.134±0.015a
Day 1	0.133±0.005a	0.117±0.007a	0.157±0.003b
Day 7	0.154±0.009a	0.116±0.011b	0.184±0.008c
Day 14	0.107±0.020a	0.115±0.014a	0.100±0.016a
	Semi-wet Material on top		
Control	0.156±0.006a	0.145±0.025a	
Day 1	0.156±0.016a	0.139±0.009 a	
Day 7	0.182±0.017a	0.133±0.013 a	
Day 14	0.103±0.016a	0.111±0.022 a	
	Moist Pile		
Control	0.152±0.004a	0.129±0.018a	
Day 1	0.170±0.004a	0.153±0.015a	
Day 7	0.198±0.019a	0.159±0.024a	
Day 14	0.116±0.025a	0.109±0.023a	
	Total		
Control	0.155±0.007a	0.136±0.020a	
Day 1	0.153±0.009a	0.137±0.008a	
Day 7	0.178±0.015a	0.136±0.005a	
Day 14	0.108±0.017a	0.112±0.018a	

Note: Values reported as mean ± standard error.

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