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16. Abstract

The objective of this study was investigation of the potential beneficial use of compost manufactured topsoil in highway rights-of-way in Texas. The water holding capacity and the physical, chemical and microbiological characteristics of composted manures (dairy cattle, poultry litter, and feedlot), composted biosolids and sandy and clay soil; compost manufacture topsoil (CMT) that contained composted manures or composted biosolids mixed with either sandy soil or clay soil; as well as erosion control compost (ECC) that contained compost and wood chips were evaluated. The characteristics of the leachate produced during "first-flush" and "long-term" column studies were determined. The onset of runoff and peak rate of runoff from CMT and ECC were monitored in channel studies at slopes of 2:1, 3:1, 5:1, and 8:1.

The porosity of the sandy soil increased and the bulk density decreased with the addition of caompost. Composted feedlot manure was the only compost that exhibited phytotoxic effects for both salt tolerant and salt intolerant plant test seedlings. Therefore, composted feedlot manure should be used with caution along highway rights-of-way due to possible phytotoxicity. Observations during the extended column studies indicate decrease in the concentrations of nitrate, total nitrogen, phosphorus, copper, zinc and total dissolved solids the after the equivalent of one-year of rainfall was applied to CMT's and ECC's . The concentrations observed in the laboratory are high compared to concentrations of constituents in water passing through the CMT in the field which infiltrates into the supporting soil where the constituents are taken up by plants and/or undergo chemical and biological transformations resulting in lower concentrations entering surface and ground water sources. The highest peak runoff occurred at the steepest slope (2:1) slope. The peak runoff rate decreased at lower slopes for the CMT's and ECC's with the onset of runoff at a 3:1 slope delayed by 15 minutes or more.

17. Key Words
Composted animal manure, composted biosolids, compost manufactured topsoil, erosion control compost, moisture holding capacity, leachate, water quality improvement

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JV Dirt and Loam, Austin, Texas donated compost, woodchips, gravel, and sandy clay loam and Maccaferri Gabions, Inc. provided the MX140 (Type 1) filter fabric.

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INTRODUCTION

Disposal of manures, biosolids, and other organic wastes is an ever-increasing issue because of the potential for contamination of surface water and groundwater resulting from high nutrient loads, metals, and bacteria. The management of these organic wastes is extremely important to minimize a major source of impairment to surface waters as a result of nonpoint source (NPS) pollution. However, organic wastes have the potential to be reused beneficially to improve soils and to provide nutrients for plant growth, if managed responsibly and effectively.

Texas is the number one producer of animal manure in the nation according to a survey conducted by Texas A&M University in 2000 and published online (TAMU, 2000). Lagooning and land application of animal manures resulted in impairment of surface waters near farming operations in north central Texas (USDA, 1992). The Texas Commission on Environmental Quality (TCEQ) and the United States Environmental Protection Agency (USEPA) are interested in investigating environmentally friendly methods of manure disposal including composting. The USEPA has provided some research funds to investigate beneficial use of manures and biosolids through composting and other means. The Texas Department of Transportation (TxDOT) advocates the beneficial application of composted manures along highway rights-of-way and has supported research to investigate the environmental impacts of compost amended soils for use on roadway projects. TxDOT has been involved in several field studies along highway rights-of-way where compost use proved successful at revegetating areas with steep slopes and severe erosion where numerous alternatives previously failed.

The passage of the Intermodal Surface Transportation Efficiency Act of 1991 encouraged the use of compost along highway rights-of-way of federally funded projects. TxDOT specified more than 400,000 cubic yards of compost in FY 2003 making TxDOT the largest market for compost in the nation (BioCycle, 2003).

This research project investigated the characteristics of compost manufactured topsoil (CMT) and erosion control composts (ECC) and the application of these materials to highway rights-of-way. TxDOT and TCEQ are interested in the beneficial use of CMT derived from dairy cattle manure, poultry litter, feedlot manure, and biosolids. CMT for general application consists of 25 percent by volume compost mixed with 75 percent by volume soil. ECC consists of a mixture of 50 percent by volume of compost and 50 percent by volume wood chips. CMT and ECC used on highway rights-of-way must meet TxDOT specifications for CMT and ECC as well as applicable state and federal regulations. TxDOT specifications address physical and chemical characteristics including heavy metals content, compost stability, organic matter content, cation exchange capacity (CEC), nutrient content, and pH.

Compost has been used successfully along roadsides to improve soils through addition of organic matter, nutrients, and microbes. Compost has reduced erosion, improved slope stabilization, and improved plant growth in roadside applications. Compost has also reduced the use and dependence on chemical fertilizers and herbicides (Mitchell, 1997b).

Beneficial use and application of composted manures and biosolids is not without problems and/or risks. One potential problem is locating reliable sources of quality composts that meet TxDOT specifications and that are available in sufficient quantities to meet project needs. Leaching of nutrients, primarily nitrogen, or other constituents from the compost must be minimized to prevent possible pollution of surface waters. Erosion and runoff must also be addressed to reduce the potential contribution of sediment, heavy metals, and trace elements to receiving streams.

Objective

The objective of this study was investigation of the potential beneficial use of CMT and ECC in highway rights-of way in Texas. The water pollution abatement capabilities of compost manufactured topsoil also were assessed.

Scope

The scope of the study included the following:

(1) Evaluation of the water holding capacity of CMT that consisted of 25 percent (by volume) composted manure and 75 percent (by volume) soil. Composted dairy cattle manure, composted poultry litter, composted feedlot manure, or composted biosolids that were produced in Texas were mixed individually with both sandy soil and clay

soil to make the CMT. The physical, chemical, and microbiological characteristics of each composted manure and each soil were determined. Results were compared with the water holding capacity of the control soils and with other published data.

(2) Evaluation of the characteristics of the leachate that was produced during first-flush leachate column studies. Deionized water was applied to each sample of CMT, ECC that consisted of a mixture of 50 percent (by volume) composted manure and 50 percent wood chips, and soil controls. Highway runoff was applied in a second series of column studies. The leachate that was produced from each series was collected and the water quality was analyzed. The CMT and ECC samples and the soil controls were replaced in the respective columns after each application of deionized water or highway runoff.

(3) Investigation of the water quality characteristics of the leachate that was produced in extended column studies in which a quantity of deionized water equivalent to one year of rainfall was applied to each column. Deionized water was applied once per week to each of the same samples of CMT and ECC and to the soil controls in the respective columns during the entire length of the study.

(4) Channel studies in which the onset of runoff and peak rates of runoff was monitored. Deionized water was applied to a sample of CMT and ECC that was placed in a sheet metal channel maintained at slopes in the ratios of 2:1, 3:1, 5:1, and 8:1 (horizontal:vertical). The channel was 3 ft wide and 9 ft long and contained CMT or ECC at a depth of 3 in. The CMT and ECC that were used in this phase of the study contained composted dairy cattle manure. The onset of runoff and peak rates of runoff from the CMT and ECC samples was compared with data observed in the studies in which water applied to control soils at the same slope. Additional channel studies were completed in which the CMT and ECC that were placed in the channel contained either composted poultry litter, composted feedlot manure, or composted biosolids, respectively, for each run. The onsets of runoff and peak rates of runoff

from channels that were maintained at a slope of 3:1 also were monitored in this phase of study for each CMT, ECC, and soil controls.

LITERATURE EVALUATION

TxDOT and the TCEQ (formerly the Texas Natural Resource Conservation Commission) joined forces to investigate the application of composted animal wastes to highway rights-of-way as a means to beneficially dispose of excess manure production in parts of Texas. These efforts demonstrated that the application of composted manures was successful in vegetating slopes and controlling erosion of slopes on highway embankments. TxDOT reports that composted manures have been used beneficially in twenty-two of the twenty-five TxDOT districts, usually with excellent results.

TxDOT and TCEQ concentrate on the use of composted animal manures, composted feedlot manure, composted biosolids, and composted yard wastes in Texas. Currently, TxDOT applies the largest amount of compost in the U.S. Disposal of organic wastes generated by municipalities, agricultural farming, animal agriculture, logging, and other industries is practiced by various DOTs throughout the nation. The USEPA estimated roughly that publicly owned treatment works would produce 15 million dry metric tons of biosolids annually by 2000 (Haug, 1993). The food production and textile industries contribute a million dry metric tons of sludge per year, and the pulp and paper industry produces two million dry metric tons of sludge per year (Haug, 1993). Animal wastes are an even bigger source of organic materials because animal production has shifted from small animal feeding operations to large confined animal feeding operations that produce enormous amounts of wastes daily. Proper disposal of these wastes is a concern.

Surface and groundwater contamination as well as a host of other concerns have driven composting research in the direction of converting animal wastes and biosolids to beneficially reusable organic material. Composting is the preferred management practice for most diverted yard waste (Haug, 1993) and is considered for the treatment of many other wastes including biosolids and animal manures. Composted organic waste is stable, free of pathogens and plant seeds, and can be beneficially applied to land (Haug, 1993). Composting also reduces greenhouse gas emissions (Daigle et al., 1989). Unfortunately, less than 3 percent of the 7.7 million dry metric tons of biosolids produced in 1989 were composted. Likewise, a very small percentage of animal manures are composted. However, the passage of the Pollution Prevention Act in 1990 and other federal, state, and local regulations resulted in an increase in composting of animal manures and biosolids.

Composting is the microbial conversion of organic matter in the presence of suitable amounts of air (oxygen) and moisture into a humus-like product (de Bertoldi et al., 1983). Composted organic residuals that meet federally regulated metals limits (40 CFR 503) can be beneficially applied to the land, provided the compost meets federally regulated metals limits (40 CFR 503) and depending on nutrient content, soil characteristics, and other environmental conditions.

Frequently noted benefits of the application of composted animal manures and biosolids along roadsides include improvement of soils through addition of organic matter, nutrients, and beneficial microbes, improved plant growth, erosion control, slope stabilization, and reduction in the use of chemical fertilizers and herbicides (Mitchell, 1997b).

The passage of the ISTEA in 1991 encouraged the use of environmentally safe compost along highway rights-of-way of federally funded projects; therefore, state departments of transportation (DOTs) began in earnest to investigate compost and compost use. In 1997, nineteen state DOTs had specifications for compost, and thirty-four DOTs reported experimental or routine use of compost on roadsides in one or more applications, including soil amendments, mulches for erosion control, and in other applications (Mitchell, 1997b). States have reported satisfactory or better results using compost for such applications when the compost meets specified standards (Mitchell, 1997b). The number of states with compost or compost related specifications had increased to thirty-one by 2000 (Alexander, 2001). Of the thirty-one states specifying compost use, twenty-six specify it for soil amending purposes, eleven for planting backfill mixes, and nine for erosion control.

Texas leads the nation with roughly 220 billion pounds of animal manures produced per year; therefore, disposal of animal manures is a major concern in Texas, especially in areas of the state where animal production operations are located. An estimate of manure production in the year 2000 is presented in Table 1.

Table 1. Manure Production in Texas in 2000

Animal	**Wet Tons (short) of Manure Per Year**
Beef Cattle	86,048,750
Dairy Cattle	7,345,625
Other Cattle	24,907,500
Swine	439,619
Sheep	876,000
Horse	4,927,500
Poultry	2,402,718
SOURCE: Texas A&M University, 2000.	

Texas ranks sixth in the number of dairy cows (Southwest Dairy Center). Erath, Hopkins and Comanche counties rank among the top 100 dairy counties in the nation. Rounding out the top ten dairy producing counties in Texas are El Paso, Archer, Hamilton, Wood, Johnson, Cherokee, and Lamb counties.

The United States Composting Council (USCC) and other public and private organizations have investigated the markets for compost. The intent of these investigations is to improve compost marketability and the economics of composting to encourage agribusiness toward more composting. The USCC and the United States Department of Transportation projected potential demand for compost use on the basis of the typical acreage planted annually by state DOTs. The projections are summarized in Table 2 for the top twenty-one states. The data indicate a potentially significant market for compost and indicate that Texas ranks highest in the potential usage of compost along roadsides.

The purpose of this literature evaluation is twofold: a) identification of the constituents and composition of various types of composted materials including animal manures and municipal wastewater sludge (biosolids) and b), documentation of the application of the composted materials alone and mixed with different soils. Characteristics of composted dairy cattle manure, composted poultry litter, composted feedlot manure, and

Table 2. Estimated and Potential Compost Use for the Twenty-One United States With the Highest Estimated Usage

State DOT	Estimated Current Usage (cu yd)	Estimated Annual Potential Usage (Acre)	Estimated Usage of Compost Applied at 1”/acre (cu yd)
Alabama	0	1,000	134,000
Arkansas	0	1,000	134,000
California	225,000	25,000	3,350,000
Florida	NA	2,000	268,000
Georgia	10,000	2,000	268,000
Iowa	12,000	2,000	268,000
Louisiana	0	2,500	335,000
Minnesota	10,000	3,000	402,000
Mississippi	0	1,500	201,000
Missouri	0	4,000	536,000
Montana	600	1,000	134,000
New Mexico	0	2,000	268,000
New York	NA	400	53,600
Oklahoma	0	2,000	268,000
Pennsylvania	NA	1,000	134,000
Rhode Island	0	1,000	134,000
Texas	100,000	80,000	10,720,000
Utah	8,000	400	53,600
Washington	80,000	400	53,600
Wisconsin	100	750	100,500
Wyoming	NA	4,000	536,000
Total	**445,700**	**136,950**	**18,351,300**

SOURCE: Adapted from USCC and the Composting Council Research and Education Foundation, 2000.

composted biosolids are of primary interest. Published data from research or projects involved with the application of composted materials along highway slopes, medians, and rights-of-way are summarized and discussed. Compost specifications, rates of application, effects of compost amendment on the water holding capacity of amended soils, issues related to measuring water holding capacity of amended soils, and pollutant attenuation in roadside applications also were considered.

The physical and chemical characteristics of compost must satisfy applicable standards and regulations. Identification and quantification of heavy metals in the compost, compost stability, compost maturity, organic matter content, CEC, nutrient content, and pH are of particular concern. A wide variation in compost quality and characteristics appears in the published literature. An abundance of published information on the characteristics and application of untreated animal manures and biosolids was available, but much less information on the characteristics and use of composted animal manures and composted biosolids was identified.

Physical characteristics of compost include but are not limited to stability and maturity, amount of inert materials, bulk density, and particle size distribution. Stability measures indicate the completeness of compost curing. Inadequate curing may inhibit plant growth, lead to excessive leaching of potential pollutants, cause odors, or attract vermin. Typically, stability is measured using the Dewar self-heating test or the Solvita test for carbon dioxide respiration, although there is some debate over which test or combination of tests and indicators provides the best measure of stability (Brinton, 2000).

The maturity assessment begins with a determination of the carbon to nitrogen (C:N) ratio, which must not exceed 25:1. After the initial screening, compost maturity is determined by conducting two tests and comparing the paired results (Brinton, 2000).

The amount of inert materials is an indication of the quantity of debris in the compost. The amount of inert material should be limited to minimize health and safety concerns when handling the material. Particle size distribution is determined through sieving. Particle size distribution affects handling of the compost, the void ratio, and the resulting particle size distribution of the soil compost mixture. Chemical characteristics of compost include pH, moisture content, organic matter content, electrical conductivity, CEC, C:N ratio, heavy metals, and nutrients [including phosphorus (P), potassium (K), and nitrogen (N)]. Higher CEC values indicate more stable compost. Low C:N values indicate stability. The CEC is used as an indicator of the relative ability of a soil to retain nutrients. The pH affects the availability of nutrients, particularly microelements.

The evaluation of available literature provided some published characteristics of compost produced from mixed feedstock, animal manures, and biosolids. Cox et al. (2001) published a study performed at the Washington State University Spillman Farm, and the data included characteristics for compost produced from unspecified animal manures (85 percent), coal ash, food waste, and landscaping waste (Cox et al., 2001). Zaccheo, et al. (2002) provided the characteristics of compost produced from a mixture of yard wastes, municipal solid waste, and biosolids. Zinati et al. (2001) reported characteristics of various composts including compost prepared from 75 percent municipal solid waste (MSW) and 25 percent biosolids and another using 100 percent biosolids. Mays et al. (1973) published characteristics for compost produced from garbage waste and up to 20 percent biosolids. Compost produced from poultry litter varies according to the bird type, number of birds, type and quality of feed, and other parameters. Henry and White (1993) published characteristics for two types of poultry litter. Data for characteristics are summarized in Table 3.

Table 3. Chemical Characteristics of Various Composts.

Parameter	Units	MFSC - 1	MFSC - 2	MFSC - 3	BC	MFSC - 4	PLC - 1	PLC - 2
pH	SU	8.9	7.7	7.1	6.0	NM	6.61	7.46
EC	dS/m	7.0	3.4	10.41	17.58	NM	NM	NM
Org. C	%	29.3	NM	NM	NM	29.43	30.2	29.0
	g/kg	NM	232	341	282	NM	NM	NM
Total N	%	0.92	NM	NM	NM	1.27	2.98	2.46
	g/kg	NM	NM	11.9	47.5	NM	NM	NM
C:N	--	31.9	NM	29.0	6.0	NM	10.2	11.8
P	%	NM	0.64	NM	NM	0.3	0.81	1.15
K	%	NM	NM	NM	NM	0.91	3.4	5.23
Ca	%	NM	7.8	NM	NM	4.87	3.2	3.51
Mg	%	NM	1.4	NM	NM	0.65	0.39	0.55
Na	%	NM	NM	NM	NM	0.66	0.8	1.08

Note: NM , not measured; MFSC , mixed feedstock compost; BC , biosolids compost; PLC , poultry litter compost.

Source: (1) Cox, et al., 2001; (2) Zaccheo,, et al., 2002; (3) Zinati, et al., 2001; (4) Mays, et al., 1973; (5) Henry & White, 1993.

Published Compost Specifications

AASHTO specifications for Compost Berms (MP-9) and Compost Blankets (MP-10) are included in the *2003 AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing* manual (Alexander, 2003). A review of available literature revealed a relative abundance of published standards for compost quality. The published standards were relatively consistent in identified parameters and quantity. A model specification for compost use for soil amendment was published by the USCC (1996). The model specification included requirements for stability and maturity and placed limits on heavy metal content and on biological contaminants. Craul & Switzenbaum (1996) developed a separate specification for compost used in amending soils in transportation projects. The specifications were similar to those of the USCC except for the minimum allowable organic matter, maximum allowable C:N ratio, and requiring stability testing results of no more than 5 mg carbon dioxide per gram or no more than 20 °C of heat rise.

Alexander (2001) summarized current practices of state DOTs. Compost specification data are summarized in Table 4.

Table 4. DOT Compost Specifications

Parameter	Units	50 State Survey[1]	Craul and Switzenbaum[2]	USCC Model[3]
		Typical Range		General Range
pH	SU	5.5 – 8.0	5.5 – 8.5	5.0 – 8.5
Organic Matter	%, dw	35 – 55	40 – 65	30 – 65
Soluble Salts	dS/m	<4	<10	<10
Moisture Content	%, dw	35 – 55	30 – 60	30 – 60
C:N		<10 – 20:1	10:1 – 25:1	Not spec.
Inerts	%, dw	<1	<1	Not spec.
Particle Size	inches	<0.5 – 1	<0.5 – 1	98%<0.75”

NOTE: SU , standard units; dw , dry weight;
SOURCE: (1) Alexander, 2001; (2) Craul and Switzenbaum, 1996; (3) USCC, 1996.

Requirements for preparation of CMT were published by Cole (1997). The CMT was prepared by combining a 1- to 3-in. layer of compost into the top 4- to 6-in. of existing soil. The compost specifications include pH is greater than 6.0, but less than 8.0, a C:N ratio less than 33:1, stable to very stable in accordance with the Solvita Maturity Test, and soluble salts less than 4.0 decisiemens per meter (dS/m).

Changes in Soil Physical and Chemical Properties with Compost Amendment

The effects of amending soils with untreated animal manures, municipal wastewater sludge, municipal solid waste, and other organic wastes have been reported; however, reports on the effects of amending soils with composted animal manures and composted municipal wastewater biosolids are less abundant.

The application of compost to soils changes the chemical and physical properties of the soil. Compost amended soil is more resistant to runoff and erosion. Therefore, compost addition to soil reduces potential pollution of surface water and groundwater via transport of N, P, heavy metals, sediment, and other constituents in runoff. Therefore, a thorough understanding of the benefits and potential limitations associated with compost addition to soil and the effects on the soil compost system is important from a water quality standpoint. Furthermore, certain chemical changes in the soil can have an impact on plant toxicity. For example, composts with a high C:N ratio immobilize N, which may result in N deficiency in plants (Briton, 2000). In addition, organic acids present in compost may contribute to phytotoxicity (Briton, 2000).

Generally, compost increases the pH of acid soils but has little or no effect on the pH of alkaline soils. Soil CEC, which is a measure of the amount of positively charged particles a soil can hold, also increases for compost amended soil as a result of the addition of organic matter (McConnell et al., 1993). The higher CEC may allow the soil to retain more metals.

Khaleel, et al. (1981) summarized changes in soil physical properties caused by the addition of various composted and uncomposted organic wastes to the soils. In general, the effect of organic amendment on physical properties of soil depends on the rate of decomposition of the organic matter and the contribution of organic carbon to the soil. The results of short-term experiments indicate increases in the amount of organic carbon content, whereas the results of long-term studies indicate smaller increases in the organic carbon content. Soil type is also a factor. Higher rates of decomposition were observed in silt loam and lower rates in clay loam.

The addition of organic matter to the soil decreases the bulk density of the soil (Khaleel, et al., 1981; McConnell, et al., 1993). Ortega et al. (1981) reported an increase in total porosity of soils to which organic matter was added. Greater porosity provides more area for gas and water interchange, which is beneficial to plant growth. The decrease in bulk density is attributed to a dilution effect as a result of mixing organic matter with the more dense mineral soil fraction (Mbagwu, 1992). However, Bresson, et al. (2001) contended that structural changes resulted from interactions between the added organic matter and the soil. The change in bulk density appears to be more pronounced in coarse soils than in finely textured soils.

Khaleel et al. (1981) reported that the decrease in bulk density and increase in porosity led to an increase in water holding capacity. Increases in water holding capacity at field capacity and wilting point were indicated for fine-textured as well as coarse-textured soils. However, whether or not the available water increased was inconclusive.

Organic material improves aggregation and stabilizes soils. These changes in the properties of soil improve the initial infiltration rate and the steady-state infiltration rate. However, build-up of sodium and potassium may reduce infiltration rates. A summary of changes in the physical and chemical composition caused by compost addition is summarized in Table 5.

Table 5. Changes in Physical and Chemical Composition with Addition of Composted Organic Material (Adapted from He et al., 1992).

Physical Property	Change	Chemical Property	Change
Total Carbon	Increased	Bulk Density	Decreased
Total Salt	Increased	Porosity	Increased
CEC	Increased	Water holding capacity	Increased
N,P, and S	Conflicting	Aggregation	Increased
pH	Increased		
Ca, Mg, and K	Increased		
Trace metals	Increased		

Moisture Retention

Moisture retention is an important parameter that is difficult to measure in the laboratory and is difficult at best to translate from the laboratory to field conditions. Several methods have been used with some success. The most widely used procedure is the pressure plate method for determination of water retention over a range of pressures from 0.1 bar to 15 bars (Klute, 1986).

The primary benefit of adding organic matter to soil is an increase in the overall water storage capacity of the soil. Huberty (1936) reported that the addition of organic matter to soil increased the storage of water in the soil. However, the application of organic matter appears to increase the field capacity and the permanent wilting point so that the available water capacity, which is the difference between the capacity at the permanent wilting point and field capacity, is not changed. The 0.33 bar value was used as an estimate of field capacity, and the 15 bar value was used to estimate the permanent wilting point (Colman, 1946; Jamison & Kroth, 1958; Bauer & Black, 1992). Diaz-Marcote & Polo (1996) and Mamo, et al. (2000) also reported that compost application increased the water holding capacity at the field capacity and at the permanent wilting point but did not change the available water capacity. A similar tendency was reported by Berdal, et al. (1992), by Fernandez, et al. (1987), by Gupta, et al. (1977), and by Epstein (1974). However, Bouyoucos (1938) reported that the addition of organic matter increased available water in clay as well as in sandy soils.

Huberty (1936) and Jamison and Kroth (1958) observed that fine-textured soils hold more water at field capacity than do coarse-textured soils. However, organic matter influenced available water capacity more than the silt content did. In general, available water capacity increased with silt content and decreased with clay or sand content.

Naeth, et al. (1991) determined the water holding capacity of poultry litter and soil organic matter by using 7-cm tall by 7-cm diameter plastic cylinders, with cotton fabric secured to the bottom of the cylinders with a rubber band. The cylinders were saturated with water for 48 hours and then allowed to drain for 48 hours on a tray of damp sand. The samples were weighed, oven dried at 105 °C for 48 hours, and then reweighed. The water holding capacity was the difference in the weight of the oven dry mass and the drained mass, divided by the oven dried mass. Hernando et al. (1989) used a similar method to determine the water holding capacity of a compost amended soil saturated with water and allowed to drain freely for 24 hours.

Physical and Chemical Changes of Sandy, Clay, and Silty Soils

Reported physical changes to soils include changes in bulk density, water holding capacity, and aggregate stability. Application of compost decreased soil bulk density, increased aggregate stability, and increased water holding capacity for all soil types. Available water capacity was reportedly not affected by additions of organic material. Reported chemical changes to soils include changes in pH, CEC, salts, nutrients, organic matter, and metals content. Compost addition appears to have a varied effect on soil pH and CEC. Soil inorganic N increased with addition of compost, but total N did not change. Researchers also found significantly higher nitrate concentrations in the intermediate to high compost treatments, whereas ammonia nitrogen showed a significant increase at only the highest compost application rate. Mamo, et al. (1999) found that additions of compost significantly affected the leaching of nitrate-N. Compost addition also increased the carbon content of the amended soil and affected the P and K content as well as some heavy metals content. Physical changes published in the literature are summarized in Table 6.

Table 6. Physical Changes for Sand, Clay, and Silty Soils Reported in the Literature

Parameter		Result	Soil Type	Application Rate	Organic Material	Reference
Physical Changes	Bulk Density	Decreased	Sand	NA	Compost	Gupta et al., 1977; Khaleel et al., 1981; Kreft, 1987; Tester, 1990; Mamo et al., 2000.
			Clay	NA	Compost	Aggelides and Londra, 2000
			Silt	NA	Compost	Cox et al., 2001; Aggelides and Londra, 2000; Mays et al., 1973.
	Water Holding Capacity	Increased	Sand	NA	Compost	Hernando et al., 1989; Diaz-Marcote and Polo, 1996.
			Clay	NA	Compost	Aggelides and Londra, 2000
			Silt	NA	Compost	Mays et al., 1973; Epstein et al., 1976; Aggelides and Londra, 2000.
	Aggregate Stability	Increased	Sand	24 - 80 mt/ha	Compost	Hernando et al., 1989; Diaz-Marcote and Polo, 1996; Albiach et al., 2001.
			Clay	NA	Compost	Aggelides and Londra, 2000
			Silt	NA	Compost	Cox et al., 2001; Aggelides and Londra, 2000.

Results reported in the published literature for chemical changes are summarized in Table 7. Results reported for silt soil studies indicated an improvement in water infiltration rates with compost amendment (Cox et al., 2001; Aggelides & Londra, 2000). The increase in water infiltration rates was beneficial because less runoff and erosion were observed.

Table 7. Chemical Changes for Sand, Clay and Silty Soil Reported in the Literature.

Parameter		Result	Soil Type	Application Rate	Organic Material	Reference
Chemical Changes	pH	No Change	Sand	2.50%	Composted Biosolids	Giusquiani et al., 1987.
			Sand	NA	Composted MSW	Cuevas et al., 2000.
			Clay	2.50%	Composted Biosolids	Giusquiani et al., 1987.
		Increased	Sand	NA	Compost	Gollardo & Nogales, 1987; Hernando et al., 1989; Buchanan & Gliessman, 1991; Diaz-Marcote and Polo, 1996.
		Decreased	Sand	NA	Composted Biosolids	Zinati et al., 2001.
	CEC	No Change	Sand	2.50%	Composted Biosolids	Giusquiani et al., 1987; Hernando et al., 1989.
			Clay	2.50%	Composted Biosolids	Giusquiani et al., 1987; Hernando et al., 1989.
		Increased	Sand	20 - 80 mt/ha	Composted MSW	Diaz-Marcote and Polo, 1996; Cuevas et al., 2000; Zinati et al., 2001.
	Carbon Content	Increased	Sand	15-60 mt/ha	Compost	Hernando et al., 1989.
			Sand	24 mt/ha	Composted Biosolids	Albiach et al., 2001.
			Silt	NA	Compost	Mays et al., 1973.
	Available K	Increased	Sand	NA	Compost	Giusquiani et al., 1987; Cuevas et al., 2000.
			Clay	NA	Compost	Giusquiani et al., 1987.
	Available P	No Change	Clay	NA	Compost	Giusquiani et al., 1987.
		Increased	Sand	NA	Compost	Cuevas et al., 2000.
		Decreased	Sand	NA	Compost	Giusquiani et al., 1987.
	Zn, Fe, Cu, Mn	Increased	Sand	NA	Compost	Giusquiani et al., 1987; Cuevas et al., 2000.
			Clay	NA	Compost	Giusquiani et al., 1987.
			Silt	NA	Compost	Mays et al., 1973.

Erosion

Erosion is a naturally occurring process that is exacerbated by new construction and road building. Many state DOTs and the United States Department of Transportation have initiated studies to combat erosion along roadsides. Much of this research focused on the use of compost for soil conditioning, for erosion control, and for added nutrients.

Compost Use as a Soil Conditioner

The addition of compost to soil changes the chemical and physical properties of the soil were reported in Tables 6 and 7. These improvements reduce erosion (Kreft, 1987; Tester, 1990) and increase the water holding capacity of soils (Kreft, 1987). Compost addition also improves drought resistance (USCC, 1996) increases the availability of soil nutrients, increases the beneficial microbial population and microbial activity, and reduces the incidence of soil nematodes and pathogens (Gallardo & Nogales, 1987). Compost addition may aid in the capacity of the soil to bind heavy metals by altering soil chemistry, including pH and CEC (USCC, 1996) and also may lead to increased crop yields (Roe et al., 1993).

McConnell et al. (1993) developed recommendations for the beneficial application of compost as a soil conditioner. The recommendations include the following:

- Apply compost containing a minimum of 50 percent organic matter at a rate of 15 tons per acre (about 0.25 in. thick) to increase organic matter in the soil.
- Apply compost at a rate of 10 to 15 tons per acre to increase water holding capacity by 5 to 10 percent.
- Apply compost at rates of 10 to 20 tons per acre to increase pH of acid soils by 0.5 to 1.0 pH unit (Hernando et al., 1989).
- Apply compost at a rate of 15 tons per acre to increase CEC of sandy soils (Hortensine & Rothwell, 1973).

Compost Use for Erosion Control

Factors affecting runoff are numerous and complex. Soils that are high in silt, low in clay, and low in organic matter tend to erode the most (Wischmeier & Mannering, 1969). Soils that are high in silt become less erodible as the silt fraction decreases. The pH affects the erodibility of silty soils. The permeability of the surface crust decreases as organic matter content, percentage of sand, aggregation index, and bulk density decreases thereby decreasing soil erodibility (Wischmeier and Mannering, 1969).

The Federal Highway Administration and the USEPA joined forces to investigate the use of composted yard trimmings and hydromulch for controlling erosion on highway embankments at a site in Washington, DC. The results indicate that compost treatment outperformed all other treatment in terms of vegetation establishment, decreased runoff, and decreased erosion (USEPA, 1997). Demars, et al. (2001) reported similar success with application of 0.75 in. to 3 in. of mulch on 2:1 slopes (horizontal:vertical). Application of a hydrocompost comprised of three parts composted dairy manure and one part recycled paper mulch resulted in lower soil erosion rates but higher water runoff rates than mat fiber mulch plots. The hydrocompost also provided better seed germination performance (Hamilton Manufacturing, 1999). Block (1999) reported that the use of the compost and woodchip mix reduced erosion.

Alexander (2002) reported that the efficacy of compost used for erosion control applications depends on the characteristics of the compost. In general, compost that is coarse in texture and applied at relatively high application rates is required in areas where the soil has a high erosivity index(a statistical index combining rainfall kinetic energy and intensity). The coarseness of the particles in the compost absorbs the energy of the rain and reduces the flow velocity of runoff. Water runoff properties were improved by compost amendment. Lag time to peak flow at the initiation of a rainfall event was greater for compost amended soils, and the base flow in the interval following a rainfall event was greater for unamended soils (Harrison et al., 1997; Bresson, et al., 2001). Chollack, et al. (2001) reported compost amendment increased soil permeability and water holding capacity thereby delaying and reducing peak runoff flow rate. Compost also aids in the rapid establishment of vegetation (Block, 2000; Alexander, 2002).

Less total solids were lost by erosion in the runoff from mulch and composted biosolids amended soils than from soils mixed with composted poultry litter (Goldstein, 2002). The performance of mulch treatment was better overall for erosion control than the compost treatments. The solids loss was lower and runoff was less for mulch amended soils than for the compost amended soils. Soils amended with composted biosolids delayed surface erosion and decreased sediment runoff (Bresson, et al., 2001; Goldstein, 2002). Nutrient losses were higher for compost amended soils than for the mulch amended soils. Total nitrogen losses were higher from the composted biosolids than from other treatments, and total phosphorus losses were greater for poultry litter than for any other treatment. URS (2000) reported results from an erosion control pilot study, which compared compost amended soils with unamended soils. In general, compost amended soils reduced total sediment loss and reduced the amount of runoff as compared with unamended (bare) soils. Runoff water quality from compost amended soils was generally better than urban runoff water quality.

Alexander (2002) reported specifications for compost use in erosion control. The national specifications for highway use of compost blankets for erosion control are presented in Table 8.

Table 8. Compost Blanket Parameters.

Parameter	Unit	Vegetated	Unvegetated
pH	Std. Units	5 – 8.5	NA
Soluble Salt	dS/m	<5	<5
Moisture Content	% wet weight	30 – 60	30 – 60
Organic Matter	% dry weight	25 – 65	25 – 100
Particle Size	% passing	100% passing 3in., 90% passing 1in., 65% passing ¾in., 75% passing ¼in.	100% passing 3in., 90% passing 1in., 65% passing ¾in., 75% passing ¼in.
Stability	mg CO2/g OM	<8	NA
Physical Content	% dry weight	<1	<1
Chemical Content	mg/kg (ppm)	Ar 41, Cd 39, Cu 1,500, Pb 300, Hg 17, Mb 75, Ni 420, Se 100, Zn 2,800	Ar 41, Cd 39, Cu 1,500, Pb 300, Hg 17, Mb 75, Ni 420, Se 100, Zn 2,800
Biological Content	MPN	Salmonella <3MPN/4 g of TS, Fecal <1,000 MPN/g of TS	Salmonella <3MPN/4 g of TS, Fecal <1,000 MPN/g of TS
NOTE: SU, standard units; ppm, parts per million; MPN, most probable number.			

The recommended application rates for compost, incorporating rainfall and soil erosivity, are summarized in Table 9. Moffitt (2000) recommended applying compost at rates of 0.5 in. to 2 in. deep, with 1 in. being the optimum depth.

Table 9. Compost Blanket Application Rates

Rainfall	Total Precipitation And Erosivity Index	Application Rate for Vegetated Compost	Application Rate for Unvegetated Compost
Low	1 – 25in. 20 – 90	½ - ¾in.	1 – 1 ½in.
Average	26 – 50in. 91 – 200	¾ - 1in.	1 ½ - 2in.
High	≥51in. ≥201	1 – 2in.	2 – 4in.

Potential Problems Associated with Compost Use

The application of composted manures and biosolids is not without problems and potential risks. A primary concern is the availability of quality compost in the quantity required (Mitchell, 1997c). Leaching of N and loss of P and heavy metals through lost sediment-bound constituents in the runoff and through erosion are other concerns.

Most problems associated with compost quality involve the use of immature compost, which can be detrimental to plant growth (Mitchell, 1997c). A single parameter may not be adequate in the assessment of compost maturity and stability. Depending on the feedstock, some stable composts may require more time to break down toxic substances, whereas in other cases some mature compost may have a relatively high respiration rate (Wu et al., 2000). Application of immature compost may result in odor problems and attraction of vermin and disease carrying vectors.

Eghball & Gilley (2001) reported loss of P from a silty clay loam amended with composted and uncomposted beef cattle feedlot manure. Erosion was the main cause of loss of total and particulate P that was attached to sediments. Loss of P from compost amended soils and soil to which manure was added was less than the loss of P from soil to which chemical fertilizers were added. But loss of P may still be problematic, depending on the application rates and characteristics of the soil. Eghball and Gilley (1999) reported increased concentrations of dissolved P, bioavailable P, and ammonia nitrogen in runoff from soils where compost was applied but not incorporated into the soil. The electrical conductivity of the runoff from the compost amended soils increased, indicating greater salt leaching. Therefore, the risk of salinization in arid and semiarid conditions is high. However, compost with high salt levels performs well in areas with sufficient rainfall (Mitchell, 1997a).

Heavy metals, if present, and N leach from compost, but the amount of leaching decreases after a period of time (Benson & Othman, 1993). Christensen and Nielsen (1983), Christensen (1983, 1984), Christensen & Tjell (1984), Diaz et al. (1977), Diaz & Trezek (1979), and de Haan (1979) observed increased amounts of carbonaceous oxygen demand and leaching of N, inorganic ions, and heavy metals from compost amended soils. Immature compost contains ammonia nitrogen and acid-hydrolyzable nitrogen, which could lead to considerable leaching of ammonia-N and other forms of N (Pare et al, 1998).

Epstein et al. (1976) reported an increase in Redox potential and higher levels of carbon dioxide concentrations in compost amended soils. Phytotoxic constituents such as hydrogen sulfide, methane, and ethylene might be created under extremely reduced conditions (e.g.,
- 150 to - 250 mv). The reduced soil conditions and poor soil aeration could adversely affect plant growth and root development.

Summary

The pH of most compost is in the neutral range, organic matter content in the 30 to 60 percent range, moisture content in the 30 to 50 percent range, and higher values of N, P, K, and salts than in typical agricultural soils. Some composts typically have higher levels of trace metals, especially copper, zinc, and lead, which can cause accumulation problems in soils with repeated applications (He et al., 1992).

The addition of compost to soil changes the chemical and physical properties of the soil. In general, compost addition improves soil structure by reducing the bulk density, increasing the permeability, and increasing aggregate stability. These improvements reduce erosion (Kreft, 1987; Tester, 1990) and increase the water holding capacity of soils (Kreft, 1987). Compost addition improves drought resistance (USCC, 1996), increases availability of soil nutrients, and increases beneficial microbial populations and microbial activity (Khaleel et al., 1981). Compost amendment also reduces the incidence of soil nematodes and pathogens (Gallardo & Nogales, 1987), increases crop yields (Roe et al., 1993), and aids in the capacity of the soil to bind heavy metals by altering soil chemistry, including pH and CEC (USCC, 1996).

Compost enhances turf establishment, reduces erosion, reduces runoff, and reduces the need for chemical fertilizers and herbicides when applied at rates of 0.5 in. to 2 in. and tilled to a depth of 5 in. to 7 in. Potential problems with compost use include poor compost quality, insufficient compost availability, nutrient loss through erosion and leaching, accumulation of heavy metals, and the potential for introduction of high salt levels during initial compost amendment.

EXPERIMENTAL APPROACH

The experimental approach was developed to meet the research objectives for this project. This section outlines procedures used for materials acquisition, handling, sampling, and storage as well as laboratory procedures and apparatus used in the first-flush and extended leachate water quality studies and the erosion control studies.

A Quality Assurance Project Plan (QAPP) was developed for this project in accordance with the requirements outlined in the *USEPA Guidance for Quality Assurance Project Plans (QA/G-5)* (EPA, 1998). The QAPP provided a formal pre-project planning document to ensure project management systems, and data quality assurance/ quality control (QA/QC) measures were in place for the project.

TxDOT Specification Item 1058, Compost, provided the quality criteria for the compost used in this project. The specification provides the following general requirements:

1. The compost must be produced by aerobic decomposition.
2. Compost must not contain any visible refuse or physical contaminants.
3. Compost must not contain any material toxic to plant growth.
4. Compost must not contain over 5 percent sand, silt, clay, or rock material.
5. Compost must meet all USEPA Code of Federal Regulations, Title 40, Part 503 Standards for Class A biosolids.
6. Compost must meet all requirements contained in the TCEQ health and safety regulations as defined in the Texas Administrative Code (TAC), Chapter 332.
7. Compost must meet the time and temperature standards in TAC Chapter 332, Subchapter B, Part 23.
8. Compost must be Seal of Testing Assurance Certified.

Specification Item 161 which has been proposed to replace 1058 requires specific criteria shown in Table 10. The test method refers to the procedures published by the United States Composting Council, Test Methods for the Examination of Composting and Compost (TMECC).

Table 10. TxDOT Specification Item 161 Requirements.

Parameter	Range	Test Method
Organic Matter Content	25% - 65%	TMECC 05.07-A
Particle Size	100% passing 5/8in., 70% greater than 3/8in.	TMECC 02.02-B
Soluble Salts	5.0 max dS/m (10.0 dS/m for compost used in CMT)	TMECC 04.10-A
Fecal Coliform	<100 MPN/g	TMECC 07.01-B
pH	5.5 – 8.5	TMECC 04.11-B
Stability	± 8	TMECC 05.08-B
Maturity	>80%	TMECC 05.05-A

Producers who supply compost for use in TxDOT projects must provide certification that the compost meets the TxDOT specifications prior to delivery of the compost to the job site. Compost producers who supplied compost for use in this research project(with the exception of biosolids compost) were required to provide certification that their compost met TxDOT specifications, because the results of this project could affect the use of compost amended soils along highway rights-of-way. The biosolids compost used in this research was prepared under stringent QA/QC in order to meet federal regulations governing Class A biosolids for sale or distribution to the public as defined in the CFR, Part 503 Sludge Regulations.

Materials Acquisition and Storage

Four types of compost were obtained for the project: dairy manure compost, poultry litter compost, feedlot manure compost, and biosolids compost. The dairy manure compost was obtained from a supplier in Stephenville, Texas. The poultry litter compost originated in Gonzales, Texas, and the feedlot manure compost originated in Lubbock, Texas. The biosolids compost, Dillo Dirt, was produced by the City of Austin. The compost was stored at 4 ºC for the duration of the project.

Local suppliers furnished the wood chips, 0.125 in. to 0.25 in. diameter pea gravel, and 0.5 in. to 1.5 in. gravel, the sandy clay loam, and the sand. The wood chips were partially composted and were less than or equal to 3 in. in length with 100 percent passing a 2-in. screen and less than 10 percent passing a 1-in. screen. The wood chips, gravel, clay loam, and sand was stockpiled outside the laboratory and covered with tarps. Maccaferri Gabions, Inc., Austin, Texas, donated the MX140 (Type 1) filter fabric used in the leachate and erosion control studies.

Highway runoff used in the first-flush leachate studies was collected from upstream of the stormwater inlet on Mopac Expressway and 35th Street in Austin, Texas. Deionized water used in the first-flush and extended leachate studies was produced in the laboratory. City of Austin tap water was used in the erosion control studies.

Preparation of Soil and Compost Mixtures

Compost manufactured topsoil was prepared by mixing one part compost with three parts soil on a volume basis. Four CMT mixtures were prepared using each of the four compost types mixed with clay loam, and another four CMT mixtures were prepared using each of the compost types mixed with sand. Erosion control compost was prepared by blending one part wood chips with one part compost on a volume basis. A total of four ECC mixtures were prepared using each of the four compost types mixed with wood chips. The various combinations are summarized in Table 11.

Table 11. Summary of CMT and ECC Mixtures

	CMT*		**ECC****
Compost Type	**Clay**	**Sand**	**Wood Chips**
Composted Dairy Cattle Manure	X	X	X
Composted Feedlot Manure	X	X	X
Composted Poultry Litter	X	X	X
Composted Biosolids	X	X	X

* Compost manufactured topsoil contains one part compost and three parts soil on a volume basis.

** Erosion control compost contains one part wood chips and one part compost on a volume basis.

The CMT and ECC mixtures used for the first-flush column study were prepared in two batches to minimize variation between samples in each set. Batching was necessary and unavoidable because of the limited refrigerated storage space. The first batch of CMT and ECC was used for the deionized water runs, and the second batch was used in the highway runoff runs. The samples were stored at 4 ºC in labeled sealable plastic bags for use as needed. The CMT and ECC that were used for the extended column study were prepared in small individual batches and placed directly in the testing apparatus. The CMT and ECC mixtures used in the erosion control studies were prepared in large batches using a motorized concrete mixer for uniform mixing and were placed directly in the erosion control testing apparatus.

Sampling of Raw Materials and Mixtures

All four types of compost were sampled to verify adherence to the TxDOT Specification 161 Compost and to establish baseline characteristic data. The composted dairy manure and composted poultry litter were delivered by the truckload transferred via wheelbarrow to separate containers and stored at 4 ºC. Fifteen grab samples were collected from each container of compost. The grab samples were collected from each container along a grid pattern, and then each set of grab samples was thoroughly mixed to form a composite sample. Three composite samples were stored in sealable plastic bags, labeled, and placed on ice packs in a cooler for shipment to a laboratory. A slightly different procedure was followed in sampling the composted biosolids and composted feedlot manure because these composts were delivered in 50-lb.bags. Grab samples were collected from 10 percent of the total number of bags of compost received for each material. The samples were collected from bags located in different positions on the pallet. The grab samples were then thoroughly mixed to form a single composite sample. The procedure was repeated to obtain three composite samples. The composite samples were then placed in sealable plastic bags, labeled, and placed in a cooler.

Samples of the CMT and ECC mixtures also were collected and tested to establish baseline characteristics. Samples were collected from each soil/compost batch prior to refrigeration. Because the mixtures were already thoroughly blended, sampling consisted of placing a portion of the mixture in a sealable plastic bag, labeling the bag, and placing the bag on ice packs in a cooler for shipment to the laboratory.

The sand and clay loam samples were collected following a similar procedure. Fifteen grab samples were collected from each bulk soil pile across a grid. The grab samples were thoroughly mixed to form a composite sample. The composite sample was then placed in a sealable plastic bag and labeled.

Analysis of Raw Materials and Soil/Compost Mixtures

The pH, stability, maturity, organic matter content, fecal coliforms, metals, soluble salts, and particle size distribution were determined for each compost type to verify compliance with the TxDOT specifications. All tests for compliance with TxDOT specifications were conducted in accordance with the United States Composting Council's TMECC and were performed by the Soil Control Laboratory, Watsonville, California. A summary of the testing performed for compliance with TxDOT specifications is presented in Table 12.

The Soil Control Laboratory also tested the compost for primary and secondary nutrients and trace elements in accordance with standard TMECC methodologies. Nitrate nitrogen, ammonia nitrogen, and total nitrogen were determined in accordance with TMECC Methods 04.02-B through 04.02-D, respectively. Phosphorus and potassium were determined by Inductively Coupled Plasma Atomic Emission Spectroscopy per TMECC Methods 04.03-A and 04.04-A. Other secondary and trace nutrients including calcium, magnesium, sulfate, manganese, boron, sodium, and chloride were determined using TMECC Method 04.05. Percentage of organic carbon, percentage moisture, and ash content were also determined via respective TMECC methodologies.

Table 12. Laboratory Analysis Performed to Characterize Compost

Parameter	Method	Measured Value
Phytotoxicity	TMECC 05.05-A	Seedling emergence and vigor
Respiration	TMECC 05.05-B	Carbon dioxide evolution
Heavy Metals	TMECC 04.06	As, Be, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Se, Zn
Salts	TMECC 04.08-A	Conductivity / resistivity
Pathogens	SM 9221E	Fecal coliform
Particle Size Distribution	TMECC 02.02-B	Particle size
pH	TMECC 04.11-A	
Organic Matter	TMECC 05.07-A	

Select physical, chemical, and mineralogical characteristics of each soil were determined by Texas A&M University System Soil Testing Laboratory, College Station, Texas. Soil pH, nitrate nitrogen, potassium, phosphorus, calcium, magnesium, sodium, salinity, sulfur, organic matter, and particle size distribution were determined using standard procedures for methods of soil analysis (Klute, 1986). Soil heavy metal content including arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), and zinc (Zn) were determined using standard procedures for methods of soil analysis (Topp, 1993). Heavy metal concentrations were determined by University of Guelph Laboratory Services, Ontario, Canada.

Moisture retention curves were obtained for each CMT mixture and for both soils using the pressure plate apparatus (Topp, 1993). The analyses were performed by University of Guelph Laboratory Services. Prior to analysis, the samples were oven dried at 35 ºC and mixed by hand to obtain representative subsamples. The oven dried material was placed in porous cheesecloth and artificially packed to a bulk density of 1.2 to 1.8 g/cm^3 in an aluminum core. Bulk density was calculated. The core along with the ceramic pressure plates was saturated for 48 hours in distilled water. The samples were analyzed by applying air pressure at 0.1, 0.3, 1, 3, and 15 bars. The gravimetric percentage soil moisture was determined at each pressure as the mass of the moist soil divided by the mass of the oven dried soil.

Testing Apparatus

First-Flush and Extended Column Studies

The first-flush and extended leachate studies were conducted using a testing apparatus consisting of sixteen columns, arranged in two rows of eight columns each, a water spray apparatus and manifold support structure, and a pumping system consisting of a dry pit pump, reservoir, suction piping, discharge piping, valves, gauges, and other appurtenances. The overall experimental setup is illustrated in Figure 1.

The sixteen columns were fabricated from 0.125-in. thick, 8-in. diameter by 10-ft long clear cast acrylic tubing. The tubing was cut into 12-in. lengths to form the sixteen columns. Each column was attached to a 1-in. thick by 7.75-in. diameter clear acrylic base with a 0.375-in. diameter hole drilled in the center of each base. Each base was machined to form a bevel to direct any liquid towards the center of the base and solvent welded into the inside of a column and sealed with silicone. A piece of clear acrylic tubing 0.375-in. outside diameter by 0.25-in. inside diameter by 2-in. was attached to the hole in each base and set flush with the inside of the base. A short length of clear plastic tubing 0.375-in. outside diameter by 0.25-in. inside diameter was then connected to the cast acrylic tubing extending from the base of the column to a sample collection jar. The completed columns are illustrated in Figure 2.

A long wooden table supported two rows of eight columns each. The table top was predrilled using 0.5-in. diameter holes to provide space for the effluent tubing. The sample collection jars were arranged in two rows beneath the table. The final experimental setup is illustrated in Figure 2.

Figure 1. Overall experimental setup.

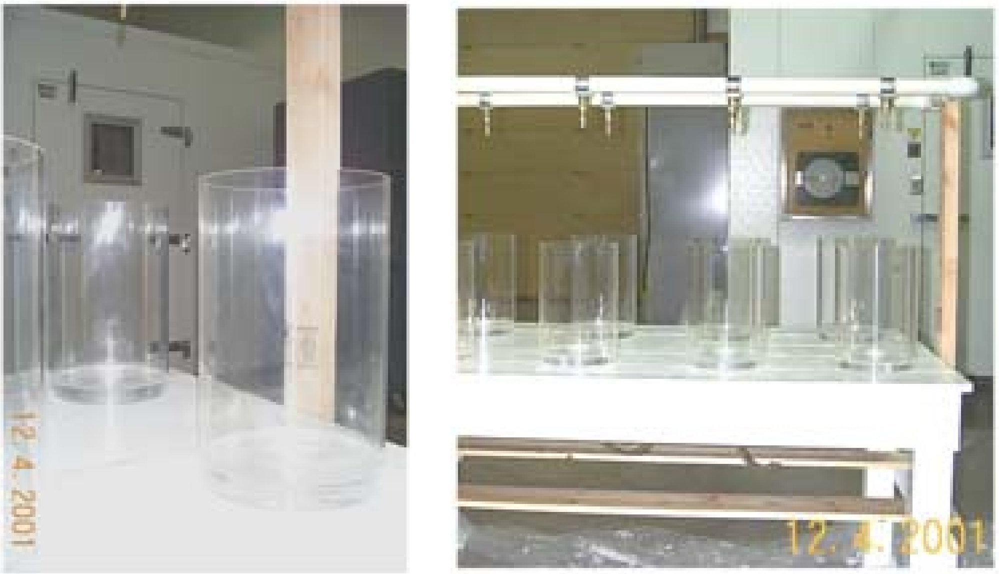


Figure 2. Columns and final experimental setup.

A header pipe was constructed to provide a controlled application of deionized water and highway runoff to each column. The header pipe was constructed from 10-ft long, 1.25-in. diameter schedule 80 polyvinyl chloride (PVC) pipe. Each 10-ft length was precision drilled with eight 0.3125-in. diameter holes starting at 7.5-in. from the end and thereafter every 15-in. The layout and spacing of the header manifold is illustrated in Figure 3.

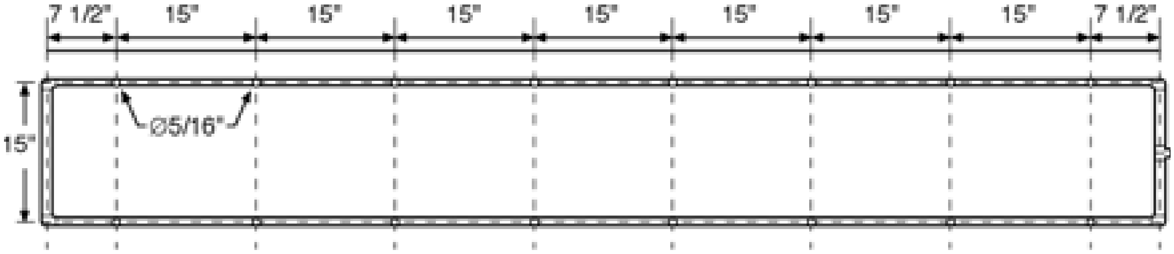


Figure 3. Schematic of header manifold.

Sixteen brass, split eyelet connectors with 0.5-in. NPT female threads were used to attach the nozzles to the manifold. Each nozzle was attached to the eyelet connector via a tip retainer and brass adapter with 0.125-in. NPT male threads. The brass, full jet nozzles were chosen to provide a cone-shaped spray pattern of medium- to large-sized drops. Each nozzle had a capacity of 0.20 gallons per minute (gpm) at 10-lb. per square inch (psi) back pressure. Two Cole Parmer pressure gauges Model EEW-68004-01, 2.5-in. diameter, 0.25-in. NPT(M) with a pressure range of 0 to15 psi were installed at either end of the header manifold to monitor the back pressure in the pipe. The eyelet connectors, retainers, adapters, and Model G2 nozzles were purchased from Spraying Systems Company, Wheaton, Illinois. The assembled nozzles are shown below in Figure 4. A wooden frame was built to support the header pipe at a design height of 12-in. above the center of each column. The design height of 12-in. was determined through beta testing of a full-scale model with a single nozzle on an 18-in. PVC pipe. The design height minimized overspray and provided a uniform application of medium to fine droplets across the media surface without excessively impacting the inside vertical walls of the columns.

Figure 4. Assembled nozzle.

Figure 5. Pump, reservoir, piping.

Water was supplied to the header pipe via a dry pit pump that drew suction from a 55-gallon polyethylene tank. The tank was fitted with two Hayward Industrial Products bulkhead fittings. A 1.25-in. fitting was used to connect to the pump suction piping, and a 1-in. fitting was used to connect a drain line for the reservoir through a 1-in. in-line PVC ball valve. A Goulds Series PO/1SN, 0.5-hp centrifugal pump was mounted adjacent to the reservoir. The 1.25-in. pump suction was connected to the 1.25-in. bulkhead fitting via a series of PVC couplings and adapters and a short length of solid wall PVC pipe. The pump discharged through a 1-in. diameter, schedule 80 PVC pipe, a pressure relief valve, solenoid valve and pressure regulating valve and into the header manifold. A portion of the discharge piping was fabricated from 1-in. PVC and 0.75-in. flexible pressure pipe to accommodate the valves, which varied in size. The installed pump, reservoir, and piping are shown in Figure 5.

The leachate test columns contained 3 in. of washed gravel (0.5 to 1.5-in. diameter), 3 in. of washed pea gravel (0.125- to 0.5-in diameter), and 3-in. of the soil, CMT, or ECC. A 50-mil filter fabric (MX140 manufactured by Maccaferri Gabions, Inc.) separated the soil, CMT, or ECC from the pea gravel. A typical column loaded with gravel and filter fabric is shown in Figure 6.

Figure 6. Typical test and column.

Erosion Control Channel Studies

The erosion control testing apparatus consisted of a galvanized steel channel, which was supported by a plywood substructure, and a spray header. The pumping system was the same as that used for the column leachate studies. The overall experimental setup is illustrated in Figure 7.

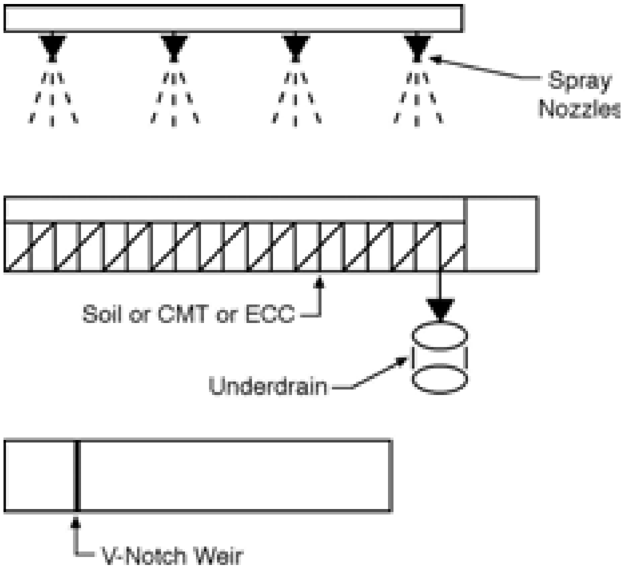


Figure 7. Overall experimental setup schematic.

The erosion control channel was fabricated from 24-gauge galvanized sheet metal soldered together to form the 9 ft long by 3 ft wide by 6 in. deep channel with an integral weir plate. The support structure included one, 0.75-in. thick plywood sheet with 2-in. by 6-in. and 2-in. by 4-in. boards used to support the channel sides and to provide cross bracing below the channel. A 1-in. diameter steel rod was used to support and lift the channel at various slopes with the help of a crane and Tuflex Roundslings. The crane was an adjustable height and span steel crane with a CM Series 622 hand chain hoist and 2- ton beam clamp. The assembled channel and crane are pictured in Figure 8.

Figure 8. Erosion control studies experimental setup.

The weir plate separated the erosion control channel, which measured 8 ft long by 3 ft wide by 6 in. deep and contained the soil, CMT or ECC, from the effluent launder measuring 1 ft long by 3 ft wide by 6 in. deep. Water that percolated through the soil was collected in an underdrain system that consisted of six inlets feeding a single manifold underdrain collection header. The six inlets were 0.75-in diameter holes drilled through the bottom of the sheet metal. A short length of clear plastic tubing 0.375-in outside diameter by 0.25-in inside diameter was inserted in each hole and sealed with silicone to provide a watertight inlet. Each piece of tubing was connected to a 1-in. diameter PVC Tee using a tubing-to-PVC adaptor. The six inlets were connected using 1-in. diameter Schedule 80 PVC to form a manifold. The underdrain collection manifold was installed with a positive slope to direct the water to the edge of the channel for collection. The underdrain manifold is illustrated in Figures 9 and 10.

Figure 9. Underdrain inlet.

Figure 10. Underdrain collection manifold.

The effluent launder captured runoff from the soil. Thirty-three, 0.25-in. diameter holes were drilled through the bottom of the sheet metal. A 4-ft length of clear extruded acrylic, 1.25-in. square tubing was used to collect the runoff from each inlet port. A in. slit (0.375 in.) was cut through one side of the tubing and the tubing was fastened to the bottom of the channel using adjustable pipe straps. The connection between the channel and the tubing was sealed with silicone. The tubing was installed with a positive slope to direct the captured runoff to the flow measurement channel for collection and measurement. The effluent launder assembly is pictured in Figure 11.

Figure 11. Effluent launder assembly.

Runoff flow rate was measured using a 22.5 ° V-notch weir installed in a flow measurement channel. The flow measurement channel was constructed from 0.5-in. thick plywood with 2-in. by 4-in. wood bracing. The interior and exterior surfaces of the channel were coated with paint to provide a watertight surface. Silicone was used to seal the edges, corners, and the weir plate. The flow measurement channel was 1 ft wide by 6 ft long by 1.5 ft deep. The 22.5 ° V-notch weir plate was installed one foot from the end of the channel. The inlet flow line elevation was set at 7.125 in. above the bottom of the channel. The V-notch was installed at 5-in. from the bottom of the channel. The channel outlet was positioned at 1-in. above the bottom of the channel. An ISCO 3230 Bubbler Flow Meter was used to monitor and record the rate of flow through the channel. The bubbler flow meter uses a small diameter bubbler tube, a transducer and algorithms to measure the flow in the channel. The bubbler flow meter supplies a constant flow of pressurized air through the bubbler tube anchored in the flow stream. In this case, the bubbler tube was installed 12-in. upstream of the weir plate and 3-in. above the bottom of the channel. The air flow rate through the bubbler tube was adjusted to release one bubble per second. When flow is introduced to the channel, the transducer in the flow meter measures the pressure required to force bubbles from the end of the tube. The pressure measured by the transducer is converted into a flow rate by the flow meter via pre-programmed algorithms. The flow measurement channel is shown in Figure 12.

Figure 12. Flow measurement channel.

A header pipe was constructed to control the application of tap water to the erosion control channel for each run. The header pipe was constructed from 10-ft long, 1.25-in. diameter schedule 80 PVC pipe. The 10-ft length was precision drilled with four 0.3125-in. diameter holes starting at 2-ft from the end and thereafter every 2-ft. Four brass, split eyelet connectors with ⅛-inch NPT female threads were used to attach the nozzle assembly to the manifold. Each nozzle assembly consisted of a brass, 0.125-in., Model GG-SQ, 4.8 ft^2 spray nozzle and a brass, 0.125-in., Model AB-10 spring-loaded, ball type check valve. The brass, square jet nozzles were chosen to provide a square-shaped spray pattern of medium to large-sized drops. Manufacturer's specifications for the nozzle indicated each nozzle had a capacity of 0.34 gpm at 5 psi back pressure to 0.48 gpm at 10 psi back pressure. The eyelet connectors, Model AB-10 ball type check valves, and Model GG-SQ nozzles were purchased from Spraying Systems Company, Wheaton, Illinois. The nozzle assembly is shown in Figure 13.

Figure 13. Erosion control study nozzle assembly.

A PVC frame was built to support the header pipe. The height of the support framework was designed to position the nozzles above the channel to maximize spray coverage, minimize overlap, and minimize overspray of the channel. The final design height of the nozzles was determined through beta testing of a full-scale model and header. The completed header and support frame is illustrated in Figure 14.

Figure 14. PVC support structure for header pipe.

Water was supplied to the header pipe for the erosion control studies via a dry pit pump that drew suction from a 55-gallon polyethylene tank. The pump and reservoir assembly used for the erosion control studies was the same as that used for the leachate column studies (Figure 6) except for a change in the configuration of the discharge piping. The pump discharged through a 1-in. diameter, schedule 80 PVC pipe, a solenoid valve, and a pressure regulating valve. The pump discharge pressure was monitored via one Cole Parmer pressure gauge Model EEW-68004-01, 2.5-in. diameter, 0.25-in. NPT(M) with a pressure range of 0 to 15 psi. A portion of the discharge piping was fabricated from 1-inch PVC and 0.75-in. flexible pressure pipe to accommodate the valves, which varied in size.

The pump, pump discharge piping, and nozzle header assembly were calibrated to determine the amount of simulated rainfall delivered to an empty erosion control channel during 1 minute of operation. The water was collected and the volume was measured in order to determine the flow rate through the nozzles for 1 minute. The procedure was repeated three times in order to calculate an average flow through each nozzle. The calibration procedure indicated each nozzle delivered 0.38 gallons per minute and that the header manifold delivered 0.00275 in. per second. Results from the calibration runs were used to simulate a 2-year, 3-hour storm event hyetograph with a total cumulative rainfall of 2.64 in. The simulated rainfall event hyetograph is included as Figure 15. The pump was cycled on and off in intervals according to the values in Table 13 to simulate the 2-year, 3-hour storm hyetograph shown in Figure 15. Table 13 is included on the following page. The runoff collected from the erosion control channel during each run was directed via the effluent launder to the flow measurement channel equipped with a bubbler tube. Rate of flow measurements were logged by the flow meter every 2 minutes. Data from the flow meter were downloaded into an Excel spreadsheet for graphing and analysis.

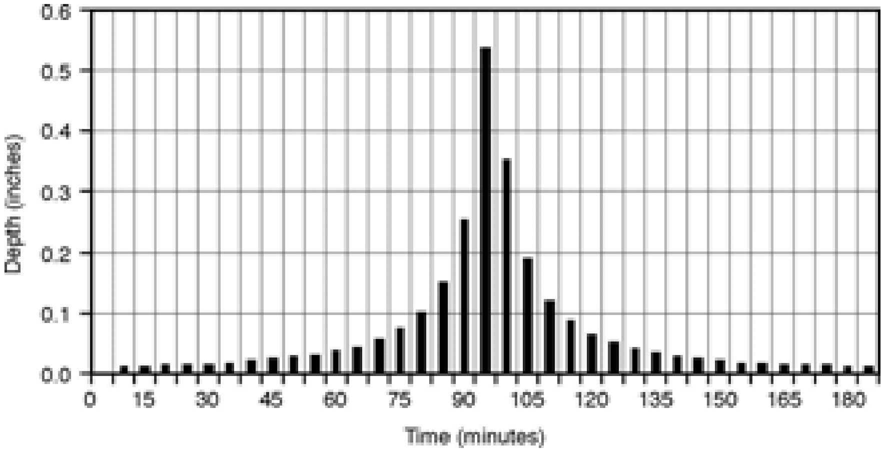


Figure 15. Simulated 2-year, 3-hour storm hyetograph.

Table 13 Simulated 2-Year, 3-Hour Design Storm Hyetograph

Interval	Inches Per Interval	Pump Run Time	Cumulative Run Time (sec)		Cumulative Run Time (min)	
(min)	(inch)	(sec)	Pump Start	Pump Stop	Pump Start	Pump Stop
0	0	0				
5	0.013	5	0	5	0 m 0 s	0 m 05 s
10	0.014	5	35	40	0 m 35 s	0 m 40 s
15	0.015	5	70	76	1 m 10 s	1 m 15 s
20	0.017	6	106	112	1 m 45 s	1 m 51 s
25	0.018	7	142	148	2 m 21 s	2 m 27 s
30	0.020	7	178	186	2 m 57 s	3 m 05 s
35	0.023	8	216	224	3 m 35 s	3 m 43 s
40	0.025	9	254	263	4 m 13 s	4 m 22 s
45	0.029	11	293	304	4 m 52 s	5 m 03 s
50	0.034	12	334	346	5 m 33 s	5 m 45 s
55	0.040	15	376	391	6 m 15 s	6 m 30 s
60	0/048	17	421	438	7 m	7 m 17 s
65	0.059	21	468	489	7 m 47 s	8 m 08 s
70	0.076	28	519	547	8 m 38 s	9 m 06 s
75	0.104	38	577	615	9 m 36 s	10 m 14 s
80	0.153	56	645	701	10 m 44 s	11 m 40 s
85	0.254	92	731	823	12 m 10 s	13 m 42 s
90	0.540	197	853	1050	14 m 12 s	17 m 29 s
95	0.356	130	1,080	1,206	17 m 59 s	20 m 08 s
100	0.193	70	1,239	1,309	20 m 38 s	21 m 48 s
105	0.124	45	1,339	1,384	22 m 18 s	23 m 03 s
110	0.088	32	1,414	1,447	23 m 33 s	24 m 06 s
115	0.067	24	1,477	1,501	24 m 36 s	25 m
120	0.053	19	1,531	1,550	25 m 30 s	25 m 49 s
125	0.043	16	1,580	1,596	26 m 19 s	26 m 35 s
130	0.036	13	1,626	1,639	27 m 05 s	27 m 18 s
135	0.031	11	1,669	1,680	27 m 48 s	27 m 59 s
140	0.027	10	1,710	1,720	28 m 29 s	28 m 39 s
145	0.024	9	1,750	1,759	29 m 09 s	29 m 18 s
150	0.021	8	1,789	1,796	29 m 48 s	29 m 55 s
155	0.019	7	1,826	1,833	30 m 25 s	30 m 32 s
160	0.017	6	1,863	1,870	31 m 02 s	31 m 09 s
165	0.016	6	1,900	1,905	31 m 39 s	31 m 44 s
170	0.015	5	1,935	1,941	32 m 14 s	32 m 20 s
175	0.014	5	1,971	1,976	32 m 50 s	32 m 55 s
180	0.013	5	2,006	2,011	33 m 25 s	33 m 30 s
SUM	**2.64**					

Experimental Procedure

First-flush column studies

The soil, CMT, and ECC samples were prepared in two batches and stored at 4 ºC until the columns were prepared and ready for the first-flush leachate studies. The large diameter gravel and pea gravel were washed with deionized water preceding the deionized water runs and with tap water preceding the highway runoff runs. The gravel was allowed to drain after washing. The gravel was then placed in layers into the columns. A layer of filter fabric was then laid on top of the pea gravel. The soil, CMT, and ECC samples were removed from the refrigerator and lightly packed into the columns. The samples used for each run are summarized in Table 14.

Table 14. Summary of First-Flush Leachate Test Samples and Runs.

Compost Type	No. of Runs	CMT*		ECC**
		Sand	Clay	
Composted Dairy Cattle Manure	3	X	X	X
Composted Feedlot Manure	3	X	X	X
Composted Poultry Litter	3	X	X	X
Composted Biosolids	3	X	X	X

* CMT contains one part compost and three parts soil on a volume basis.
** ECC contains one part wood chips and one part compost on a volume basis.

Two controls and one blank were included in each run. The controls were 3 in. of sand and 3 in. of sandy clay loam (clay). The blank consisted of a column with 3 in. of washed gravel, 3 in. of washed pea gravel, and the geotextile fabric.

After the columns were packed as described above, deionized water or highway runoff was applied. Originally, 2.64 in. of total rainfall was to be applied to each column to simulate a 2-year, 3-hour storm event. The total volume of leachate obtained from each column was not sufficient for the full range of water quality analyses desired when 2.64 in. of simulated rainfall was applied in the first-flush leachate studies. The volume of water needed for the analyses was approximately 0.8 gallons per column, equivalent to approximately 3.45 in. of simulated rainfall. The 3.45 in. of simulated rainfall is slightly less than the ~ 3.6 in. of rainfall produced by a 2-year, 12-hour storm. The 2-year, 24-hour storm produces 4.1 in. of rainfall. The nozzles applied water at a rate of 0.2 gallons per minute, on average. The pump was operated for 30 seconds followed by 1 minute of rest for ten cycles to achieve the required application volume without overloading the columns.

Leachate was collected from the columns after the simulated rainfall stopped until no more water visibly drained from the columns. The collected leachate from each column was placed in five sample bottles for analysis, as summarized in Table 15.

Table 15. Summary of Sample Bottles and Analyses.

Sample Volume (ml)	Analysis	Preservative
1,000	Total suspended solids (TSS), total dissolved solids (TDS)	Unpreserved
500	Nitrogen, Phosphorus	Sulfuric acid
500	Metals	Nitric acid
100	Fecal Coliform	Sodium Thiosulfate
100	Fecal Enterococci	Sodium Thiosulfate

The sample bottles were immediately placed in a cooler with ice for temporary storage and transport to the Lower Colorado River Authority (LCRA) Environmental Laboratory, Austin, Texas. A summary of the analyses performed by the LCRA is included in Table 16. All analyses performed by the LCRA Environmental Laboratory were done in strict accordance with the QA/QC measures established in the QAPP.

Table 16. Summary of Analyses Performed by LCRA.

Parameter	Method	Parameter	Method
METALS			
Copper	EPA 200.7	Zinc	EPA E200.7
Lead	EPA 200.7		
BACTERIOLOGICAL			
Fecal Coliform	SM 9222D	Fecal Enterococci	ASTM D6503-99
NITROGEN			
Nitrate-N	EPA 300	Nitrite-N	EPA 300
Ammonia-N	EPA 350.1	TKN	EPA 351.2
SOLIDS ANALYSIS			
TDS	EPA 160.1	TSS	EPA 160.2

Once the first-flush leachate samples were collected from each column and delivered to the laboratory for analysis, the columns were emptied of all materials, washed with Alconox, rinsed with deionized water, and allowed to air dry. Alconox is a biodegradable, odorless, colorless, and mild detergent that leaves no residue after rinsing. The clean and dry columns were then reloaded with washed gravel and topped with a new piece of filter fabric. The next set of CMT and ECC samples were removed from the 4 ºC refrigerator and lightly packed into the columns ready for the next first-flush column study run. The entire procedure was repeated three times using deionized water and three times using highway runoff.

Extended Column Studies

The columns were washed with Alconox, rinsed with deionized water, and allowed to air dry. The clean, dry columns were loaded with 3 in. of large diameter gravel and pea gravel that had been washed and drained. A new filter fabric was placed over the pea gravel. The CMT and ECC test samples prepared for the extended column studies were placed directly in the prepared columns. Once assembled, the columns were used throughout the extended column studies without intermediate cleaning and reloading. The extended column studies test samples are summarized in Table 17.

Table 17. Summary of Extended Column Studies Test Samples.

Compost Type	CMT*		ECC**
	Sand	Clay	
Composted Dairy Cattle Manure	X	X	X
Composted Feedlot Manure	X	X	X
Composted Poultry Litter	X	X	X
Composted Biosolids	X	X	X

* CMT contains one part compost and three parts soil on a volume basis.
** ECC contains one part wood chips and one part compost on a volume basis.

The extended column runs also included two controls and one blank. The soil controls were 3 in. of sand and 3 in. of clay. The blank consisted of a column loaded with 3 in. of washed gravel, 3 in. of washed pea gravel, and the geotextile fabric.

Each run of the extended column studies consisted of applying a volume of deionized water to each column to simulate rainfall that would occur in 1.5 months in Austin, TX. After applying the water, the columns were allowed to drain until no more water visibly drained from the columns. The collected leachate was placed in five sample bottles as shown in Table 6 for TSS, TDS, nitrogen and phosphorus, metals, and bacteria analyses. The sample bottles were immediately placed in a cooler with ice for temporary storage and transport to the LCRA Environmental Laboratory, Austin, Texas. A summary of the analyses performed by the LCRA for the extended column study was the same as those performed for the first-flush column study (Table 16).

The columns were allowed to stand idle for 1 week, at which time a quantity of deionized water was again applied to each column to simulate 1.5 months of rainfall. The collected leachate that drained from the columns was sampled and sent to the LCRA Environmental Laboratory for analysis. The procedure was repeated eight times to simulate one year of rainfall in Austin, TX.

Erosion Control Channel Studies

The experimental procedure for each erosion control channel study consisted of loading the main compartment of the erosion control channel with washed pea gravel and 3-in. of soil, CMT, or ECC. The 0.125-in. to 0.5-in. diameter pea gravel was used to fill the voids of a 1-in. thick, Type III fiberglass sheet with 1-in. square openings. The fiberglass grid and gravel provided support for the soil, CMT, or ECC and provided drainage for any water that percolated through. The same geotextile filter fabric that was used in the column studies separated the soil, CMT, or ECC from the support grid and gravel. A 3-in. layer of soil, CMT, or ECC, was placed on top of the geotextile fabric and lightly packed. The CMT and ECC mixtures used in the erosion control studies were prepared in large batches using a motorized concrete mixer for uniform mixing. The slope of the erosion control channel with the appropriate soil, CMT, or ECC was adjusted using the crane and hoist. The erosion control channel was adjustable for a 2:1, 3:1, 5:1, or 8:1 slope (horizontal:vertical). Tap water was applied to the channel that was positioned at the desired slope until the test sample was saturated with water. Leachate was allowed to drain freely from the soil, CMT, or ECC for 24 hours. The erosion control test was begun after waiting 24 hours by applying a volume of water to the sample in the erosion control channel to simulate the 2-year, 3-hour design storm. The pump was cycled on and off in intervals that are indicated in Table 13 to simulate the storm hyetograph shown in Figure 15. The rate of flow of the runoff from the soil, CMT, or ECC in the erosion control channel during each run was measured using a bubbler tube in a flume equipped with a V-notch weir. Rate of flow measurements were logged by the flow meter every 2 minutes. The soil, CMT, or ECC sample was removed from the channel when no runoff was visible. The channel was cleaned, and a new test sample was loaded and lightly packed into the channel. The entire procedure was repeated for each sample of soil, CMT or ECC at each test slope. The composted dairy cattle manure, CMT, and ECC mixtures were tested at 2:1, 3:1, 5:1, and 8:1 slopes. The hydraulic characteristics of composted feedlot manure, composted poultry litter, and composted biosolids CMT and ECC mixtures were evaluated only at a 3:1 slope. The soil controls were tested at 2:1, 3:1, 5:1, and 8:1 slopes. The erosion control study samples and runs are summarized in Table 18.

Table 18. Summary of Erosion Control Study Samples and Runs.

	Sand				**Clay**				**ECC**			
	2:1	**3:1**	**5:1**	**8:1**	**2:1**	**3:1**	**5:1**	**8:1**	**2:1**	**3:1**	**5:1**	**8:1**
Composted Dairy Cattle Manure	X	X	X	X	X	X	X	X	X	X	X	X
Composted Feedlot Manure		X				X				X		
Composted Poultry Litter		X				X				X		
Composted Biosolids		X				X				X		
Sand	X	X	X	X	X	X	X	X				
Clay	X	X	X	X	X	X	X	X				

One water quality sample was collected from the composted dairy cattle manure CMT and ECC samples at a 3:1 slope and submitted to the LCRA Environmental Laboratory for analysis. The erosion control water quality samples were analyzed for the same litany of constituents as the leachate studies (Table 16).

RESULTS AND DISCUSSION

The results section is organized into subsections. The first subsection includes results from the physical, chemical, and biological characterization of the soil controls and of each type of compost. The second subsection includes results from the first-flush studies. The third subsection includes results from the extended column study. The last subsection includes results from the erosion control channel studies.

Soil Characteristics

Soil characterization was performed by Texas A&M University System Soil Testing Laboratory and included analyses of both physical and physico-chemical properties. Of particular interest was determination of soil texture, bulk density, pH, CEC, salts, and metals content. Soil texture analysis determined the relative proportions of sand, silt, and clay particles, and the particle size distribution determined the relative amount of each particle size across a range of sizes. Results from the textural analysis indicated the control soils were sand and sandy clay loam (clay). Texture analysis indicated the sand contained 95 percent sand, 1 percent silt, and 4 percent clay, and the clay contained 47 percent sand, 27 percent silt, and 26 percent clay. Neither the sand nor the clay had appreciable amounts of organic matter. The particle size distribution is depicted graphically in Figure 16.

Physico-chemical testing indicated both soils were slightly alkaline. Soil pH affects nutrient availability, rates of organic mineralization, and metals adsorption. The analytical results indicate that both the sand and the clay had very low salinity. Mixing these soils with high salt content compost could be beneficial in diluting the compost and therefore could accommodate application of compost with higher salinity. Soil organic matter for both soils was low, as expected. Results from the analysis of a single composite sample taken from both soil sources are summarized in Table 19.

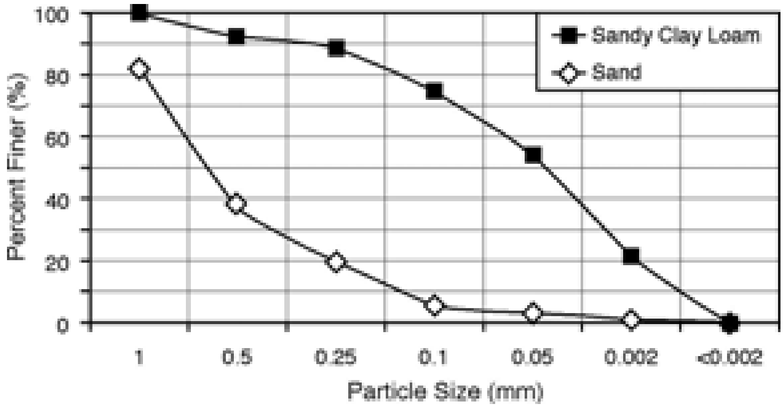


Figure 16. Particle size distribution for sand and clay.

Table 19. Physico-chemical Results for Soils

Parameter	Units	Clay	Sand
pH	SU	8.3	9.1
Nitrate-N	ppm	10	3
Phosphorus	ppm	35	22
Potassium	ppm	160	38
Calcium	ppm	58,650	69,740
Magnesium	ppm	620	658
Salinity	ppm	172	71
Electrical Conductivity	dS/m	0.135	0.084
Sodium	ppm	299	302
Sulphur	ppm	80	103
Organic Matter	%	0.2	0.1

Results from metals analysis indicate neither the clay nor the sand contained appreciable heavy metals concentrations. The only metal that registered greater than the minimum quantification limit for the sand was arsenic, and the amount of arsenic in the soil still was very small. The clay had trace amounts of arsenic and nickel. Results from the metals analyses are summarized in Table 20.

Table 20. Metals Content of Sand and Clay

Metals	Units	Clay	Sand
Arsenic	µg/g	2	1.2
Cadmium	µg/g	<1.0	<1.0
Chromium	µg/g	<5.0	<5.0
Cobalt	µg/g	2.7	<2.5
Copper	µg/g	<5.0	<5.0
Lead	µg/g	<10	<10
Mercury	µg/g	<0.050	<0.050
Molybdenum	µg/g	<2.5	<2.5
Nickel	µg/g	8	<2.5
Selenium	µg/g	<1.0	<1.0
Zinc	µg/g	<25	<25

Compost Characteristics

All of the compost used in this research project was tested in accordance with the test methods outlined in the Test Methods for the Examination of Composting and Compost published by the USCC. The physical and physico-chemical tests were conducted by the Soil Control Laboratory, Watsonville, California. Results from the physical and physico-chemical tests are presented on the following pages.

Particle Size Analysis

A particle size analysis of the four composted products was conducted. The composted feedlot manure, composted biosolids, and composted poultry litter had very similar particle size distributions in the 9.5 to 2.0 mm range though composted feedlot manure had the most particles <2.0 mm in size with 80 percent passing. Results for the composted dairy cattle manure indicated significantly more, larger diameter particles in the 9.5 to 2.0 mm range and fewer particles in the <2.0 m range with 50 percent versus 70 percent to 80 percent for the other three composts. The particle size distribution results for the composted products are shown in Figure 17. The particle size distribution of the clay and sand ranged from 1 to <0.002 mm, and the size distribution of compost ranged from 16 to <2.0 mm with an average of 50 to 60 percent of particles in the 2.0 to 16.0 mm range. Addition of the larger diameter compost particles to the soil particles increases the range of pore sizes in the mixture. The increase in both pore size and range of pore size increases porosity and decreases bulk density of the mixture.

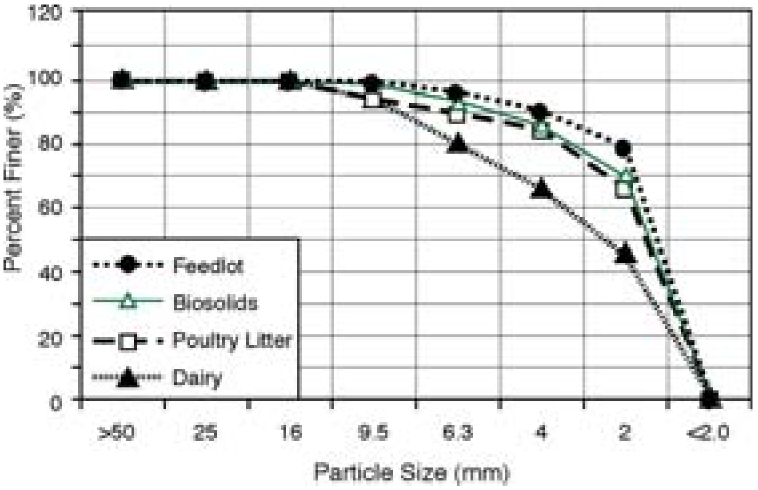


Figure 17. Particle size distribution for composts.

Stability and Maturity

Compost maturity is defined as the degree of completeness of composting (Brinton, 2000). Compost stability is used as an indicator of microbial activity in the compost based on the respiration rate of the microorganisms. In general, compost should be both mature and stable to ensure compost quality does not deteriorate during shipment and storage and to ensure that the compost does not inhibit plant growth.

A preliminary screening of the carbon to nitrogen (C:N) ratio provides a baseline for determination of compost stability and maturity. A C:N ratio of less than 25:1 is mandatory, though the Soil Control Laboratory uses an upper limit of 13:1 as an indicator of maturity. All four composted products had C:N values less than 13:1. Respiration rates of the compost were measured as a test for stability. The respiration rates of the compost were measured optimizing moisture. The respiration rates of the compost were also measured separately optimizing nutrients, pH, moisture, and porosity to simulate conditions optimized for plant growth. The compost conditions are optimum if both conditions result in similar rates of respiration. If, however, the respiration rate with conditions optimized for nutrients, pH, moisture and porosity is higher, the compost may be limited by pH, moisture, nutrients, or aeration. Stability testing indicates all four composts had very low rates of respiration. Taken alone, results from the respiration rate analysis indicate composted biosolids and composted dairy cattle manure were categorized as very mature, and composted feedlot and composted poultry litter were categorized as mature.

Biological assays provide one method of determining phytotoxicity. All four composted products were tested using germination rates of cucumber, a salt tolerant plant, and red clover, a salt intolerant and clopyralid sensitive plant. All of the composted products except the composted feedlot manure supported growth of the cucumber seedlings. All of the composted products except composted feedlot manure supported growth of the more sensitive red clover when the compost was diluted with potting soil at a 4:1 ratio. Because compost used along highway rights-of-way would be combined with soil to make CMT or with wood chips to make ECC, phytotoxicity results for all composted products were positive except for composted feedlot manure. In addition, native Central Texas grasses, such as buffalo grass, tend to exhibit high salt and drought tolerance and are generally heartier than the red clover used in the laboratory testing. Composted feedlot manure exhibited phytotoxic effects for the range of conditions tested and would likely exhibit phytotoxicity when mixed to form CMT and ECC.

The last maturity indicator is ammonia to nitrogen ratio and total ammonia concentration. The ammonia to nitrogen ratio indicated that composted biosolids and composted poultry litter were immature, whereas composted feedlot manure and composted dairy manure were mature. The complete data set is included in the Appendix in Table A-1. A summary of the average of three samples is included in Table 21.

Table 21. Summary of Stability and Maturity Test Results

Compost Type	**C:N Ratio**	**Respiration**	**Seedling Emergence**	**Ammonia: Nitrogen Ratio**
Composted Biosolids	11.5	Very Mature	Very Mature/Dilute	Immature
Composted Feedlot Manure	9.3	Mature	Immature/Toxic	Mature
Composted Dairy Cattle Manure	10.2	Very Mature	Mature/Dilute	Mature
Composted Poultry Litter	11.8	Mature	Mature/Dilute	Immature

The stability and maturity test results for the composted manures and composted biosolids indicate that composted dairy cattle manure is the most mature. However, the composted dairy cattle manure must be diluted to support more sensitive plants. Composted biosolids and composted poultry litter are also mature, but the ammonia to nitrogen ratio is high and toxic to sensitive plants. Composted biosolids and composted poultry litter would require dilution prior to application to sensitive plants. The composted feedlot manure is mature but toxic to sensitive and less sensitive plants even when diluted.

Nutrients and Ash Content

Macronutrients including nitrogen (N), phosphorus (P), and potassium (K) are essential for plant growth. Compost often is used as an amendment to soils for nutrient addition. However, not all macronutrients in the compost or in the compost amended soils are actually plant available. For example, nitrogen is available to plants in the form of nitrate and ammonia. Some forms of phosphorus are available, but phosphorus availability is highly dependent on soil pH. The sand and clay were alkaline; therefore, it is likely calcium phosphates will form and less phosphorus will be available for plant growth (USDA, 1999). One of the benefits of using compost to supply plant nutrients is that compost generally releases nutrients more slowly than do commercial fertilizers (NRCS, 1999). However, it is important to remember nutrients can leach from the soil and that low nitrate levels coupled with high ammonium levels may lead to nitrogen deficiency in plants if the compost is applied to a nitrogen deficient soil (Brinton, 2000).

Ash content often is measured as an indicator of the age and the amount of sand and minerals in the compost and the nutrient quality of compost. High ash content may indicate the compost is old, or it may indicate sand or soil was added. The composted biosolids, composted feedlot manure, and composted poultry litter had average ash content, whereas the composted dairy cattle manure had a high ash content. Physico-chemical results, reported as the average of three composite samples, are summarized in Table 22. The complete data set is included in the Appendix in Table A-1.

Table 22. Mean Values for Physico-Chemical Characteristics of Compost

Parameter	**Units**	**Composted Feedlot Manure**	**Composted Biosolids**	**Composted Poultry Litter**	**Composted Dairy Cattle Manure**
		Mean Values			
Maturity	%	1.7	86.7	86.7	96.7
Stability	mg CO_2-C/g OM/d	2.1	1.1	2.8	1.2
Total N	%	2.1	2.0	1.3	0.6
Ammonia	mg/kg dw	277	919	598	37
Nitrate	mg/kg dw	499	24	42	637
Phosphorus	mg/kg dw	10,452	13,069	14,835	2,885
Potassium	mg/kg dw	28,280	6,015	11,925	9,556
pH	SU	9.48	7.98	8.95	9.02
EC	mmhos/c	12.562	2.569	4.150	3.583
Bulk Density	lb/cu ft dw	34.7	25.3	30.0	55.3
Organic Matter	% (dw)	40.6	49.1	30.9	10.8
Organic Carbon	% (dw)	19.8	22.8	15.0	6.1
Ash Content	% (dw)	59.4	50.9	69.1	89.2
C:N Ratio	ratio	9.3	11.5	11.9	10.2
Moisture	%	24.0	38.4	19.6	22.7
Fecal Coliform	MPN/g dw	<2	<2	<2	<2

The compost characteristics reported in Table 22 indicate considerable variability among composted manures and composted biosolids, both among the composted animal manures and between the manures and biosolids compost. However, comparing the range of values obtained in this project with values reported in the literature review reveal similar variability and similar ranges among some parameters. The ranges of values for organic matter and C:N obtained in this study are narrow, and both fell within the range of values reported in the literature. Some ranges, including those for total N and electrical conductivity (EC; a measurement of all soluble ions including nutrients, sodium, and chloride), were similar. The main difference appeared to be variability in pH among composts, with the compost tested in this study more alkaline than those reported in the literature. A comparison of the range of mean values for compost is summarized in Table 23. The complete data set is included in the Appendix in Table A-1.

Table 23. Comparison of Ranges of Mean Values for Characteristics of Compost Used in This Study and Values Reported in the Literature

Parameter	Units	Range of Mean Values	
		TxDOT Compost*	Literature Review Values**
Total N	%	0.6 - 2.1	0.92 – 2.98
C:N	--	9.3 – 11.8	6.0 – 31.9
EC	dS/m	2.6 – 12.6	3.4 – 17.6
pH	SU	8.0 – 9.5	6.0 – 8.9
Organic Matter	%	10.8 – 49.1	29.0 – 30.2

* Includes composted dairy cattle manure, composted feedlot manure, composted poultry litter, and composted biosolids.

** Includes mixed feedstock composts and composts derived from biosolids and poultry litter. Values were previously summarized in Table 3 of this report.

Metals

The University of Guelph (Ontario) performed metals analyses for all of the composts. Mean values from the analysis of three composite samples for each composted manure and composted biosolids, along with the maximum allowable metals content per USEPA Class A Standard, 40 CFR §503.13, are summarized in Table 24. Composted biosolids contained the highest concentration of each metal with the exception of nickel, which is highest in composted poultry litter. However, all of the heavy metals concentrations reported in Table 24 are well within the maximum allowable concentrations established by the USEPA, Standards for the Use or Disposal of Sewage Sludge, regulations published in the Code of Federal Regulations, Title 40, Part 503. The Part 503 regulations establish pollutant concentration limits for Class A biosolids as well as the limits for compost, per TxDOT Specification Item 161, independent of feedstock. Normalizing metals concentrations in the composts according to the maximum allowable pollutant concentration for each metal established by the USEPA Part 503 regulations indicates five of the ten metals are at less than 10 percent of the maximum allowable level, and four of the remainder are less than 25 percent of the maximum allowable level. The concentration of molybdenum in the biosolids compost was the highest concentration found of any metal in any of the composts. Even so, the molybdenum concentration in the biosolids did not exceed the maximum allowable concentration of molybdenum per USEPA Part 503 regulations. Comparison of the metals content of the four composts normalized to the maximum allowable pollutant concentration per USEPA Part 503 Rules is shown in Figure 18.

Table 24. Mean Metal Content for Four Composted Products

Metal	Units	Composted Feedlot Manure	Composted Biosolids	Composted Poultry Litter	Composted Dairy Cattle Manure	Max. Allowable
Arsenic	mg/kg dw	1.4	6.0	2.4	5.4	41
Beryllium	mg/kg dw	50.1	52.7	29.8	19.4	--
Cadmium	mg/kg dw	<1	2.3	<1	<1	39
Chromium	mg/kg dw	8.0	30.0	12.0	10.0	--
Copper	mg/kg dw	39.3	337.7	294.0	22.3	1,500
Lead	mg/kg dw	1.5	33.3	3.0	<1	300
Mercury	mg/kg dw	<1	<1	<1	<1	17
Molybdenum	mg/kg dw	3.3	12.3	2.7	1.5	75
Nickel	mg/kg dw	14.3	15.3	17.3	10.3	420
Selenium	mg/kg dw	1.0	1.9	1.0	1.0	100
Zinc	mg/kg dw	229.7	483.3	487.0	101.7	2,800

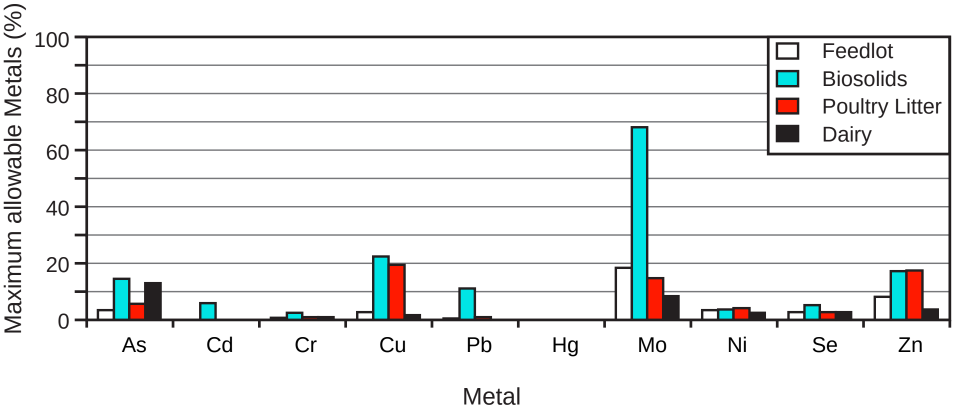


Figure 18. Average metals content normalized as percentage of maximum allowable pollutant concentration per USEPA Part 503 Regulations, TxDOT Specification Item 161.2.

TxDOT Specifications

The Texas Department of Transportation is interested in compost for use along highway rights-of-way, especially in areas with poor or severely eroded soils. TxDOT has used compost in the field in several test cases and has found that CMTs are effective in establishing vegetative cover in very severe applications. TxDOT developed minimum acceptable standards for compost quality, testing, mixing, and application procedures to promote the use of compost and to assure a quality product for use on Texas roadsides. The current TxDOT specifications for compost are summarized in Table 25.

The composted products used in this research project were considered to be representative of the types and quality of composted manures and biosolids that might be used on TxDOT projects. All of the composted materials that were used in this project were tested to ensure conformance to TxDOT specifications. The average of three composite samples for each specified parameter are reported along with the TxDOT requirements. A model specification is included to illustrate that the TxDOT specification is in line with specifications used across the country in other DOTs. The highlighted cells indicate results that do not meet TxDOT specification parameters.

Table 25. TxDOT Compost Quality Specifications and Results of Project Composts

	Specifications		**Compost**			
	TxDOT[1]	**Model[2]**	**Feedlot Manure**	**Biosolids**	**Poultry Litter**	**Dairy Manure**
Organic Matter (%)	25 - 65	30-65	40.6	49.1	30.9	**10.8**
Particle Size	95% <5/8in.; 70%>3/8in.	98% <3/4in.	Pass	Pass	Pass	Pass
Salts (dS/m)	< 5.0[3]	<10.0	**12.6**	3.1	4.1	3.6
Fecal	Pass (<1000/g dw)	Pass	Pass	Pass	Pass	Pass
pH (SU)	5.5 - 8.5	5.0-8.5	**9.5**	8.0	**9.0**	**9.0**
Stability	<8	<8	2.1	1.1	2.8	1.2
Maturity	>80%	>80%	**1.7%**	86.7%	86.7%	96.7%
Metals	Pass	Pass	Pass	Pass	Pass	Pass
Moisture (%)	NA	30-60	24%	38.4%	19.6%	22.7%
Inerts (%)	NA	<1	<1	<1	<1	<1

[1] Source: TxDOT Specification Item 161, 2003.
[2] USCC, 1996.
[3] <10.0 with CMT.

The only compost that passed all parameters in the specifications was the composted biosolids. The composted biosolids produced by the City of Austin meet USEPA Part 503, Class A biosolids regulations for sale to individual consumers. The composted poultry litter only failed the upper limit for pH. The composted dairy cattle manure exceeded both the upper limit for pH and the lower limit for organic matter content. Several attempts were made to obtain composted dairy manure that met the minimum organic matter requirement, but those efforts proved to be unsuccessful. The composted feedlot manure failed to meet the specifications, with higher than allowable salts, pH, and maturity. Comparisons of each compost and select parameters are included in Figure 19.

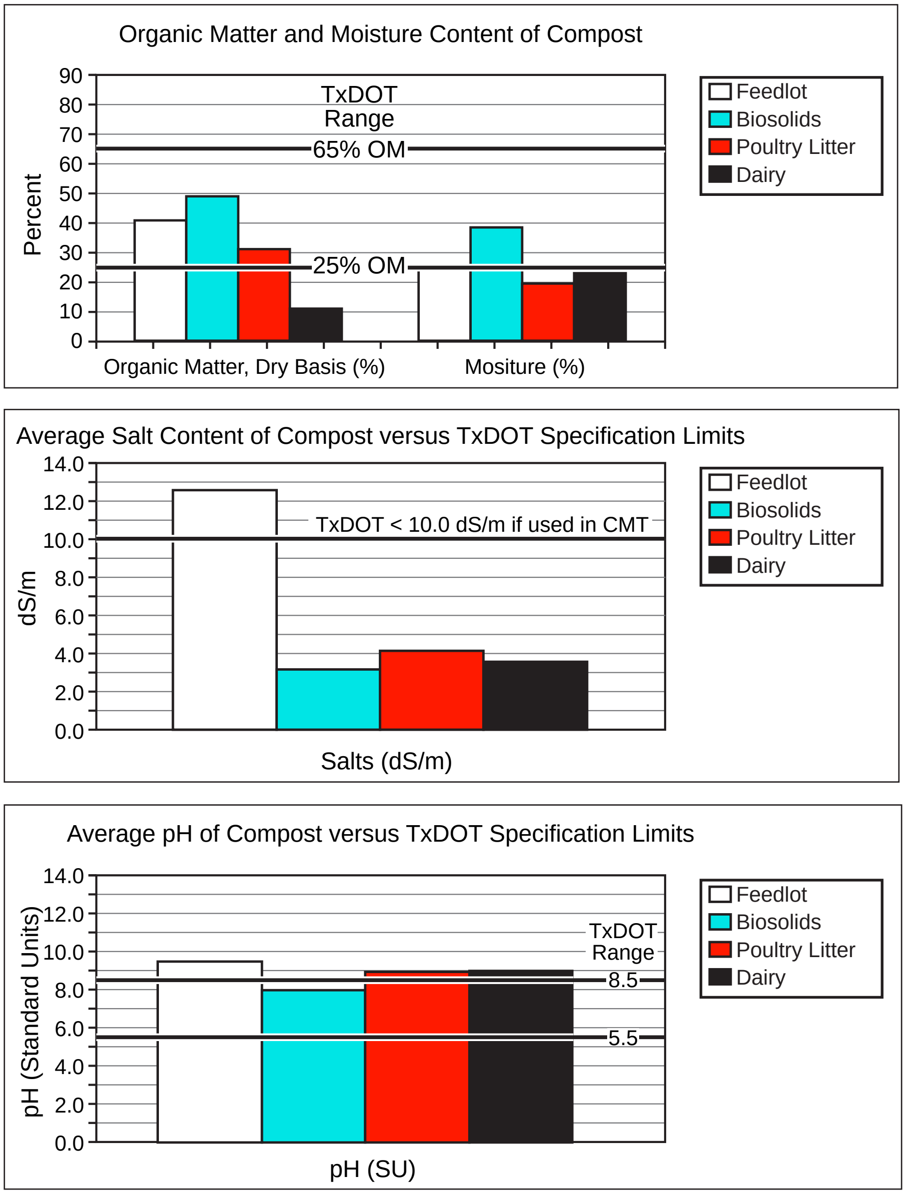


Figure 19. Comparison of select TxDOT specification parameters.

Moisture Retention in CMT And Control Soils

Moisture retention curves were developed for the control soils and for each CMT blend by the University of Guelph. These data quantify the change in water retention through addition of compost to soil. Water retained at 0.3 bars is a good approximation of field capacity that is, the maximum moisture content of a soil before drainage by gravity begins (Diaz-Marcote & Polo, 1996; Mamo, et al., 2000). The water retained at 15 bars is a good approximation of the wilting point, which refers to the moisture content of a soil that is held so tightly in the soil matrix that it cannot be extracted and used by plants (Diaz-Marcote & Polo, 1996; Mamo, et al., 2000). The increase in water holding capacity is much larger in sands than in clays (Huberty, 1936).

Results of the moisture retention analysis for the sand CMT blends are included in Figure 20. The moisture retention curves for the clay CMT blends are included in Figure 21. Abbreviations for the figures are as follows:

- Biosolids compost (BC)
- Feedlot manure compost (FLC)
- Dairy manure compost (DMC)
- Poultry litter compost (PLC)
- Sand CMT (SM)
- Sand (S)
- Clay (CM)
- Clay CMT (C)

The complete data set is in the Appendix in Table A-2. These data indicate a shift upward in the moisture retention curves for the CMT mixtures blended with sand and clay. The data also indicate that the increase in the moisture retention is much greater in the sand blends than in the clay blends. The clay blends retain much more moisture than do the sand blends. The upward shift in the moisture retention curves indicates an increase in the moisture retention of all CMT blends over the control soils at all pressure points tested. Amending sand, a coarse-textured soil, with compost resulted in the greatest overall increase in water retention. However, the clay CMT retained more water overall.

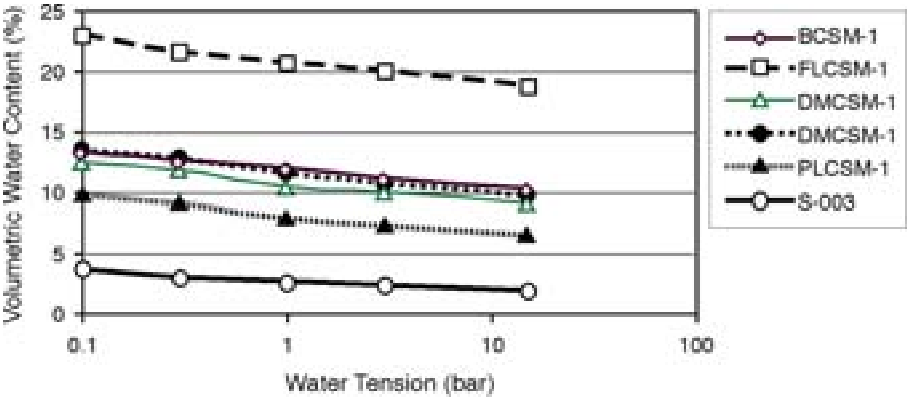


Figure 20. Moisture retention of CMT manufactured with sand.

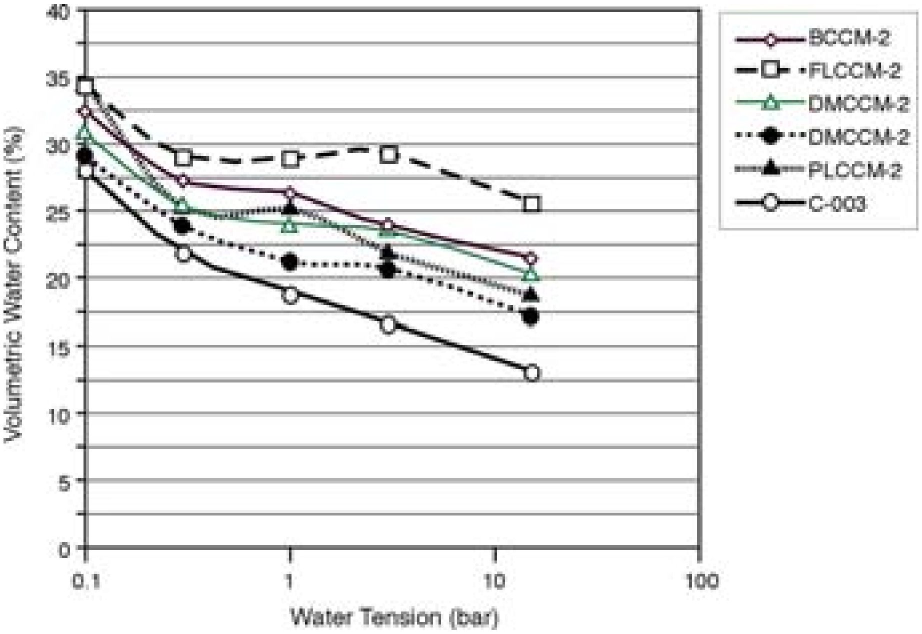


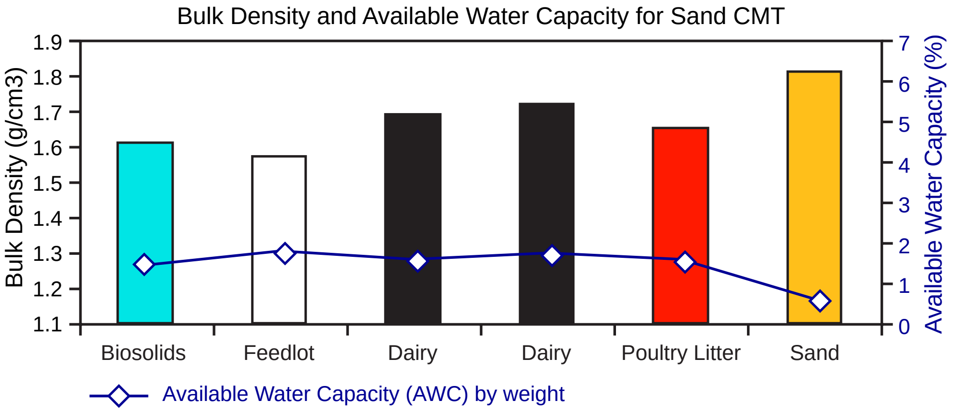
Figure 21. Moisture retention curves of CMT manufactured with clay.

Examining the series of moisture retention curves for the sand and CMT blends reveals a significant difference between the composted poultry litter CMT and the composted feedlot manure CMT. The composted feedlot manure CMT retained more moisture at each pressure point than did the composted poultry litter CMT. The composted feedlot manure CMT also retained the most moisture overall in the clay CMT blends. Therefore, composted feedlot manure blended with either clay or sandy soils would result in the greatest increase in moisture retention, and the greatest overall gain is in blends manufactured with coarse-textured soils. The other three composted blends appear to result in equivalent improvement in water retention across all pressures, in both soil blends. However, the composted feedlot manure did not meet the phytotoxicity requirements of TxDOT Specification 1058 or other requirements. Therefore, a range of factors should be considered when selecting composted materials for use in CMT and ECC.

The difference in water retention at ~0.3 bars and 15 bars approximates the available water capacity. A comparison of the available water capacities of each CMT indicates that the addition of composted animal manure or biosolids increases available water in the sand mixes but not in the clay mixes. The trend is illustrated in Figure 22.

The bulk density data also are presented in Figure 22. Increases in water holding capacity may be attributed to a number of factors including a decrease in bulk density, changes in the pore size distribution of soils with the number of small pores increasing, and increased aggregation (Khaleel et al., 1981).

The observed data are insufficient to support or refute earlier research results that correlated increases in water holding capacity to increases in the number of small pores and to increased aggregation. However, the data support a decrease in the average bulk density in both the sand and clay CMTs prepared using composted biosolids and composted feedlot manure. It should be noted that the bulk density values are for single samples.



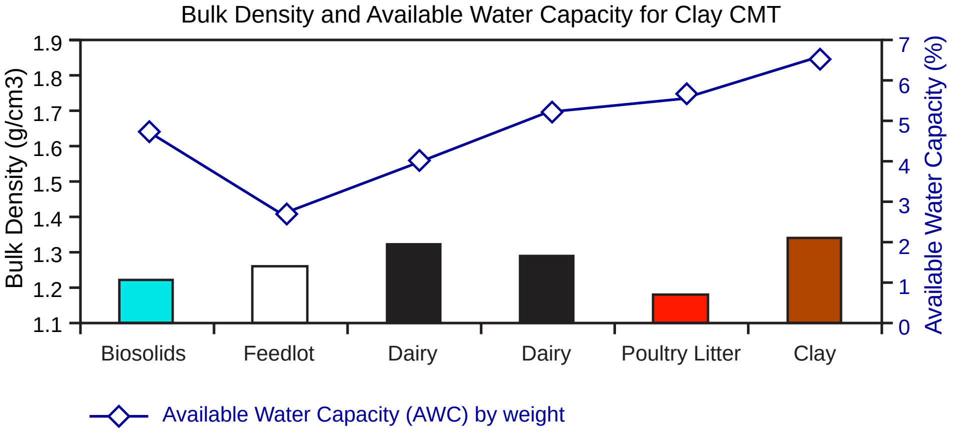


Figure 22. Bulk density and available water for sand and clay CMT.

Leachate Studies

Natural events and nonpoint source (NPS) contributions resulting from human activities impact water quality. Agricultural NPS pollution is a major contributor to impairments of rivers, lakes, estuaries, groundwater, and wetlands. Major constituents in runoff from agricultural land include sediment, nutrients, pesticides, pathogens, and salt. Runoff from residential and commercial landscaping also contribute pesticides, fertilizer, and sediments to NPS pollution load. Highway construction, runoff from highways, and highway maintenance including but not limited to bridge painting, slope repair, and the use of herbicides to control roadside vegetation contribute to NPS pollution.

Leachate studies evaluate the potential for NPS contributions from the constituents of compost amended soils as well as the potential of compost to improve water quality by mitigating pollution from highway runoff. The principal potential NPS contributions from the application of compost amended soils to highway rights-of-way are nutrients (N and P), heavy metals, bacteria, and sediment (total suspended solids).

Results from the deionized water and highway runoff first-flush leachate studies are included in the Appendix as Tables A-3 and A-4, respectively. The data contain some anomalies, especially in the deionized water studies. The noted anomalies include concentrations of constituents in the leachate from the control that were higher than the concentrations in the leachate from the CMT and ECC, outliers, and extremely high fecal coliform densities. The elevated bacteria concentrations can most likely be explained by cross-contamination in the laboratory from an experiment involving wastewater treatment plant sludge. The source of cross-contamination was removed after the deionized water runs. The high concentrations in the leachate from the control and outliers may be a result of laboratory error during dilution or difficulty in analyzing samples that contained high concentrations of color-producing substances.

The leachate from the first-flush column study and from the extended column study were compared with pollutant limits established as Texas Surface Water Quality Standards (SWQS) by the TCEQ. Results from the extended column studies are included in the Appendix as Tables A-5 and A-25, respectively. The Texas SWQS are intended to protect surface water bodies in Texas from degradation so that designated uses are maintained. The SWQS for Lake Austin per TAC 307.10, Appendix A, are listed in Table 26.
The comparison of characteristics of leachate observed in the first-flush studies for this project with the characteristics of highway runoff for the Austin site and the characteristics of highway runoff reported in the literature resulted in several interesting findings. Fecal coliform concentrations in the highway runoff collected at the Austin site are higher than the average range of values reported in the literature (Barrett et al., 1995). Concentrations of metals in highway runoff from the Austin site were lower than those reported in the literature.

Table 26. TCEQ SWQS for Lake Austin,
Segment 1403 of the Colorado River Basin

Parameter	Units	Limit
Chloride	mg/L	100
Sulfate	mg/L	75
TDS	mg/L	400
Dissolved Oxygen	mg/L	5.0
pH	SU	6.5 – 9.0
Fecal Coliform	MPN/100 mL	200
Total P[1]	μg/L	128
Total N[1]	mg/L	0.76

[1] Nutrient limits are under development. Values listed in table are currently recommended regional nutrient criteria developed by the USEPA National Strategy for the Development of Regional Nutrient Criteria, June 1998.

Highway Runoff

Highway runoff is a NPS contribution. Constituents of concern in highway runoff include sediment (TSS), nutrients, heavy metals, herbicides, pesticides, hydrocarbons, and bacteria.

The characteristics of leachate from the controls of the highway runoff first-flush study are presented in Table 27. Barrett et al.(1995a) reported concentrations of constituent for highway runoff collected from the same site as that used in the present research project, and these data also are presented in Table 27. Barrett et al. reported average concentrations for 49 samples collected from September 1993 through May 1995 during rain storms of varying intensity and duration. The highway runoff used in the present project was from a single storm event that occurred in 2002.

The data for the first-flush leachate study indicate lower concentrations of copper and lead than those reported by Barrett et al. (1995a). The nitrate concentrations in the leachate from the gravel and clay controls were lower than those reported by Barrett et al. (1995a) and those reported in the literature. Total phosphorus concentrations in the leachate from the gravel and sand control were lower those reported by Barrett et al, (1995a), and those reported in the literature; however, total phosphorus concentrations in the leachate from the clay control was higher.

Table 27. Characteristic Pollutant Concentrations for Highway Runoff.

Parameter	**Mean Concentration (Barrett et al., 1995a)**	**HRO first-flush Leachate Concentration Ranges**		
		Blank	**Clay Control**	**Sand Control**
	(mg/L)	**(mg/L)**	**(mg/L)**	**(mg/L)**
TDS	NR	185-395	350-830	190-335
TSS	202	120-520	825-3720	ND-2900
Zinc	0.237	0.12-0.13	0.14-0.20	ND-0.09
Copper	0.038	0.01	0.02-0.03	ND
Lead	0.099	ND	ND	ND
Ammonia	NR	0.03-0.09	ND-0.1	ND
Nitrate	1.25	0.46-0.54	0.97-1.19	2.54-3.23
Nitrite	NR	0.07-0.39	0.08-0.09	0.07-0.1
TKN	NR	0.17-1.61	1.97-2.75	0.52-1.05
TP	0.42	0.07-0.15	1.15-1.32	ND-0.53
Fecal Coliforms (org./100 mL)	13,000	1,000->20,000	1,000-15,700	500-3,000

Note : TDS, total dissolved solids; TSS, total suspended solids; TP, total phosphorus; NR, not reported.

First-flush bacterial concentration observed for the gravel and the clay controls were similar to those reported by Barrett et al. (1995a). However, lower fecal coliform concentrations were observed for the leachate from the sand control. The observed fecal coliform concentrations in the leachate from the controls in this study and the bacterial concentrations reported by Barrett et al. (1995a) were higher than fecal coliform levels typically observed in highway runoff (Barrett et al., 1995b).

Nutrients

Nutrient loading levels have not been established for runoff impacting Town Lake in Austin, Texas. However, the USEPA recommended regional nutrient criteria for total N is 0.76 mg/L (Table 26). The Natural Resources Conservation Service recommends limiting nitrate concentrations to less than 100 mg/L in water used for irrigation (NRCS, 1999). Nitrite is considered a pollutant at concentrations greater than 1 mg/L.

First-flush Column Studies: Nitrate

Characteristics of leachate observed in the first-flush studies are summarized in Table 28. The results represent average concentrations from three deionized water and three highway runoff runs. Complete data are included in the Appendix in Tables A-3 and A-4.

Table 28. First-Flush Leachate Study Analytical Results for Nitrate.

			Nitrate(N)	
			Deionized Water	**Highway Runoff**
			mg/L	**mg/L**
Controls	Blank	NA	0.24	0.51
	Clay	Soil	0.38	2.97
	Sand	Soil	0.34	1.09
Composted Poultry Litter	Clay	CMT	1.50	5.01
	Sand	CMT	1.05	1.80
	Wood Chips	ECC	0.62	0.59
Composted Biosolids	Clay	CMT	31.64	2.62
	Sand	CMT	0.51	1.41
	Wood Chips	ECC	74.55	0.62
Composted Feedlot Manure	Clay	CMT	39.96	65.3
	Sand	CMT	77.00	48.2
	Wood Chips	ECC	34.80	14.2
Composted Dairy Cattle Manure	Clay	CMT	65.21	122
	Sand	CMT	77.10	109.6
	Wood Chips	ECC	54.50	29.5

Nitrate concentrations in the compost by itself were lowest for the composted biosolids and composted poultry litter at 24 and 42 mg/kg dry weight, respectively. Likewise, nitrate concentrations in the leachate observed in first-flush highway runoff studies from the composted biosolids and composted poultry litter CMT and ECC were lower than those observed for the leachate produced from composted dairy cattle manure and composted feed lot manure CMTs. Average nitrate concentrations for the first-flush leachate from the composted biosolids and composted poultry litter CMTs ranged from 1.41 to 5.01 mg/L, as compared with 48.2 to 122 mg/L for the composted feedlot manure and composted dairy cattle manure CMTs. The first-flush deionized water leachate from the composted poultry litter CMT ranged from 0.62 to 1.56 mg/L and was the lowest for the deionized water runs. The composted biosolids CMT first-flush leachate was lower than the composted feedlot manure and composted dairy manure CMT for the clay and sand blends but not for the ECC runs. Results from the first-flush column studies support the correlation between the amount of nitrate in the compost by itself and the potential for nitrates in the leachate from the CMT. Nitrate concentration in the leachate from the controls in the first-flush studies was negligible. The nitrate concentration in highway runoff was <1 mg/L.

The nitrate concentrations in the leachate from composted poultry litter ECC and the composted biosolids sand CMT observed in the deionized water first-flush studies and those observed in the leachate from the composted biosolids ECC highway runoff first-flush studies were less than the USEPA recommended nitrate criteria of 0.76 mg/L. However, the nitrate concentration in the leachate from the composted dairy manure CMT observed during the highway runoff runs exceeds the recommended maximum of 100 mg/L nitrate for irrigation water.

Extended Column Studies: Nitrate

Nitrate concentrations in the leachate for clay CMTs are presented in Figure 23. Initial nitrate concentrations in the leachate from composted biosolids CMT and ECC ranged from 0.37 to 0.56 mg/L for sand and clay CMT, respectively, to 30.5 mg/L for ECC. These nitrate concentrations were lowest for all CMT and ECC blends. Initial nitrate concentrations in the leachate from composted poultry litter sand CMT and ECC were 1.08 and 51.7 mg/L, respectively. The highest initial nitrate concentrations were observed for the leachate from composted dairy cattle manure CMT and ECC blends. The nitrate concentrations ranged from 1.11 to 91.4 and 163 mg/L for clay CMT and sand CMT and ECC, respectively. Nitrate concentrations in the leachate from the controls were 0.18 and 0.2 mg/L for the clay and sand, respectively, or approximately one-half the average nitrate concentrations observed in the first-flush studies.

Nitrate concentrations in the leachate, after the equivalent of 3 months of rainfall, decreased for composted poultry litter and composted biosolids clay CMTs, for all sand CMT and ECC blends, and for the sand control. Nitrate concentrations in the leachate from composted biosolids clay CMTs decreased from 0.37 to 0.15 mg/L, and the nitrate concentration in the leachate from the composted poultry litter clay CMT decreased from 1.18 to 0.16 mg/L. In contrast, after the equivalent of 3 months of rainfall, nitrate concentrations in the leachate from composted feedlot manure and composted dairy cattle manure clay CMT and from the clay control increased by a factor of two. Nitrate concentrations in the leachate for composted biosolids clay CMT increased from 0.15 to 0.69 mg/L and from 0.16 to 1.88 mg/L for composted poultry litter clay CMT. Nitrate concentrations in the leachate from composted feedlot manure clay CMT increased from 1.23 to 7.73 mg/L after 4.5 months of equivalent rainfall. Nitrate concentrations of the leachate continued to increase after 6 months of equivalent rainfall for composted biosolids and composted poultry litter clay CMT, although the increase between 4.5 and 6 months of equivalent rainfall was much greater than the increase observed earlier. Nitrate concentrations in the leachate for composted biosolids clay CMT increased from 0.69 to 12.2 mg/L and from 1.88 to 20.1 mg/L for composted poultry litter clay CMT. Nitrate concentrations in the leachate from the clay control continued to increase between 4.5 and 6 months of equivalent rainfall. Nitrate concentrations in the leachate from composted biosolids and composted poultry litter clay CMT decreased between 6 and 9 months of equivalent rainfall but increased after 10.5 and 12 months of equivalent rainfall.

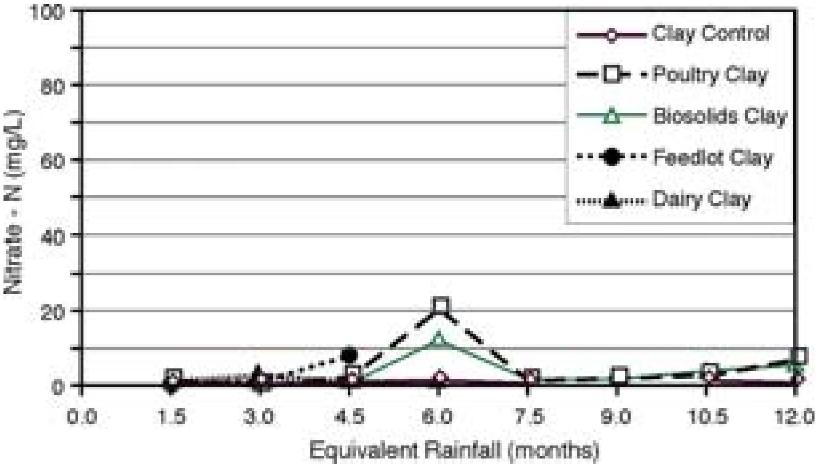


Figure 23. Extended column study results, leachate nitrate concentration from clay CMT blends.

Nitrate concentrations in the leachate observed for sand CMTs are presented in Figure 24. Nitrate concentrations in the leachate for all sand CMT blends decreased after 3 months of equivalent rainfall. Nitrate concentrations in the leachate for composted biosolids sand CMTs decreased from 0.56 to 0.28 mg/L, and composted poultry litter sand CMT decreased from 1.08 to 0.72 mg/L. Observed decreases in nitrate concentrations in the leachate from composted feedlot and composted dairy cattle manure sand CMT were 43.1 to 0.97 mg/L and 91.4 to 13.5 mg/L, respectively. Nitrate concentrations in the leachate from the sand control decreased from 0.2 to 0.14 mg/L. An increase in nitrate concentrations in the leachate was observed in composted biosolids and composted poultry litter CMT and ECC blends, composted feedlot manure clay CMT, and the controls after the equivalent of 3 months of applied rainfall. This trend was similar to that observed for the clay control and the composted feedlot manure clay CMT. Nitrate concentrations in the leachate from composted biosolids sand CMT increased from 0.28 to 24.5 mg/L. Nitrate concentrations in the leachate from composted poultry litter sand CMT increased from 0.72 to 10.6 mg/L. Decreases in nitrate concentrations in the leachate were observed for composted dairy cattle manure sand CMT after 6 months of equivalent applied rainfall. Nitrate concentrations in the leachate from composted biosolids and composted poultry litter sand CMT reversed the trend and decreased between 4.5 months and 6 months. Meanwhile, nitrate concentrations slightly increased in the leachate between 4.5 months and 6 months for the composted feedlot manure and composted dairy cattle manure.

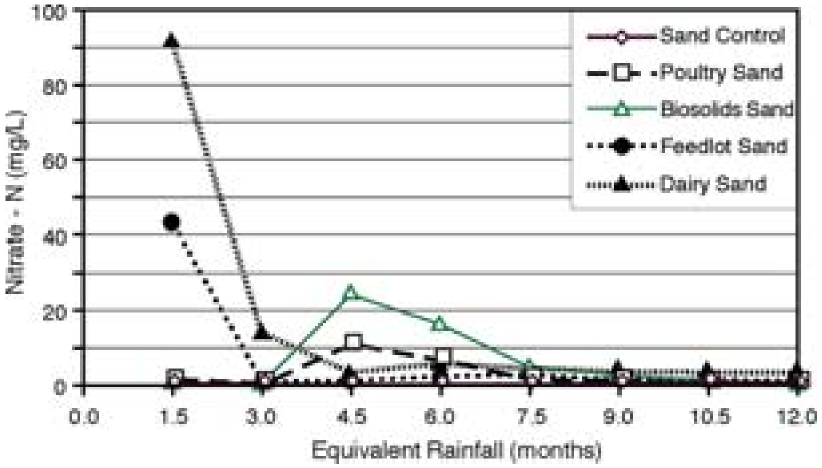


Figure 24. Extended column study results, leachate nitrate concentration from sand CMT blends.

Nitrate concentrations in the leachate observed for ECC columns are presented in Figure 25. Nitrate concentrations in the leachate from all ECC blends decreased after 3 months of applied rainfall. Nitrate concentrations in the leachate from composted biosolids and composted poultry litter ECC decreased from 30.5 and 51.7 mg/L, respectively, to < 1 mg/L, and the decreases for composted feedlot manure and composted dairy cattle manure were from 71.6 and 163 mg/L, respectively, to less than 13 mg/L. However, increases in nitrate concentrations in the leachate were observed in the composted biosolids and composted poultry litter ECC blends between 3 and 6 months of applied rainfall. Nitrate concentrations in the leachate from composted biosolids ECC increased from to 16.2 mg/L, and for composted poultry litter ECC the increase was from 0.57 to 8.64 mg/L. The nitrate concentrations in the leachate from composted dairy cattle manure ECC blends and composted feedlot manure ECC decreased after 4.5 months of equivalent applied rainfall. Nitrate concentrations in the leachate for all ECC blends generally continued to decrease after 6 months of applied rainfall.

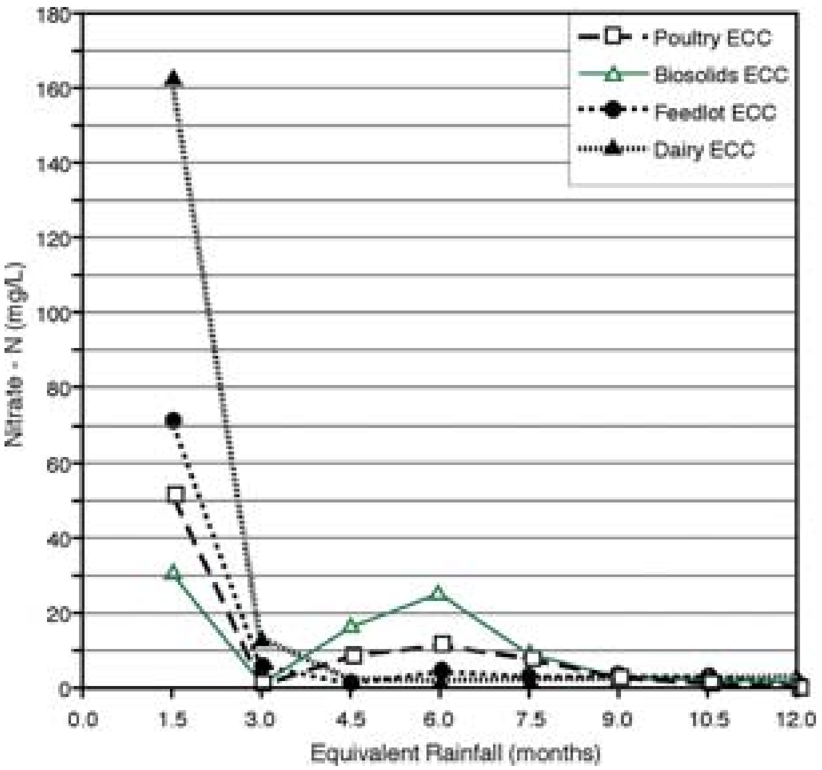


Figure 25. Extended column study results, leachate nitrate concentration from ECC blends.

The fluctuation in nitrate concentrations in the leachate over time can be attributed to the conversion of ammonia to nitrate in the soil, CMT, and ECC mixtures. This conversion is typical of slow release fertilizers. These observations support the addition of compost to soil as a beneficial source of available N for plants. The conversion of ammonia to nitrate is further supported by the concentrations of total nitrogen in the leachate from the soil, CMT, or ECC in the columns, which is discussed below. Nitrate concentrations observed during the extended column studies are included in the Appendix in Tables A-5 through A-7.

Extended Column Studies: Total Nitrogen

Total nitrogen concentrations in the leachate from clay CMT blends are presented in Figure 26, sand CMTs in Figure 27, and ECC blends in Figure 28. Initial total nitrogen concentration observed in the leachate for composted biosolids clay CMT blends was approximately 300 mg/L. Initial total nitrogen concentrations in the leachate from composted dairy cattle manure and composted feedlot manure clay CMT were approximately 250 mg/L. Initial total nitrogen concentrations in the leachate from composted poultry litter and composted feedlot manure sand CMT blends were highest at 593 and 763 mg/L, respectively, and initial total nitrogen concentrations in the leachate from composted dairy manure and composted biosolids sand CMT were 159 and 172 mg/L. Initial total nitrogen concentrations in the leachate from composted feedlot manure and composted biosolids ECC were 987 and 607 mg/L, respectively. Initial total nitrogen concentrations in the leachate from composted dairy cattle manure and composted poultry litter were 281 and 122 mg/L, respectively. Initial total nitrogen concentrations in the leachate from the controls were 0.88 and 2.05 mg/L for the clay and sand, respectively.

Total nitrogen concentrations decreased for all CMT and ECC blends after 3 months of equivalent applied rainfall. Similarly, nitrate concentrations decreased for all sand CMT and ECC blends and for composted poultry litter and composted biosolids clay CMTs after 3 months of equivalent applied rainfall. Total nitrogen concentrations in the leachate from the clay CMT are presented in Figure 26. Total nitrogen concentrations in the leachate from clay CMT blends increased between the 3 and 4.5 months of equivalent applied rainfall for the composted feedlot and composted poultry litter clay CMT, but decreased for all other blends. Total nitrogen concentrations in the leachate from composted poultry litter clay CMT continued to increase from 12.6 to 32.22 mg/L through 6 months of applied rainfall, decreased to 1.83ml after 7.5 months of applied rainfall, and increased to 8.19 mg/L between 10.5 months and 12 months. The fluctuations in total nitrogen concentrations in the leachate from composted poultry litter clay CMT were similar to the fluctuations in the nitrate concentrations in the leachate from the same material. The total nitrogen concentration in the leachate for composted biosolids clay CMT increased from 20.5 mg/L at 4.5 months of equivalent rainfall to 26.19 mg/L after 6 months of equivalent rainfall, decreased to 3.37 mg/L through 9 months of equivalent applied rainfall, and increased after 10.5 months. This trend tracks the observed nitrate concentrations. Total nitrogen in the clay control fluctuated between 0.60 and 1.37 mg/L throughout the study, alternately increasing and decreasing almost each week.

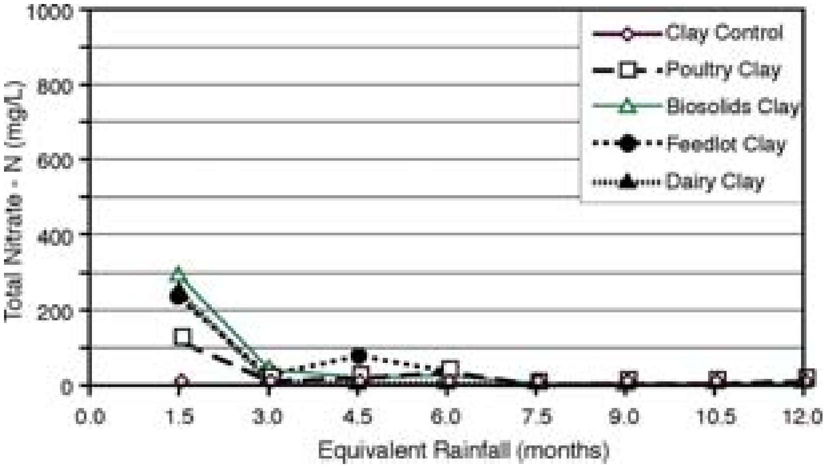


Figure 26. Extended column study results, leachate total nitrogen concentration from clay CMT blends.

Total nitrogen concentrations in the leachate from sand CMT are illustrated in Figure 27. Total nitrogen concentrations in the leachate from sand CMT blends appeared to decrease throughout the 12 months of equivalent applied rainfall, with the exception of the composted dairy cattle manure, for which an increase was observed between 4.5 and 6 months of equivalent applied rainfall before decreasing again. Nitrate concentrations in the leachate from sand CMT blends appeared to increase between 3 and 4.5 months of equivalent rainfall before decreasing through the latter rainfall applications. Total nitrogen concentrations in the leachate from the sand control decreased after three months of equivalent rainfall, increased after 4.5 through 7.5 months of equivalent rainfall, and then decreased through the end of the study.

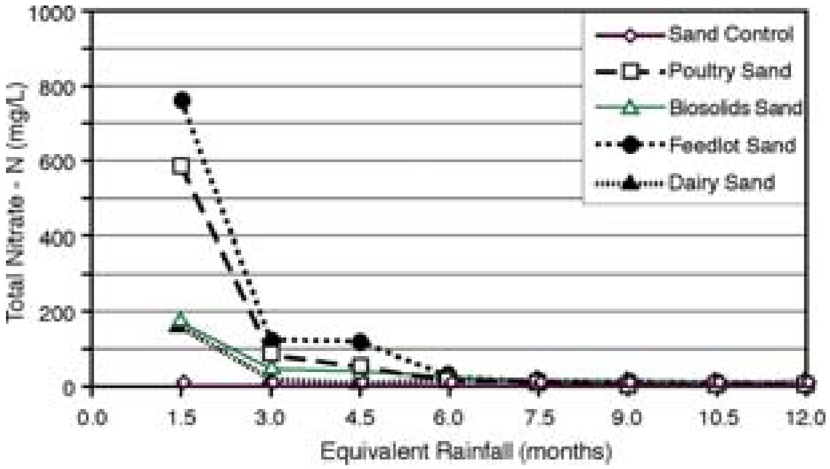


Figure 27. Extended column study results, leachate total nitrogen concentration from sand CMT blends.

Total nitrogen concentrations in the leachate from ECC blends are presented in Figure 28. The total nitrogen concentration appeared to decrease continuously through the course of the extended column study with the exception of composted feedlot manure, for which an increase was observed between 6 and 7.5 months of equivalent applied rainfall before decreasing again after 9 months of equivalent rainfall through the end of the study. The decreasing trend for total nitrogen concentrations differs somewhat from the fluctuations in nitrate concentrations, which appeared to increase for composted biosolids, composted poultry litter, and to a slight degree, composted feedlot manure between 4.5 and 6 months of equivalent applied rainfall before decreasing through the latter part of the study.

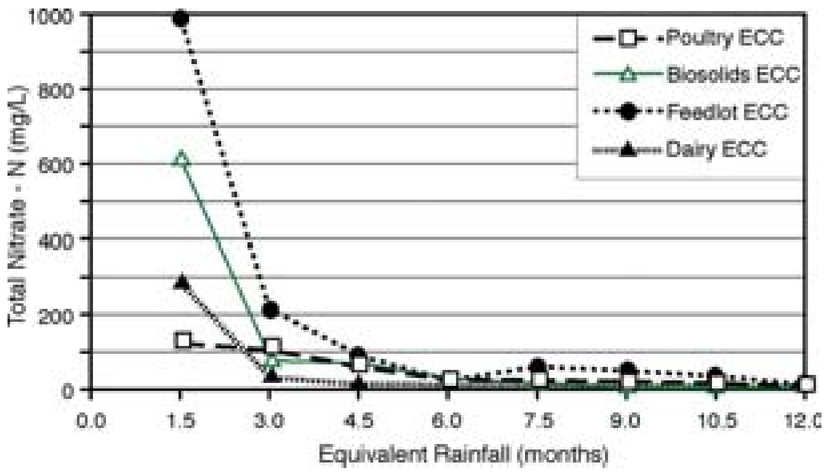


Figure 28. Extended column study results, leachate total nitrogen concentration from ECC blends.

The total nitrogen results support the conclusion that ammonia is converted to nitrate in the soil, CMT, and ECC mixtures. The nitrate concentrations in the leachate fluctuated throughout the study, but total nitrogen concentrations in the leachate decreased over time. Total nitrogen concentrations for the extended column study are included in the Appendix in Tables A-8 through A-10.

First-flush Column Studies: Phosphorus

Phosphorus is much less soluble in water than nitrate. The main method of phosphorus loss from soil is through erosion of sediments to which phosphorus is bound. The USEPA recommended criteria for phosphorus is 0.128 mg/L.

The observed first-flush results indicate very little phosphorus is leached from the control soils in the deionized water runs. However, the average total phosphorus leached from the deionized water blank was 3.68 mg/L, which is inconsistent with the results for the control soils. The phosphorus in the first-flush leachate from the control soils had 0.19 and 0.20 mg/L, respectively, for the clay and sand. In general, more total phosphorus leached from the sand CMT and ECC than from the clay CMTs in the first-flush deionized water runs. The trend was not evident with highway runoff. The leachate from the sand CMT mixtures in the highway runoff first-flush studies contained more total phosphorus than the clay CMT or the ECC mixtures. A correlation between the quantity of phosphorus in the composted manure or biosolids and the quantity of total phosphorus in the leachate for the deionized water was observed in the first-flush runs and, to a lesser extent, in the highway runoff runs.

The total phosphorus in the first-flush leachate from the highway runoff control soils (sand) was <1.21 mg/L. However, only the total phosphorus concentration observed in the leachate from the blank (0.11 mg/L) fell below the USEPA recommended criteria for phosphorus. Average values from three test runs are presented in Table 29. The complete data set is included in the Appendix in Tables A-3 and A-4.

Table 29. First-Flush Leachate Study Analytical Results for Phosphorus

			Phosphorus	
			Deionized Water	**Highway Runoff**
			mg/L	**mg/L**
Controls	Blank	NA	3.68	0.11
	Clay	Soil	0.19	0.19
	Sand	Soil	0.20	1.21
Composted Poultry Litter	Clay	CMT	22.03	12.8
	Sand	CMT	59.00	24.2
	Wood Chips	ECC	26.21	3.83
Composted Biosolids	Clay	CMT	32.02	0.58
	Sand	CMT	16.99	4.18
	Wood Chips	ECC	9.10	1.56
Composted Feedlot Manure	Clay	CMT	3.42	20.1
	Sand	CMT	25.36	27.3
	Wood Chips	ECC	32.33	9.2
Composted Dairy Cattle Manure	Clay	CMT	3.89	0.37
	Sand	CMT	12.34	2.89
	Wood Chips	ECC	9.47	0.88

Extended Column Studies: Phosphorus

Concentrations of total phosphorus in the leachate of clay CMT extended column studies are presented in Figure 29. Initial total phosphorus concentrations in the leachate from the composted poultry litter and composted biosolids clay CMT blends were 1.71 and 5.38 mg/L, respectively, and are lower than the average first-flush total phosphorus concentrations for the same blends. However, the total phosphorus concentrations in the leachate from the composted feedlot manure and composted dairy cattle manure clay CMT blends correlated well with the average first-flush total phosphorus leachate concentrations. Total phosphorus concentrations in the leachate from composted dairy cattle manure clay CMT decreased throughout the extended study from 4.12 mg/L after 1.5 months of equivalent rainfall to 0.74 mg/L after 9 months of equivalent rainfall. Total phosphorus concentrations in the leachate from composted poultry litter clay CMT were as low as 1.71 mg/L, increased through 4.5 months of equivalent rainfall to 10 mg/L, decreased to 0.73 mg/L through 10.5 months of equivalent rainfall, and increased again to 1.33 mg/L after 12 months of equivalent rainfall. Similarly, total phosphorus concentrations in the leachate from composted biosolids clay CMT decreased from 5.38mg/L after 1.5 months of equivalent rainfall to 1.31 mg/L after 4.5 months of equivalent rainfall, alternately increased and decreased through 7.5 months of equivalent rainfall, and finally decreased to 0.32 mg/L after 12 months of equivalent rainfall. Total phosphorus concentration in the leachate from composted feedlot manure clay CMT stayed relatively unchanged through the first 3 months of equivalent rainfall, increased to 26.2 mg/L after 4.5 months of equivalent rainfall, and decreased to 13.5 mg/L after 6 months of equivalent rainfall. An insufficient volume of leachate was collected from the composted feedlot manure clay CMT to obtain any further data. Total phosphorus concentrations in the leachate from the clay control alternately increased to a high of 0.73 mg/L and decreased to a low of 0.02 mg/L throughout the extended study.

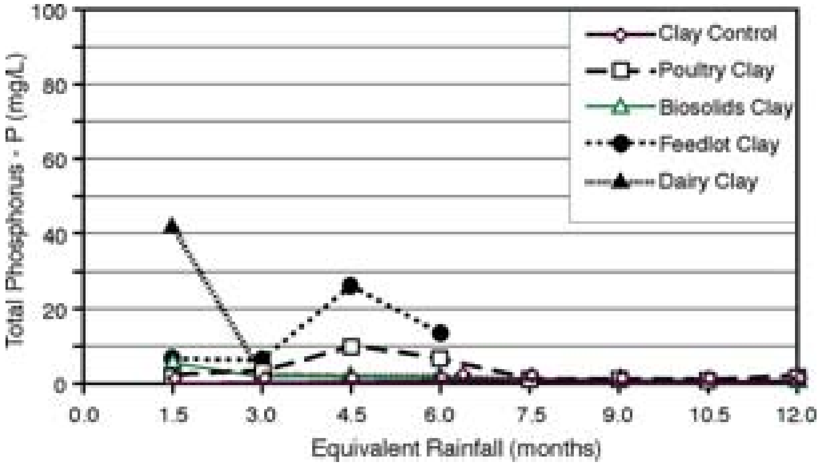


Figure 29. Extended column study results, leachate phosphorus concentration from clay CMT blends.

Concentrations of total phosphorus in leachate of sand CMT extended column studies are presented in Figure 30. Initial total phosphorus concentrations in the leachate from all sand CMT blends correlated well with first-flush total phosphorus leachate concentrations. Initial total phosphorus concentrations in the leachate from composted feedlot manure and composted poultry litter sand CMTs were 65.8 and 63.7 mg/L, respectively. The total phosphorus concentrations in the leachate from composted feedlot manure and composted poultry litter sand CMT decreased throughout the extended study to less than 7 mg/L. The total phosphorus concentrations in the leachate from composted biosolids and composted dairy cattle manure initially were 3.0 and 4.06 mg/L, respectively, and alternately increased and decreased. The total phosphorus concentrations in the leachate from composted biosolids sand CMT increased from 3.0 to 3.62 mg/L between 1.5 and 3 months of equivalent rainfall, decreased to 2.65 mg/L after 4.5 months, increased again to 3.5 mg/L after 9 months of equivalent rainfall, and remained virtually unchanged through the remainder of the study. The total phosphorus concentration in the leachate from composted dairy cattle manure increased from 4.06 to 8.3 mg/L between 1.5 and 3 months of applied rainfall, decreased to 6.09 mg/L after 4.5 months, and alternately increased and decreased until 9 months of equivalent rainfall, at which time total phosphorus concentrations in the leachate from composted dairy cattle manure sand CMT decreased from 7.52 to 4.8 mg/L after 12 months of equivalent rainfall. Total phosphorus concentrations in the leachate from the sand control decreased from 0.62 to 0.10 mg/L between 1.5 months of equivalent rainfall and 3 months of equivalent rainfall, increased to 0.57 mg/L after 4.5 months, decreased to 0.20 mg/L after 6 months of equivalent rainfall, and increased again to 3.39 mg/L after 7.5 months. Phosphorus concentrations decreased to approximately 0.2 mg/L and remained low through 12 months of equivalent rainfall.

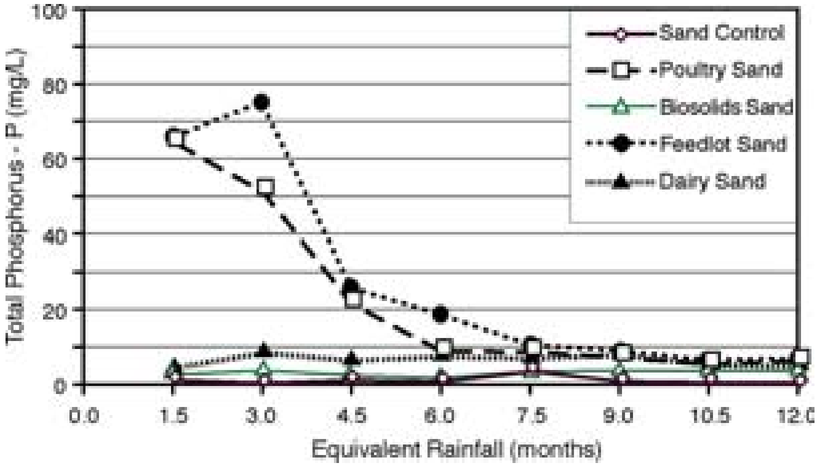


Figure 30. Extended column study results, leachate phosphorus concentration from sand CMT blends.

Concentration of total phosphorus in leachate of ECC extended column studies are illustrated in Figure 31. As in the first-flush leachate results, initial concentrations of total phosphorus in the leachate were highest in the composted feedlot manure ECC. Total phosphorus concentrations in the leachate from all ECC blends decreased from the first application of rainfall through 6 months of equivalent applied rainfall, then increased between 6 and 7.5 months, and decreased through the end of the study. Extended column study analytical results for phosphorus concentration are included in the Appendix in Tables A-11 through A-13.

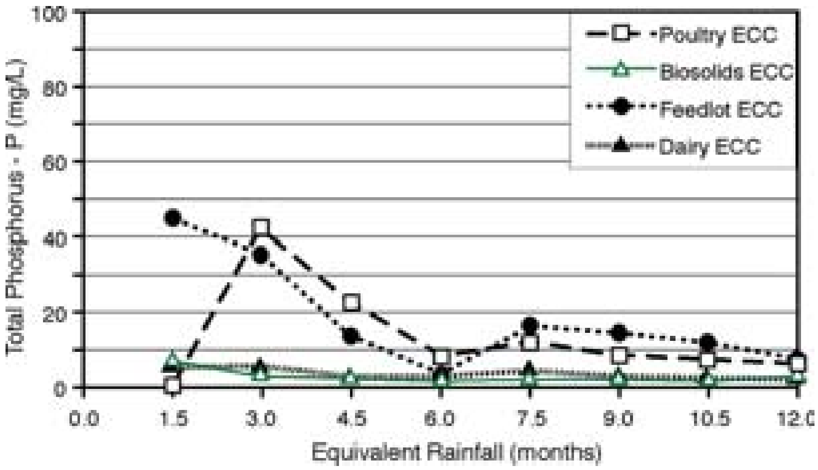


Figure 31. Extended column study results, leachate phosphorus concentration from ECC blends.

Metals

The concentration of metals in the leachate was also investigated. The concentration of metals in the leachate was expected to be small because of the immobilization reactions between metals and soil particles including chemical exchange, adsorption, precipitation, cation exchange capacity, and complexation. Only a few metals were selected for analysis to be representative of the potential for contamination. The three metals chosen somewhat arbitrarily, were copper, zinc, and lead.

Average concentrations of copper, zinc, and lead in leachate are presented in Table 30. These data are based on three test runs. The complete data set is included in the Appendix in Tables A-3 and A-4.

Table 30. First-Flush Leachate Study Analytical Results for Metals

			Copper		**Lead**		**Zinc**	
			Deionized Water	**Highway Runoff**	**Deionized Water**	**Highway Runoff**	**Deionized Water**	**Highway Runoff**
			mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Controls	Blank	NA	0.04	0.00	ND	ND	0.09	0.13
	Clay	Soil	ND	ND	ND	ND	ND	0.03
	Sand	Soil	ND	ND	ND	ND	0.02	0.17
Composted Poultry Litter	Clay	CMT	0.52	0.09	0.02	ND	0.65	ND
	Sand	CMT	0.59	0.50	ND	ND	0.56	0.62
	Wood Chips	ECC	0.48	0.08	ND	ND	0.51	0.18
Composted Biosolids	Clay	CMT	0.15	0.02	ND	ND	0.42	ND
	Sand	CMT	0.14	0.16	ND	ND	0.14	0.28
	Wood Chips	ECC	0.08	0.06	ND	ND	0.13	0.17
Composted Feedlot Manure	Clay	CMT	0.10	0.13	ND	ND	0.20	0.23
	Sand	CMT	0.08	0.10	ND	ND	0.25	0.34
	Wood Chips	ECC	0.15	0.03	ND	ND	0.55	0.21
Composted Dairy Cattle Manure	Clay	CMT	0.04	ND	ND	ND	0.17	ND
	Sand	CMT	0.07	0.03	ND	ND	0.19	0.14
	Wood Chips	ECC	0.07	0.01	ND	ND	0.14	0.13

First-flush Column Studies: Copper

Copper was non-detectable in the leachate from the sand and clay controls. The concentration in the leachate from the blank (gravel) was <0.04 mg/L. Concentrations of copper in the leachate from the composted biosolids, composted feedlot manure, and composted dairy cattle manure CMT and ECC mixtures were less than 0.16 mg/L for the first-flush highway runoff and deionized water studies. Concentrations of copper in the leachate from composted poultry litter CMT and ECC ranged from 0.48 to 0.59 mg/L in the deionized water first-flush studies.

The concentrations of copper in the leachate from the composted poultry litter sand CMT was 0.50 mg/L in the highway runoff first-flush studies. Copper concentrations on a dry weight basis were 294 and 337.7mg/kg, respectively, for composted poultry litter and composted biosolids. However, the high copper concentration in the composted biosolids did not translate to a high first-flush leachate concentration for the composted biosolids CMT and ECC. The data indicate that clay mixtures retained more metals than did sand mixtures in the highway runoff series. Clay mixtures were expected to retain more metals as a result of the interaction between negatively charged clay soil particles and positively charged metal ions. However, concentrations of metal in the leachate in the first-flush deionized water studies were independent of soil type.

Extended Column Studies: Copper

Concentrations of copper in leachate from clay CMT are illustrated in Figure 32. Copper concentrations in the leachate from all CMT and ECC blends decreased from the first application of equivalent rainfall through 12 months of equivalent rainfall except for the composted poultry litter and composted feedlot manure CMT and ECC blends. Copper concentrations in the leachate from composted poultry litter and composted feedlot manure CMT and ECC blends increased between 1.5 and 3 months of equivalent applied rainfall and decreased thereafter. Initial copper concentrations ranged from 0.08 mg/L in the leachate from the composted poultry litter clay CMT to 0.43 mg/L in the leachate from the composted dairy cattle manure clay CMT. Copper concentrations in the leachate from composted dairy cattle manure clay CMT initially were approximately 0.4 mg/L; and the copper concentrations decreased to 0.03 mg/L after 3 months of equivalent rainfall and remained at 0.02 mg/L through 12 months of equivalent applied rainfall. In all cases copper concentrations in the leachate of clay CMTs were less than 0.10 mg/L after 6 months of equivalent applied rainfall.

Concentration of copper in the leachate from the sand CMT column studies are illustrated in Figure 33. Initial copper concentrations in the leachate from the sand control and the composted poultry litter sand CMT were 0.02 and 0.50 mg/L, respectively. Copper concentrations in the leachate from composted biosolids, composted feedlot manure, and composted dairy cattle manure were less than 0.1 mg/L after 3 months of equivalent rainfall. Copper concentrations in the leachate from composted poultry litter sand CMT was less than 0.10 mg/L after 9 months of equivalent rainfall. Copper concentrations in the leachate from the sand control remained at 0.02 mg/L or below throughout the extended study.

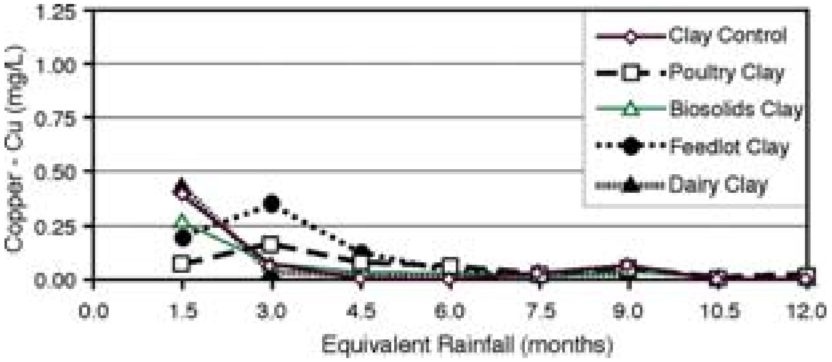


Figure 32. Extended column study results, leachate copper concentration from clay CMT blends.

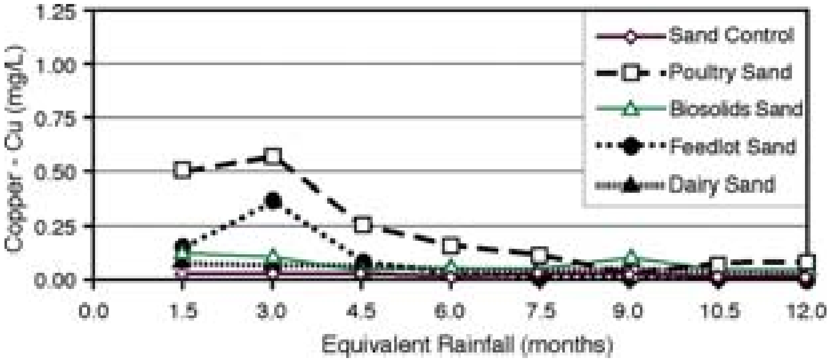


Figure 33. Extended column study results, leachate copper concentration from sand CMT blends.

Concentration of copper in the leachate from ECC extended column studies are illustrated in Figure 34. Copper concentrations in the leachate from all ECC blends ranged from 0.04 mg/L for the composted poultry litter ECC leachate to 0.30 mg/L for the composted biosolids ECC leachate. Copper concentrations in the leachate from composted biosolids, composted feedlot manure, and composted dairy cattle manure decreased to less than 0.1 mg/L after 4.5 months of equivalent rainfall. Similarly, copper concentrations in the leachate from composted poultry litter ECC decreased to less than 0.10 mg/L after 9 months of equivalent rainfall. Extended column study analytical results for copper concentration are included in the Appendix in Tables A-14 through A-16.

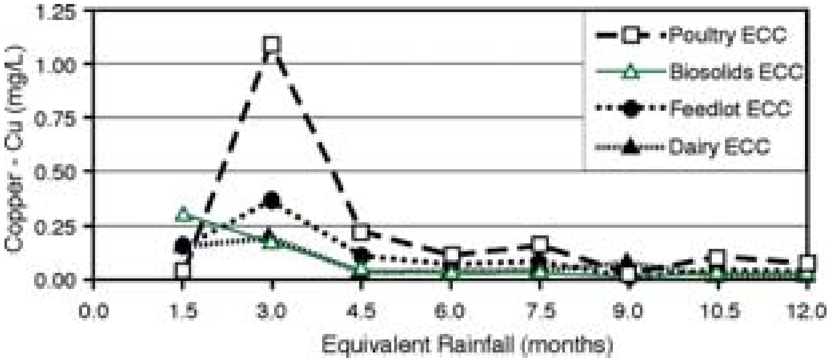


Figure 34. Extended column study results, leachate copper concentration from ECC blends.

First-flush and Extended Column Studies: Lead

Lead concentration in the compost by itself was less than 33.3 mg/kg dry weight for all four composts. Lead concentrations in the leachate from the first-flush studies were non detectable with the exception of the composted poultry litter CMT clay blend with deionized water, in which the concentration was 0.02 mg/L. Average values from three test runs are presented in Table 30. Lead was not analyzed in the extended column studies because lead was essentially non detectable in the deionized water runs in the first-flush column studies. The complete first-flush data set is included in the Appendix in Tables A-3 and A-4.

First-flush Leachate Column Studies: Zinc

Zinc concentrations in the leachate from the sand, clay, and gravel controls in the first-flush studies were low. Zinc concentrations in the leachate from the controls for the highway runoff first-flush studies ranged from 0.03 to 0.17 mg/L. A correlation exists between the quantity of zinc in the compost and the concentration in the leachate. The zinc concentrations in the composted poultry litter and composted biosolids by themselves was two to three times greater than the zinc content of the other two composted materials. However, the zinc concentration in the composted material did not translate to high zinc concentrations in the first-flush leachate for the composted biosolids mixtures. The concentration of zinc in the first-flush leachate from the composted poultry litter CMT ranged from 0.56 to 0.65 mg/L. First-flush leachate concentrations on the whole were less than 0.7 mg/L. Average values from three test runs are presented in Table 30. The complete data set is included in the Appendix in Tables A-3 and A-4.

Extended Column Studies: Zinc

Zinc concentrations in the leachate from the clay CMT extended column studies are illustrated in Figure 35. Initial zinc leachate concentrations ranged from 0.84 mg/L for composted feedlot manure clay CMT to 1.57 mg/L for composted biosolids clay CMT. Zinc concentrations in the leachate from composted poultry litter clay CMT decreased from 1.28 mg/L to less than 0.20 mg/L after 10.5 months of equivalent rainfall. Zinc concentrations in the leachate from composted biosolids clay CMT increased from 1.57 to 2.75 mg/L after 3 months of equivalent rainfall but generally decreased thereafter to less than 0.30 mg/L. Zinc concentrations in the leachate from composted feedlot manure clay CMT increased from 0.84 to 2.93 mg/L after 4.5 months of equivalent rainfall and decreased to 1.05 mg/L after 7.5 months of equivalent rainfall. The volume of leachate collected was insufficient to obtain any additional data points for composted feedlot manure clay CMT. Zinc concentrations in the leachate from composted dairy cattle manure clay CMT decreased from 0.90 to 0.39 mg/L after 4.5 months of equivalent rainfall but increased to 1.93 and 1.64 mg/L between 7.5 and 9 months of equivalent rainfall, respectively.

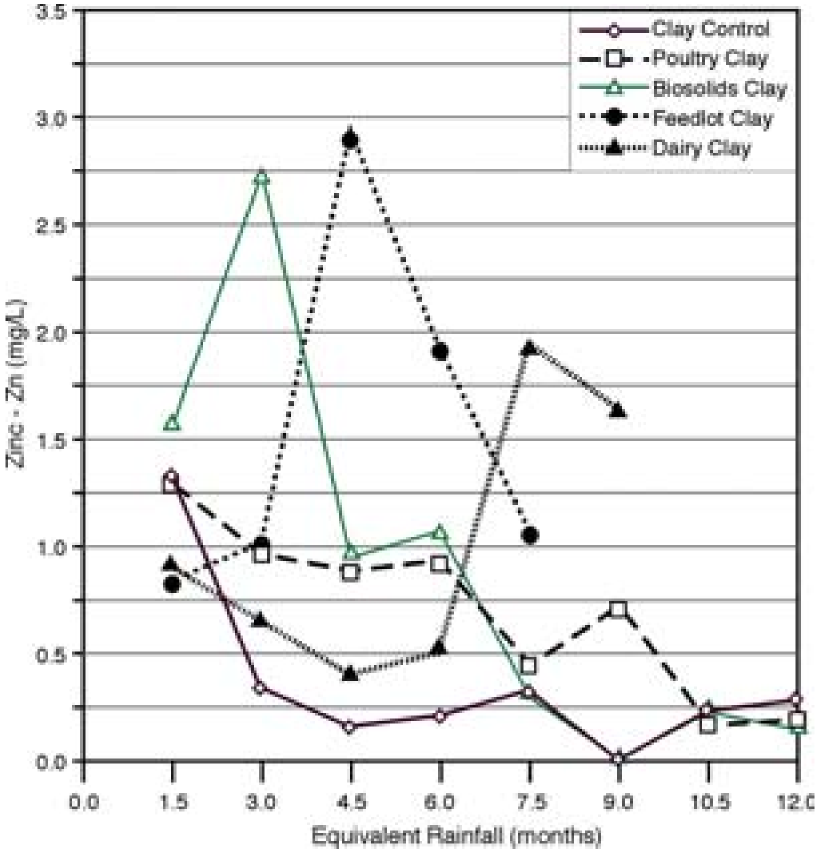


Figure 35. Extended column study results, leachate zinc concentration from clay CMT blends.

Concentration of zinc in the leachate from the sand CMT extended column studies are illustrated in Figure 36. Initial zinc concentrations in the leachate ranged from 0.39 mg/L for composted dairy cattle manure sand CMT to 1.27 mg/L for feedlot manure sand CMT. Zinc concentrations in the leachate from composted poultry litter sand CMT increased from 0.85 to 1.28 mg/L after 3 months of equivalent rainfall but generally decreased thereafter to 0.2 mg/L after 12 months of equivalent rainfall. Zinc concentrations in the leachate from composted biosolids sand CMT increased from 0.7 to 1.17 mg/L after 3 months of equivalent rainfall but generally decreased thereafter to less than 0.40 mg/L. Zinc concentrations in the leachate from composted feedlot manure sand CMT increased from 1.27 to 2.48 mg/L after 3 months of equivalent rainfall but decreased thereafter to less than 0.20 mg/L after 12 months of equivalent rainfall. Zinc concentrations in the leachate from composted dairy cattle manure sand CMT increased from 0.39 to 0.49 mg/L after 4.5 months of equivalent rainfall, but generally decreased thereafter to less than 0.30 mg/L after 12 months of equivalent applied rainfall. Zinc concentrations in the leachate from the sand control decreased from 0.46 mg/L after 1.5 months to 0.12 mg/L after 12 months of equivalent applied rainfall.

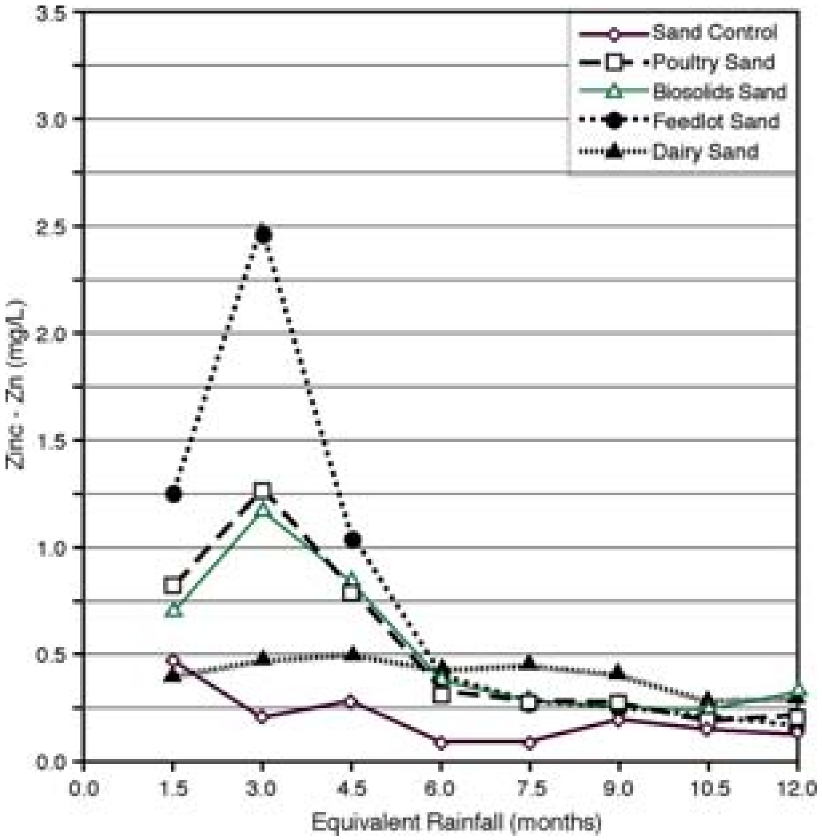


Figure 36. Extended column study results, leachate zinc concentration from sand CMT blends.

Concentrations of zinc in leachate from the ECC extended column studies are illustrated in Figure 37. Initial zinc concentrations in the leachate ranged from 0.54 mg/L for composted dairy cattle manure ECC to 3.02 mg/L for composted biosolids ECC. Zinc concentrations in the leachate from composted poultry litter ECC increased from 0.76 to 1.15 mg/L after 3 months of equivalent rainfall but decreased to less than 0.30 mg/L after 7.5 months of applied rainfall. Zinc concentrations in the leachate from composted biosolids ECC decreased from 3.02 mg/L to less than 0.30 mg/L after 6 months of applied rainfall. Zinc concentrations in the leachate from composted feedlot manure ECC increased from 2.18 to 2.52 mg/L after 3 months of applied rainfall and generally decreased thereafter to 0.40 mg/L or less after 9 months of equivalent rainfall. Zinc concentrations in the leachate from composted dairy cattle manure ECC increased from 0.54 to 1.03 mg/L after 3 months of equivalent rainfall but generally decreased thereafter to less than 0.30 mg/L after 12 months of equivalent rainfall. Extended column study analytical results for zinc concentration are included in the Appendix in Tables A-17 through A-19.

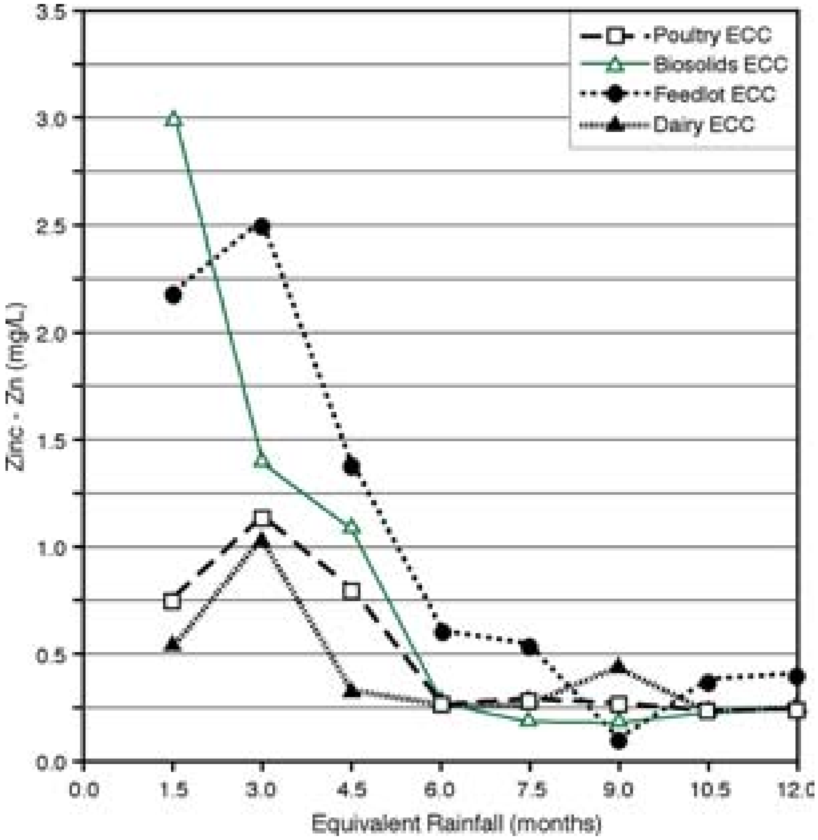


Figure 37. Extended column study results leachate zinc concentration from ECC blends.

Solids

The concentrations of dissolved and suspended solids also were evaluated. The TCEQ SWQS established a maximum annual average of 400 mg/L for TDS. Total suspended solids also should be limited because sediment can transport immobilized metals and other contaminants that are associated with the suspended solids into receiving streams.

First-flush Column Studies: TDS

The total dissolved solids concentrations in the leachate from the sand and clay controls in the first-flush deionized water studies were 118 and 113 mg/L, respectively.

These concentrations of TDS are less than the average TDS concentrations of highway runoff reported by Barrett (1995b). An average TDS concentration of 2,440 mg/L was observed for the leachate from the gravel-only control, which appears to be an anomaly. A dilution calculation error in reporting the concentration for the gravel only blank may account for a TDS concentration that is ten times higher than the TDS in the leachate from the soil controls. The average TDS concentrations were 597 mg/L, 290 mg/L, and 240 mg/L, for the sand, gravel-only, and clay controls, respectively for the highway runoff first-flush studies. None of the leachate from the CMT or ECC first-flush studies contained less than 500 mg/L TDS. Observed first-flush results indicate TDS concentrations from CMT and ECC averaged 3,000 mg/L for the deionized water runs and somewhat less than 3,000 mg/L for the highway runoff runs. The leachate from the composted poultry litter consistently had the lowest concentration of TDS in the first-flush studies, and the composted feedlot manure blends consistently produced leachate with the greatest concentration of TDS. Average values from three test runs are presented in Table 31. The full data set is included in the Appendix in Tables A-3 and A-4.

Table 31. First-Flush Leachate Study Analytical Results for Total Dissolved Solids

			TDS	
			Deionized Water	**Highway Runoff**
			mg/L	**mg/L**
Controls	Blank	NA	2440	290
	Clay	Soil	118	240
	Sand	Soil	113	597
Composted Poultry Litter	Clay	CMT	1800	1533
	Sand	CMT	1977	2287
	Wood Chips	ECC	1590	667
Composted Biosolids	Clay	CMT	4332	1062
	Sand	CMT	1217	1540
	Wood Chips	ECC	2048	583
Composted Feedlot Manure	Clay	CMT	4830	7880
	Sand	CMT	3213	7287
	Wood Chips	ECC	7093	2193
Composted Dairy Cattle Manure	Clay	CMT	2447	2103
	Sand	CMT	2788	2527
	Wood Chips	ECC	1061	790

Extended Leachate Column Study: TDS

Clay CMT TDS concentrations are illustrated in Figure 38. Initial total dissolved solids concentrations in the leachate for composted feedlot and composted biosolids ECC and composted feedlot sand CMT ranged from 15,800 to 8,700 mg/L. Initial and final TDS concentrations in the leachate from clay CMT blends were lowest overall. Initial TDS concentrations in the leachate ranged from 229 mg/L for the clay control to 2,830 mg/L for composted dairy cattle manure clay CMT. TDS concentrations in the leachate were less than 400 mg/L for composted poultry litter, composted biosolids clay CMT, and the clay control after 12 months of equivalent applied rainfall. The volume of leachate collected from the feedlot manure and dairy cattle manure during the last half of the extended study was insufficient to obtain additional data points.

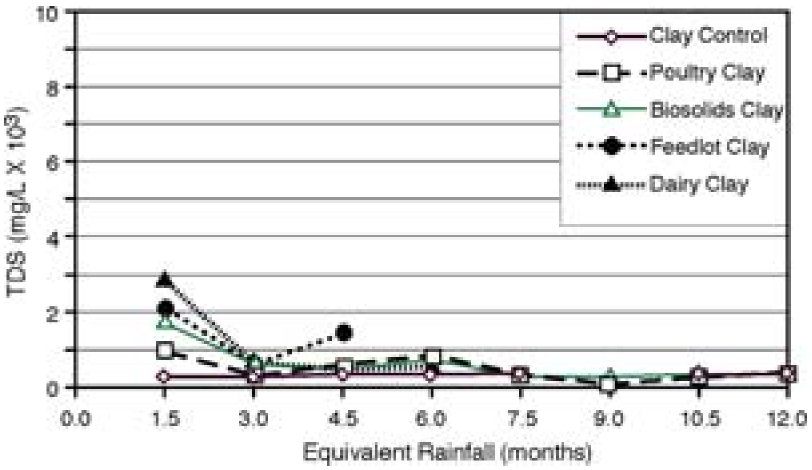


Figure 38. Extended column study results, leachate TDS concentration from clay CMT blends.

Sand CMT TDS concentration in the leachate from the extended column studies are illustrated in Figure 39. Initial TDS concentrations in the sand CMT blends ranged from 445 mg/L for the sand control to 8,700 mg/L for the composted feedlot manure sand CMT. TDS concentrations in the sand control leachate dropped below 400 mg/L after 3 months of equivalent applied rainfall and to 220 mg/L after 12 months of equivalent applied rainfall. TDS concentrations in the leachate from composted biosolids decreased to less than 1,000 mg/L after 3 months of applied rainfall and below 400 mg/L after 12 months of equivalent applied rainfall. TDS concentrations in the leachate from composted poultry litter and composted dairy cattle manure sand CMT were below 1,000 mg/L after 4.5 months of equivalent applied rainfall and less than 400 mg/L after 12 months of equivalent applied rainfall. TDS concentrations in the leachate from composted feedlot manure sand CMT were below 1,000 mg/L after 6 months of equivalent applied rainfall and less than 400 mg/L after 12 months of equivalent applied rainfall.

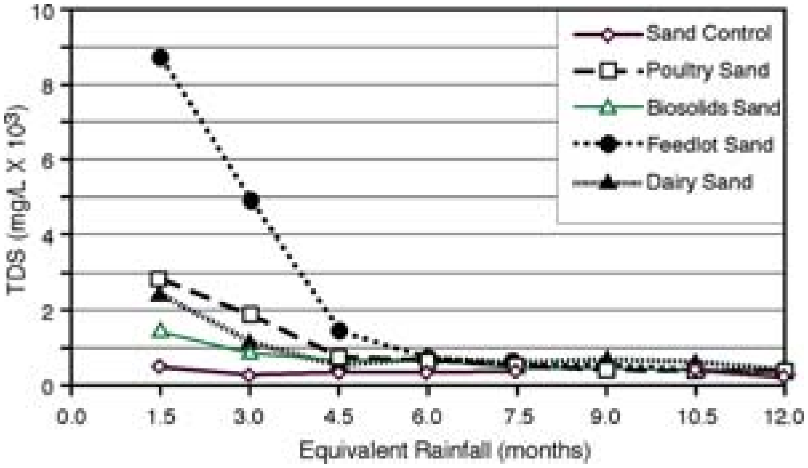


Figure 39. Extended column study results, leachate TDS concentration from sand CMT blends.

TDS concentrations in leachate from ECC extended column studies are illustrated in Figure 40. Initial TDS concentrations in the ECC blends ranged from 1,260 mg/L for composted poultry litter to 15,800 mg/L for composted feedlot manure. TDS concentrations in the leachate from composted dairy cattle manure was less than 1,000 mg/L after 3 months of equivalent applied rainfall and below 400 mg/L after 12 months of equivalent applied rainfall. TDS concentrations in the leachate from composted biosolids and composted poultry litter ECCs decreased below 1,000 mg/L after 4.5 months of equivalent applied rainfall. TDS concentrations in the leachate from composted biosolids dropped to less than 400 mg/L after 10.5 months of equivalent applied rainfall, and concentrations in the leachate from composted poultry litter dropped to 450 mg/L after 12 months of equivalent applied rainfall. TDS concentrations in the leachate from composted feedlot manure ECC dropped below 1,000 mg/L after 10.5 months of equivalent applied rainfall to less than 750 mg/L after

12 months of equivalent applied rainfall. Extended column study analytical results for TDS concentrations are included in the Appendix in Tables A-20 through A-22.

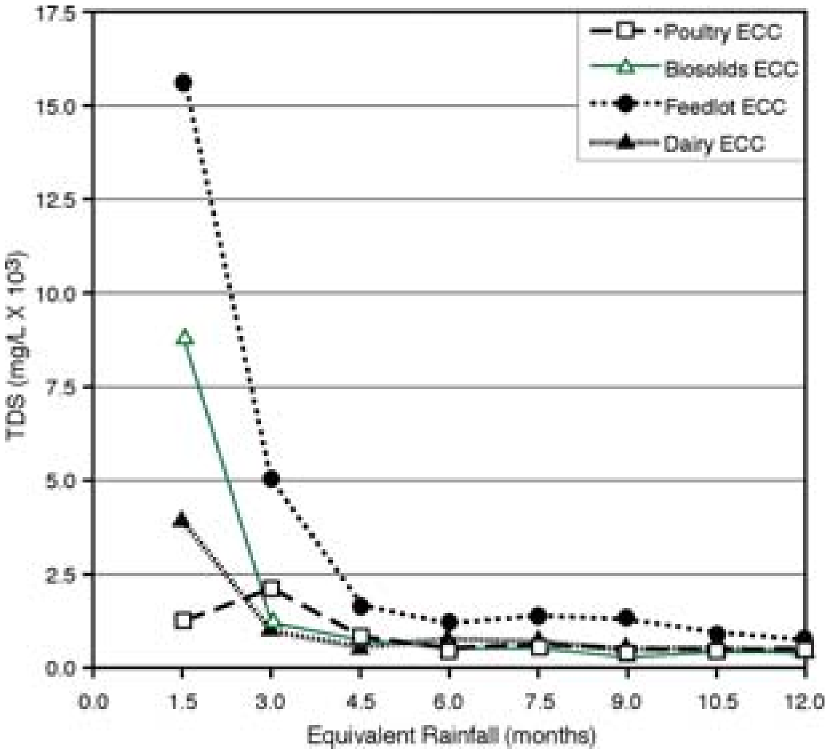


Figure 40. Extended column study results, leachate TDS concentration from ECC blends.

First-flush Column Studies: TSS

Average concentrations of total suspended solids (TSS) on the basis of three test runs are presented in Table 32. These results indicate that TSS concentrations in the leachate of the first-flush studies were highest in the sand mixtures in both the deionized water and highway runoff for all soil compost blends. TSS concentrations in the leachate observed in the deionized water first-flush studies were 463 to 1,070 mg/L for the sand CMT, 199 to 568 mg/L for the clay CMT, and 170 to 650 mg/L for the ECC. Leachate from the sand control contained 2,425 mg/L of TSS and the clay control contained 993 mg/L of TSS in highway runoff First-flush studies. The results indicate that the TSS concentrations range from 32 to 93 mg/L for all compost clay CMTs, as compared to 215 to 1,848 mg/L for all compost sand CMTs in the highway runoff first-flush studies. The TSS concentrations for the ECC mixes were consistent for all four composts ranging from 245 to 325 mg/L TSS. The addition of compost to the clay increased the TSS of the leachate for the deionized water first-flush studies but decreased the TSS in the highway runoff first-flush studies. Addition of compost to sand decreased TSS concentrations in the leachate in the highway runoff first-flush studies. The complete data set is included in the Appendix in Tables A-3 and A-4.

Table 32. First-Flush Leachate Study Analytical Results for Total Suspended Solids.

			TSS	
			Deionized Water mg/L	Highway Runoff mg/L
Controls	Blank	NA	232	300
	Clay	Soil	133	993
	Sand	Soil	538	2425
Composted Poultry Litter	Clay	CMT	568	40
	Sand	CMT	628	1848
	Wood Chips	ECC	420	302
Composted Biosolids	Clay	CMT	518	32
	Sand	CMT	863	908
	Wood Chips	ECC	650	325
Composted Feedlot Manure	Clay	CMT	328	65
	Sand	CMT	1070	215
	Wood Chips	ECC	170	292
Composted Dairy Cattle Manure	Clay	CMT	199	93
	Sand	CMT	463	533
	Wood Chips	ECC	293	245

Extended Column Studies: TSS

The TSS concentrations in the leachate from the clay CMT extended column studies are illustrated in Figure 41. Initial total suspended solids concentrations in the leachate from clay CMT ranged from 10 mg/L for composted poultry litter to 495 mg/L for composted biosolids. Initial TSS concentrations in the leachate from the clay control were 53 mg/L, and they decreased through the extended study to 4 mg/L. Initial TSS concentration in the leachate from composted feedlot manure was 230 mg/L and decreased to 30 mg/L after 4.5 months of equivalent applied rainfall. Initial TSS concentrations in the leachate from composted dairy cattle manure was 325 mg/L and decreased to 15 mg/L after 6 months of equivalent applied rainfall. TSS concentrations in the leachate from composted biosolids and composted poultry litter initially declined, increased after 7.5 months of equivalent applied rainfall, then decreased again through the 12th month of equivalent applied rainfall. The volume of leachate that could be collected in a given application of simulated rainfall from the composted feedlot manure and composted dairy cattle manure during the last half of the extended study was insufficient to obtain additional data points.

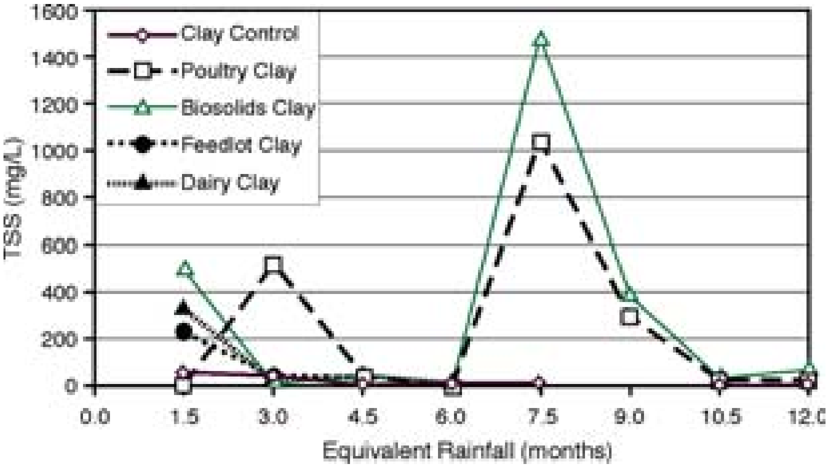


Figure 41. Extended column study results
leachate TSS concentration from clay CMT blends.

The TSS concentrations in the leachate from the sand CMT extended column studies are illustrated in Figure 42. Initial TSS concentrations in the leachate in the sand CMT blends ranged from 130 mg/L for composted dairy cattle manure CMT to 1,180 mg/L for the sand control. TSS concentrations in the leachate from all sand CMT blends and the sand control initially decreased from 1.5 to 3 months of equivalent applied rainfall, but increased after the third application before decreasing again through the remainder of the study. TSS concentrations in the leachate from composted dairy cattle manure initially decreased from 130 to 5 mg/L, increased to 920 mg/L after 6 months of equivalent applied rainfall, and decreased to 235 mg/L after 12 months of equivalent applied rainfall. TSS concentrations in the leachate from composted biosolids initially decreased from 150 to 20 mg/L, increased to 255 mg/L after 4.5 months of equivalent applied rainfall, and decreased again to 55 mg/L in the 9th through 12th months of equivalent applied rainfall. TSS concentrations in the leachate from composted feedlot manure initially decreased from 155 to 110 mg/L, increased to 135 mg/L after 4.5 months of equivalent rainfall, and decreased to 20 mg/L after 10.5 months of equivalent rainfall. TSS concentrations in the leachate from composted poultry litter initially decreased from 455 to 134 mg/L, increased to 345 mg/L after 4.5 months of equivalent rainfall, and decreased again to 60 mg/L after 12 months of equivalent rainfall. TSS concentrations in the leachate from the sand control initially decreased from 1,180 to 79 mg/L, increased to 605 mg/L after 4.5 months of equivalent rainfall, and decreased again to 100 mg/L after 12 months of equivalent applied rainfall.

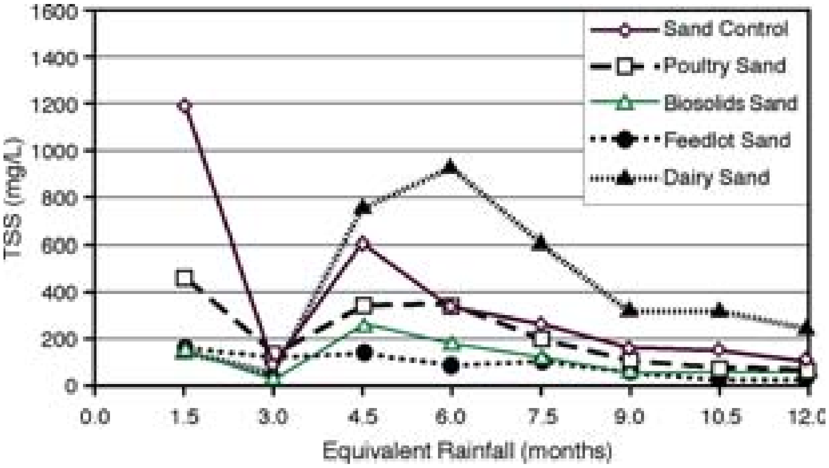


Figure 42. Extended column study results,
leachate TSS concentration from sand CMT blends.

The TSS concentrations in the leachate from the ECC extended column studies are illustrated in Figure 43. Initial TSS concentrations in the ECC blends ranged from 25 mg/L for the composted poultry litter to 525 mg/L for the composted feedlot manure. TSS concentrations in the leachate from composted poultry litter and composted biosolids ECCs initially increased. TSS concentrations in the leachate from composted poultry litter increased from 25 mg/L after 1.5 months equivalent rainfall to 340 mg/L after 6 months of equivalent rainfall, and decreased to 35 mg/L after 12 months of equivalent rainfall. TSS concentrations leachate from the composted biosolids initially increased from 30 mg/L after 1.5 months of equivalent rainfall to 390 mg/L after 4.5 months of equivalent rainfall. TSS concentrations dropped to 95 mg/L after 6 months of equivalent rainfall, and increased after 9 months to 160 mg/L, and decreased again in the last third of the extended study. TSS concentrations in the leachate from composted dairy cattle manure and feedlot manure initially decreased, then increased after the third and fourth rainfall applications, and decreased again through the last half of the study. TSS concentrations in the leachate from composted dairy cattle manure decreased from 185 mg/L after the first application to 55 mg/L after the second application, then increased to 530 mg/L after the third application or 4.5 months of equivalent rainfall. TSS concentrations decreased through the remainder of the study to 60 mg/L by 10.5 months of equivalent rainfall. TSS concentrations in the leachate from feedlot manure initially decreased from 525 mg/L to 105 mg/L through the second and third applications, then increased to 150 mg/L after the fourth application, and decreased again to10 mg/L after eight applications or 12 months of equivalent rainfall. Extended column study analytical results for TSS concentration are included in the Appendix in Tables A-23 through A-25.

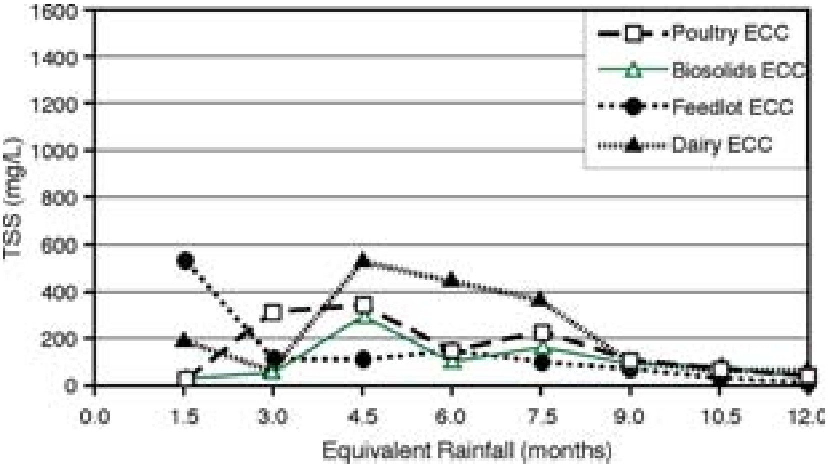


Figure 43. Extended column study results leachate TSS concentration from ECC blends.

Fecal Coliform

Barrett et al. (1995a) reported average fecal coliform of 13,000 MPN/100 mL in the runoff from the Austin site. Results from the first-flush study indicate average bacterial levels of 1,000 to 6,000 MPN/100 mL in the leachate from the CMT, ECC, and control soils. Unfortunately, the highway runoff used for this project was not analyzed for fecal coliform prior to being applied to either gravel-only or soil controls. Therefore, it is difficult to ascertain the baseline condition independent of other factors. Furthermore, the presence of a separate project involving the study of municipal wastewater treatment plant sludge appears to have caused some cross-contamination of the samples. CMT and ECC may reduce bacterial concentrations in highway runoff if bacteria levels are in the 10,000+ MPN/100 mL range, as is indicated in the Barrett et al. (1995a) study.

Erosion Control Studies

Two water quality samples were collected, one each from the composted dairy cattle manure CMT and the composted dairy cattle manure ECC runoff. Results from the analysis are included in the Appendix as Table A-26.

Erosion control study results for clay control versus composted dairy cattle manure clay CMT are illustrated in Figure 44, and results for clay control versus composted dairy cattle manure ECC are illustrated in Figure 45. Results from the erosion control studies indicate highest peak runoff occurred at the steepest channel slope (2:1 slope) for both the clay control and the composted dairy cattle manure clay CMT blend. However, the composted dairy cattle manure clay CMT blend reduced the peak runoff rate from approximately 0.7 to 0.6 gpm. The composted dairy cattle manure ECC blend reduced the peak runoff to 0.56 gpm. The peak runoff rate decreased with decreasing slope for the control, CMT, and ECC. In addition to lowering the peak runoff rate when compared with the control, the CMT and ECC delayed the onset of runoff for all slopes versus the control soil. Initial runoff for the control soil at 2:1 slope occurred at approximately 18 minutes, whereas initial runoff for the CMT occurred at approximately 24 minutes or 6 minutes later. ECC blends appeared to delay runoff more than CMT blends did. Initial runoff for the ECC blend at 2:1 slope occurred at approximately 26 minutes or 8 minutes later. The greatest delay in onset of runoff was observed at 3:1 and 5:1 slopes for both CMT and ECC.

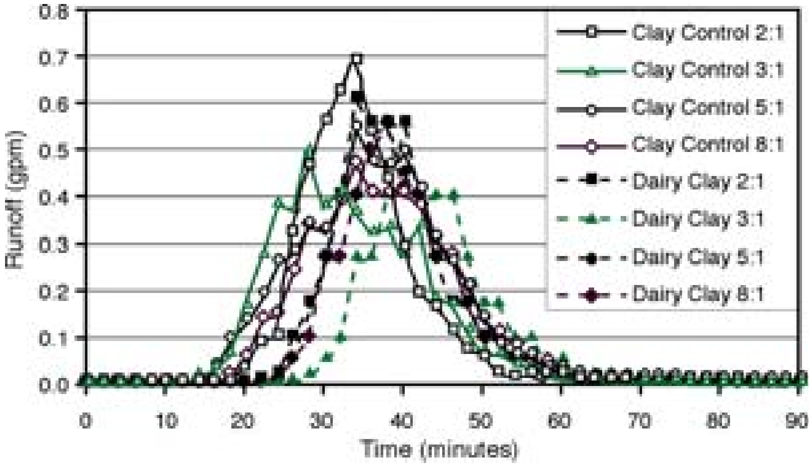


Figure 44. Runoff from clay control versus dairy cattle manure clay CMT at various slopes.

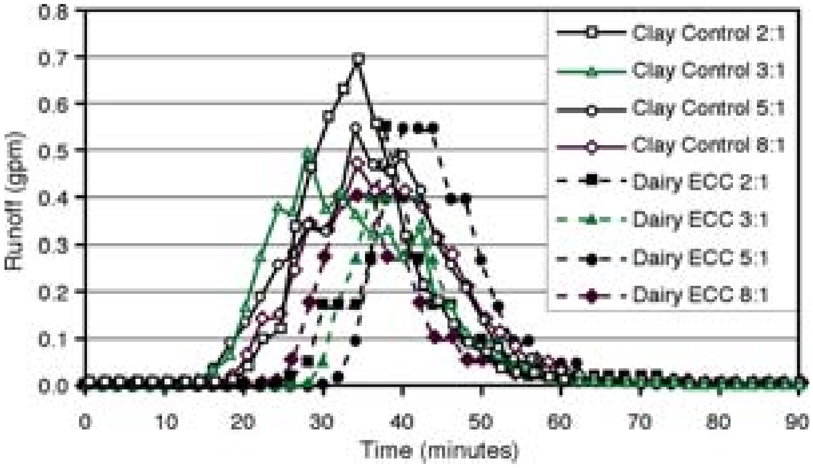


Figure 45. Runoff from clay control versus dairy cattle manure ECC at various slopes.

Results from the erosion control studies indicate all four compost clay CMT blends delayed the onset of runoff, as compared with the control, at a 3:1 slope. Composted biosolids and composted dairy cattle manure clay CMT appeared to delay runoff to the greatest extent of the CMT blends. Composted biosolids and composted dairy cattle manure CMT delayed the onset of runoff by approximately 15 minutes, whereas composted feedlot manure and composted poultry litter delayed the onset of runoff by approximately 8 minutes. Composted biosolids and composted poultry litter CMT lowered the peak runoff from 0.5 to

0.27 and to 0.4 gpm, respectively. Composted feedlot manure and composted dairy cattle manure did not appear to lower the peak runoff rate at a 3:1 slope. Erosion control study results for clay control versus all compost clay CMT blends at a 3:1 slope are illustrated in Figure 46.

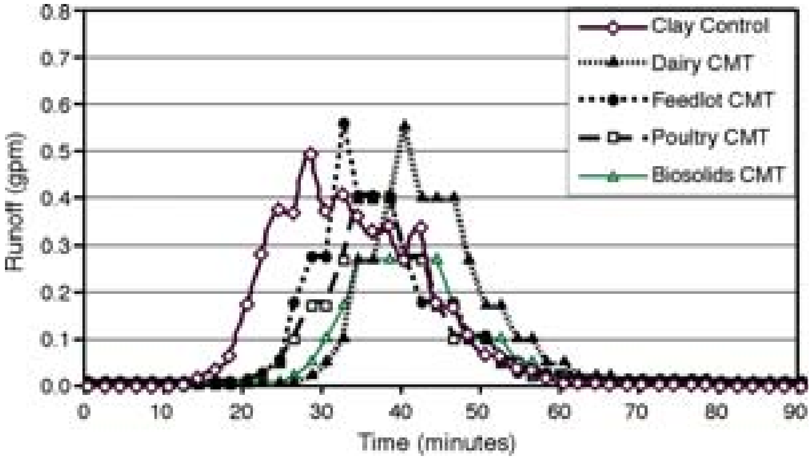


Figure 46. Runoff from clay control versus dairy, feedlot, poultry, and biosolids clay CMT blends at a 3:1 slope.

Results from the erosion control studies indicate all three compost ECC blends delayed the onset of runoff in comparison with the control at a 3:1 slope. No runoff was observed for the composted poultry litter ECC. The composted dairy cattle manure, composted feedlot manure, and composted biosolids ECC blends generally delayed the onset of runoff by approximately 15 minutes or more. Composted dairy cattle manure and composted feedlot manure ECC lowered the peak runoff rate from 0.5 to 0.4 gpm, composted biosolids reduced the peak runoff to 0.05 gpm, and composted poultry litter eliminated runoff altogether. Erosion control study results for clay control in comparison with all compost ECC blends at a 3:1 slope are illustrated in Figure 47.

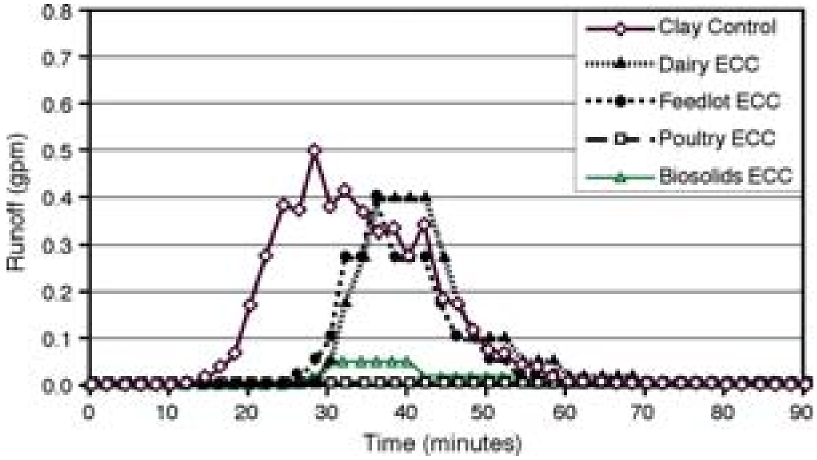


Figure 47. Runoff from clay control versus dairy, feedlot, poultry, and biosolids ECC blends at a 3:1 slope.

CONCLUSIONS

Compost Characteristics

The requirements of TxDOT Specification Item 161 are consistent with the model compost specifications set forth by AASHTO as well as those applied by other DOT's. Composted biosolids met all the limits specified in the TxDOT Specification Item 161. However the composted dairy cattle manure, composted poultry litter, composted feedlot manure failed to meet the specifications in at least one category.

Organic Matter Content should be in the range of 25-65%. Three of the four composts satisfied this criterion; however, composted dairy cattle manure only contained 10.8% organic matter partly because organic bulking agents such as wood chips or yard trimmings, etc. were not incorporated in the compost. Composted biosolids, on the other hand, in which ground yard wastes are incorporated in the composting process contained 49.1% organic matter.

Particle Size of all composted manures and the composted biosolids passed the TxDOT specifications of 95% passing the 5/8 in. sieve and 70% passing the 3/8 in. sieve.

Inert particles of all four composted materials were less than 1% inerts. TxDOT does not impose a limitation on percentage of inerts.

Salts are reported in terms of electrical conductivity. The conductivity of composted dairy cattle manure, composted poultry litter, and composted biosolids was less than the 5 dS/m which is the upper limit specified by TxDOT. Only composted feedlot manure exceeded the upper limit with a value of 12.6 dS/m.

pH specified by TxDOT should be greater than pH=5.5 and less than pH=8.5. The composted biosolids had pH =8.0. The pH of the three composted manures exceeded the upper limit with pH between 9.0 and 9.5.

Stability specified by TxDOT has an upper limit of 8 which corresponds to medium stability. The stability of all composted manures and biosolids were less than 8 or high to high-medium stability.

Maturity established by TxDOT has a lower limit of 80% seedling emergence which is in the moderately toxic range. Composts with maturity greater than 85% seedling emergence are considered non-toxic. The composted biosolids, composted dairy cattle manure, and composted poultry litter exceeded 80% seedling emergence. However, the composted feedlot manure had 0% seedling emergence which indicates extreme phytotoxicity.

Metals are regulated by the USEPA 503 regulations. All composted manures and composted biosolids passed the maximum allowed concentration of heavy metals.

Moisture is not specified by TxDOT. The moisture content of the composted manures and biosolids ranged from 20% to 38.4%. The recommended optimum moisture content for compost is 30-60% range.

Water Holding Capacity of the composted biosolids was the highest at 149 mL/100 grams and composted dairy manure was the lowest at 60 mL/100 grams. The water holding capacities of the composted feedlot manure and composted poultry litter were 105 and 111 mL/100 grams, respectively.

Characteristics of Compost Manufactures Topsoil (CMT)

Addition of compost to sandy soil and to sandy clay loam increased the pore size and the range of pore sizes and the porosity of the CMT. The bulk density of the CMT and ECC decreased compared with the soil controls. The water holding capacity of the sandy CMT increased but the water holding capacity of the clay CMT decreased compared to the soil controls.

Leachate Studies

The concentrations of constituents in the leachate produced in the laboratory from the CMT and ECC are more concentrated than the leachate produced field conditions. Under field conditions, water passing through the CMT or ECC would continue to percolate into the supporting soil, be taken up by plants and/or undergo chemical and biological transformations by microbial activities in the supporting soil resulting in lower concentrations, if the leachate reached surface and ground water sources.

The results of the first-flush column study indicated that the leachate produced from the CMT or ECC contains primarily soluble constituents. The results of the extended column study indicated that the concentrations of soluble constituents in the leachate decreased with subsequent applications of water to the CMT or ECC over time.

There is a correlation between the amount of nutrients (N and P) in the compost used in the CMT or ECC and the amount of nutrients in the leachate. The concentrations of nitrates in the first-flush leachate from the CMT or ECC in the “worst case” study were less than 80 mg/L. Observations during the extended column leachate study indicated fluctuations in the nitrate concentrations in the leachate over time. These fluctuations can be attributed to conversion of ammonia to nitrate in the CMT and ECC during the time between water applications. These observations are supported by the total nitrogen concentrations which decreased over time for all CMTs and ECCs. Nitrogen in the compost used in the CMT and ECC is available to plants.

The results of the first-flush and extended column studies indicated that the concentrations of phosphorus in the leachate from the sand CMT and ECC mixtures were higher than in the leachate from the clay CMT when deionized water was applied. The leachate from the sand CMT contained more total phosphorus than the leachate from the clay CMT or ECC when highway runoff was applied. The results of the extended column study indicated phosphorus concentrations in the leachate decreased over time for all CMTs and ECCs. The total phosphorus concentration after 12 months of equivalent rainfall were less than 2 mg/L for clay CMT blends and less than 10 mg/L for sand CMTs and ECCs.

The concentration of heavy metals in the leachate in the first-flush study can be correlated to the quantity of heavy metals in the compost with the exception of the composted biosolids. The composted biosolids contained more zinc and copper than did the composted dairy cattle manure or the composted feedlot manure, but the concentrations of copper and zinc in the leachate were comparable. The clay CMT retained more heavy metals than the sand CMT. Results from the extended column study indicated that the concentrations of copper and zinc in the leachate decreased over time. The clay CMT retained more copper than the sand CMT, but the reverse was true for zinc.

TSS concentrations in the leachate in the first-flush studies using highway runoff were reduced by 28 to 90 percent for the sand CMTs and by 90 to 95 percent for the clay

CMTs compared with the TSS concentrations of the leachate from the soil controls. The results of the extended column study indicated that TSS concentrations in the leachate decreased over time to less than 100 mg/L for clay CMTs and ECC and less than 400 mg/L for sand CMTs.

Channel Studies

The highest peak runoff rate occurred for the clay control and the composted dairy cattle manure clay CMTs at the steepest slope (2:1) used in the channel studies. The peak runoff rate decreased with decreasing slope for the soil controls, CMTs, and ECCs. The onsets of runoff for CMTs and ECCs at all slopes were delayed compared with soil controls. ECCs delay runoff more than CMTs. The clay CMTs at a 3:1 slope delayed the onset of runoff compared to soil controls by 8 to 15 minutes, and the peak runoff flow rate was reduced from 0.5 to 0.4 gpm or less. The ECCs at a slope of 3:1 delayed the onsets of runoff by 15 minutes or more compared to the soil controls.

RECOMMENDATIONS

The TxDOT Specification Item 161 “Compost” is consistent with the “model” specification proposed by the United States Composting Council. Composted manures and biosolids that are applied as Compost Manufactured Topsoil, Erosion Control Compost, and General Use Compost in TxDOT projects should meet all the quality characteristics defined in Specification Item 161. The use of these materials should be encouraged on all construction projects because the compost and compost blends supply needed nutrients and increase water holding capacity for enhanced plant establishment.

Composted biosolids are the preferred material for producing Compost Manufactured Topsoil because this material appears to more reliably and consistently meet the TxDOT Specification Item 161.

Composted dairy cattle manure is not suitable for use in Compost Manufactured Topsoil or Erosion Control Compost without increasing the organic matter content and reducing the pH. Wood chips, yard trimmings, or similar materials should be incorporated as organic bulking agents when composting dairy cattle manure in order to increase the organic matter content of the finished compost to meet the TxDOT Specification 161 organic content of 25% to 65%. The organic bulking material also would provide a source of carbon which upon aerobic decomposition will be converted to carbon dioxide which would tend to decrease the pH of the final compost to less than the specified pH = 8.5.

Composted feedlot manure is not suitable for use in Compost Manufactured Topsoil or in Erosion Control Compost because the composted feedlot manure had a pH = 9.5 which exceeded the specified maximum pH = 8.5 limit and the exceeded the specified salt limit with a conductivity of 12.6 dS/m. In addition the maturity of the composted feedlot manure was only 1.7% which is much lower than the specified maturity limit of greater than 80%. These characteristics along with phytotoxicity exhibited by the composted feedlot manure would inhibit the establishment of vegetation on rights-of-way of new highways.

Composted poultry litter could be used in Compost Manufactured Topsoil or in Erosion Control Compost, if the pH is reduced to less than pH=8.5. Increasing the amount of organic bulking material would provide a source of carbon which upon aerobic decomposition will be converted to carbon dioxide which would tend to decrease the pH of the final compost to less than the specified pH = 8.5.

Clay or sandy clay are the soils of choice to be blended with composted manures and biosolids in Compost Manufactured Topsoils. The clay CMTs are more efficient in the removal of total nitrogen, phosphorus, total suspended solids and heavy metals than sand CMTs.

Application of clay CMTs is appropriate especially on fill slopes because of the ability to retain the pollutants washed off the adjacent roadway.

Use of sand CMTs is appropriate particularly in areas with sandy soils because of the water holding capacity is increased by blending the composted manure or biosolids with the sand and because generally sandy soils are low in nutrients. Therefore, the CMT should enhance vegetation establishment.

Elevated nutrient (nitrogen and phosphorus) concentrations in leachate from the first few rain events on Compost Manufactured Topsoil and Erosion Control Compost indicate that placement of CMT should be done carefully to minimize potential pollution of surface water.

The maximum slope for the application of Compost Manufactured Topsoil or Erosion Control Compost is 3:1 (horizontal: vertical). Runoff delay and reduction in the peak flow rate are enhanced at slopes below 3:1.

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APPENDIX

Table A-1. Characteristics of Compost Soil Control Lab

Parameter	Units	COMPOSTED FEEDLOT MANURE		
		FLC-004	FLC-005	FLC-006
Bulk Density	g/cc	0.545	0.541	0.569
WHC	mls/100g	108	104	104
Particle Size	% <5/8"	100	100	100
	% <3/8"	95.2	95.0	95.1
	% Inerts	<1	<1	<1
Maturity	%	0	5	0
Stability	mg CO_2-C/g OM/d	1.7	2.5	2.2
Total N	%	2.2	2.2	2.0
NH3-N	mg/kg dw	273	289	269
Nitrate	mg/kg dw	492	505	499
P	mg/kg dw	10,243	10,399	10,715
K	mg/kg dw	26,962	28,369	29,508
pH	SU	9.54	9.46	9.45
EC	mmhos/cc	11.856	13.224	12.605
Bulk Density	lb/ cu ft dw	34	34	36
OM	% (dw)	40.2	41.0	40.6
OC	% (dw)	20.2	20.3	18.9
C:N		9.2	9.4	9.4
Moisture	%	24.3	23.9	23.9
Fecal Coliform	MPN/g dw	<2	<2	<2
Ar	mg/kg dw	<1	<1	4.1
Cd	mg/kg dw	<1	<1	<1
Cr	mg/kg dw	8	8	8
Cu	mg/kg dw	39	42	37
Pb	mg/kg dw	1	<1	2
Hg	mg/kg dw	<1	<1	<1
Mo	mg/kg dw	3	4	3
Ni	mg/kg dw	25	12	6
Se	mg/kg dw	1	1	1
Zn	mg/kg dw	225	261	203

Table A-1. Characteristics of Compost Soil Control Lab

Parameter	Units	COMPOSTED BIOSOLIDS		
		BC-004	BC-005	BC-006
Bulk Density	g/cc	0.428	0.411	0.397
WHC	mls/100g	150	148	150
Particle Size	% <5/8"	95.7	100.0	94.3
	% <3/8"	87.7	89.9	85.7
	% Inerts	<1	<1	<1
Maturity	%	100	75	85
Stability	mg CO_2-C/g OM/d	1.0	1.1	1.1
Total N	%	2.0	1.9	2.0
NH3-N	mg/kg dw	932	991	834
Nitrate	mg/kg dw	31	21	20
P	mg/kg dw	10,989	13,646	14,571
K	mg/kg dw	5,245	6,327	6,474
pH	SU	7.99	8.04	7.92
EC	mmhos/cc	2.578	2.676	2.453
Bulk Density	lb/ cu ft dw	24.9	26	25
OM	% (dw)	50.5	48.4	48.3
OC	% (dw)	22.2	21.9	24.2
C:N		11.1	11.6	11.8
Moisture	%	38.5	38.9	37.9
Fecal Coliform	MPN/g dw	<2	<2	<2
Ar	mg/kg dw	3.5	6.7	7.7
Cd	mg/kg dw	2.4	2.3	2.1
Cr	mg/kg dw	29	31	30
Cu	mg/kg dw	328	372	313
Pb	mg/kg dw	32	34	34
Hg	mg/kg dw	<1	<1	<1
Mo	mg/kg dw	14	12	11
Ni	mg/kg dw	16	16	14
Se	mg/kg dw	2.6	1.0	2.0
Zn	mg/kg dw	469	518	463

Table A-1. Characteristics of Compost Soil Control Lab

Parameter	Units	COMPOSTED POULTRY LITTER		
		PLC-004	PLC-005	PLC-006
Bulk Density	g/cc	0.441	0.501	0.475
WHC	mls/100g	117	105	111
Particle Size	% <5/8"	96.1	93.3	96.4
	% <3/8"	91.1	90.6	89.6
	% Inerts	<1	<1	<1
Maturity	%	80	80	100
Stability	mg CO_2-C/g OM/d	2.2	3.9	2.3
Total N	%	1.5	1.1	1.2
NH3-N	mg/kg dw	566	604	624
Nitrate	mg/kg dw	41	41	44
P	mg/kg dw	14,468	15,496	14,541
K	mg/kg dw	12,144	12,726	10,904
pH	SU	8.94	8.97	8.95
EC	mmhos/cc	3.913	4.039	4.499
Bulk Density	lb/ cu ft dw	30	30	30
OM	% (dw)	31.8	31.0	29.9
OC	% (dw)	19.0	12.8	13.1
C:N		12.6	11.8	11.2
Moisture	%	19.8	19.5	19.4
Fecal Coliform	MPN/g dw	<2	<2	<2
Ar	mg/kg dw	1.4	2.2	3.5
Cd	mg/kg dw	<1	<1	<1
Cr	mg/kg dw	12	12	12
Cu	mg/kg dw	301	294	287
Pb	mg/kg dw	4	<1	2
Hg	mg/kg dw	<1	<1	<1
Mo	mg/kg dw	2	3	3
Ni	mg/kg dw	24	13	15
Se	mg/kg dw	1	1	1
Zn	mg/kg dw	500	480	481

Table A-1. Characteristics of Compost Soil Control Lab

Parameter	Units	COMPOSTED DAIRY MANURE		
		DMC-004	DMC-005	DMC-006
Bulk Density	g/cc	0.895	0.942	0.935
WHC	mls/100g	65	59	57
Particle Size	% <5/8"	95.5	97.1	93.6
	% <3/8"	75.3	82.4	80.3
	% Inerts	<1	<1	<1
Maturity	%	100	90	100
Stability	mg CO_2-C/g OM/d	1.2	0.9	1.5
Total N	%	0.6	0.6	0.6
NH3-N	mg/kg dw	25	48	37
Nitrate	mg/kg dw	589	659	663
P	mg/kg dw	3,170	2,575	2,911
K	mg/kg dw	9,876	8,598	10,194
pH	SU	9.00	8.99	9.07
EC	mmhos/cc	3.325	3.705	3.718
Bulk Density	lb/ cu ft dw	56	55	55
OM	% (dw)	10.8	11.3	10.4
OC	% (dw)	6.3	6.4	5.7
C:N		10.7	10.2	9.8
Moisture	%	22.1	23.5	22.5
Fecal Coliform	MPN/g dw	<2	<2	<2
Ar	mg/kg dw	5.9	4.8	<1
Cd	mg/kg dw	<1	<1	<1
Cr	mg/kg dw	10	9	11
Cu	mg/kg dw	22	23	22
Pb	mg/kg dw	<1	<1	<1
Hg	mg/kg dw	<1	<1	<1
Mo	mg/kg dw	<1	1	2
Ni	mg/kg dw	7	10	14
Se	mg/kg dw	1	1	1
Zn	mg/kg dw	80	115	110

Table A-2. Bulk Density and Pressure Plate Soil Moisture University of Guelph

		COMPOSTED BIOSOLIDS		COMPOSTED FEEDLOT MANURE	
		Sand	Clay	Sand	Clay
Parameter	Units	CMT	CMT	CMT	CMT
Bulk Density	g/cm^3	1.61	1.22	1.57	1.26
Gravimetric Soil Moisture					
SM grav at sat.	%	26.60	48.78	28.61	44.00
SM grav at 0.1 bar	%	8.20	26.63	14.64	27.31
SM grav at 0.3 bar	%	7.73	22.33	13.76	23.14
SM grav at 1 bar	%	7.38	21.42	13.21	23.00
SM grav at 3 bar	%	6.86	19.52	12.76	23.31
SM grav at 15 bar	%	6.29	17.56	11.94	20.42
Volumetric Soil Moisture					
SM vol at sat.	%	42.91	59.51	44.82	55.34
SM vol at 0.1 bar	%	13.22	32.48	22.94	34.35
SM vol at 0.3 bar	%	12.47	27.24	21.56	29.10
SM vol at 1 bar	%	11.90	26.13	20.69	28.93
SM vol at 3 bar	%	11.07	23.81	19.99	29.31
SM vol at 15 bar	%	10.15	21.42	18.70	25.68

Table A-2. Bulk Density and Pressure Plate Soil Moisture University of Guelph

		COMPOSTED DAIRY MANURE			
		Sand	Sand	Clay	Clay
Parameter	Units	CMT	CMT	CMT	CMT
Bulk Density	g/cm^3	1.69	1.72	1.32	1.29
Gravimetric Soil Moisture					
SM grav at sat.	%	22.96	22.36	39.99	41.72
SM grav at 0.1 bar	%	7.37	7.77	23.41	22.54
SM grav at 0.3 bar	%	6.99	7.38	19.16	18.54
SM grav at 1 bar	%	6.14	6.66	18.13	16.44
SM grav at 3 bar	%	5.88	6.15	17.70	16.00
SM grav at 15 bar	%	5.38	5.61	15.22	13.33
Volumetric Soil Moisture					
SM vol at sat.	%	38.70	38.53	52.80	53.84
SM vol at 0.1 bar	%	12.43	13.39	30.90	29.09
SM vol at 0.3 bar	%	11.78	12.72	25.30	23.93
SM vol at 1 bar	%	10.35	11.48	23.93	21.21
SM vol at 3 bar	%	9.92	10.60	23.37	20.65
SM vol at 15 bar	%	9.08	9.67	20.09	17.20

Table A-2. Bulk Density and Pressure Plate Soil Moisture University of Guelph

		COMPOSTED POULTRY LITTER		CONTROLS	
		Sand	Clay	Sand	Clay
Parameter	Units	CMT	CMT	Soil	Soil
Bulk Density	g/cm^3	1.65	1.18	1.81	1.34
Gravimetric Soil Moisture					
SM grav at sat.	%	24.66	47.59	19.11	40.54
SM grav at 0.1 bar	%	5.86	29.03	2.02	20.97
SM grav at 0.3 bar	%	5.45	21.24	1.62	16.36
SM grav at 1 bar	%	4.71	21.22	1.43	14.03
SM grav at 3 bar	%	4.37	18.42	1.26	12.40
SM grav at 15 bar	%	3.84	15.68	1.01	9.79
Volumetric Soil Moisture					
SM vol at sat.	%	40.58	56.30	34.53	54.32
SM vol at 0.1 bar	%	9.65	34.34	3.65	28.09
SM vol at 0.3 bar	%	8.97	25.13	2.94	21.92
SM vol at 1 bar	%	7.75	25.11	2.59	18.80
SM vol at 3 bar	%	7.19	21.79	2.27	16.62
SM vol at 15 bar	%	6.32	18.55	1.83	13.12

Table A-3. Leachate Study with Deionized Water LCRA Analytical Results

			Metals			Bacteria	
		Parameter	Copper	Lead	Zinc	Enterococci	Fecal Coliform
		Units	mg/L	mg/L	mg/L	MPN/100 mL	MPN/100 mL
		Sample ID					
CONTROLS	Blank	DI-C4	0.03	ND	0.16	960	<100
		DI-C13	0.09	ND	0.26	>48000	<100
		DI2-C7	ND	ND	ND	>24000	500
		DI2-C16	0.10	ND	0.10	>240000	6,000
		RDI-C9	ND	ND	ND	<2	<2
		DI3-C14	ND	ND	ND	<1	<2
	Clay Only	DI-C1	ND	ND	ND	<10	<100
		DI2-C1	ND	ND	ND	92	<100
		RDI-C3	ND	ND	ND	10	<20
		DI3-C8	ND	ND	ND	3	<2
	Sand Only	DI-C9	ND	ND	ND	20	<100
		DI2-C9	ND	ND	ND	<2	<100
		RDI-C1	ND	ND	ND	<10	<20
		DI3-C1	ND	ND	0.07	<10	300
COMPOSTED POULTRY LITTER	Poultry Clay CMT	DI-C2	1.26	0.05	1.65	1,400	<100
		DI2-C12	0.14	ND	0.25	690	<100
		DI3-C2	0.15	ND	0.06	>240000	<10
	Poultry Sand CMT	DI-C14	0.67	ND	0.6	1,600	<1000
		DI2-C2	0.15	ND	0.12	>240000	9,000
		DI3-C9	0.96	ND	0.97	>240000	200
	Poultry ECC	DI-C15	ND	ND	ND	30	100
		DI2-C14	0.83	ND	1.06	>120000	<100
		DI3-C6	0.60	ND	0.47	>240000	<20
COMPOSTED BIOSOLIDS	Biosolids Clay CMT	DI-C3	0.26	ND	0.46	10	100
		DI2-C5	0.17	ND	0.72	>240000	<100
		DI3-C11	0.02	ND	0.07	>24000	<5
	Biosolids Sand CMT	DI-C12	0.19	ND	0.12	>48000	<100
		DI2-C3	0.03	ND	ND	>240000	<100
		DI3-C7	0.2	ND	0.30	>240000	<20
	Biosolids ECC	DI-C16	ND	ND	ND	80	<10
		DI2-C6	0.06	ND	0.21	>24000	<100
		DI3-C10	0.17	ND	0.18	26,000	40

Table A-3. Leachate Study with Deionized Water LCRA Analytical Results

			Nitrogen				Phosphorus
		Parameter	Nitrate-N	Nitrite-N	Ammonia	TKN	Total P
		Units	mg/L	mg/L	mg/L	mg/L	mg/L
		Sample ID					
CONTROLS	Blank	DI-C4	NR	ND	0.58	28.8	1.66
		DI-C13	NR	ND	51	145	12.5
		DI2-C7	44.8	ND	0.13	13.3	2.18
		DI2-C16	0.48	ND	61.7	99.3	5.65
		RDI-C9	0.14	ND	ND	0.46	ND
		DI3-C14	0.09	ND	ND	1.54	0.07
	Clay Only	DI-C1	NR	ND	ND	0.43	0.21
		DI2-C1	0.33	ND	ND	0.77	0.3
		RDI-C3	0.25	ND	ND	0.45	0.15
		DI3-C8	0.57	ND	ND	0.7	0.11
	Sand Only	DI-C9	NR	ND	ND	1.99	ND
		DI2-C9	0.20	ND	ND	0.50	ND
		RDI-C1	0.16	ND	ND	0.54	0.32
		DI3-C1	0.67	0.03	ND	1.17	0.46
COMPOSTED POULTRY LITTER	Poultry Clay CMT	DI-C2	NR	ND	174	189	40.3
		DI2-C12	0.44	ND	40.3	103	10.2
		DI3-C2	2.56	ND	26.9	72.9	15.6
	Poultry Sand CMT	DI-C14	NR	ND	113	129	22.7
		DI2-C2	1.02	ND	32.9	68.8	19.3
		DI3-C9	1.07	ND	223	458	135
	Poultry ECC	DI-C15	NR	ND	0.53	0.86	0.13
		DI2-C14	0.72	ND	ND	120	46.4
		DI3-C6	0.51	ND	36.7	90.2	32.1
COMPOSTED BIOSOLIDS	Biosolids Clay CMT	DI-C3	NR	ND	102	141	20.9
		DI2-C5	60.9	ND	29.3	228	74.4
		DI3-C11	2.37	ND	26.7	107	0.77
	Biosolids Sand CMT	DI-C12	NR	ND	51.8	73.5	14.4
		DI2-C3	0.64	ND	35.6	48.5	1.28
		DI3-C7	0.38	ND	160	156	35.3
	Biosolids ECC	DI-C16	NR	ND	ND	0.26	ND
		DI2-C6	148	ND	2.12	56.4	9.51
		DI3-C10	1.1	ND	178	149	17.8

Table A-3. Leachate Study with Deionized Water LCRA Analytical Results

			Solids	
		Parameter	TDS	TSS
		Units	mg/L	mg/L
		Sample ID		
CONTROLS	Blank	DI-C4	4,300	140
		DI-C13	8,260	340
		DI2-C7	1,100	610
		DI2-C16	960	280
		RDI-C9	12	3
		DI3-C14	7	17
	Clay Only	DI-C1	144	130
		DI2-C1	90	300
		RDI-C3	140	80
		DI3-C8	96	20
	Sand Only	DI-C9	100	440
		DI2-C9	82	500
		RDI-C1	165	380
		DI3-C1	105	830
COMPOSTED POULTRY LITTER	Poultry Clay	DI-C2	3,200	850
		DI2-C12	700	820
		DI3-C2	1,500	35
	Poultry Sand	DI-C14	2,030	340
		DI2-C2	2,010	740
		DI3-C9	1,890	805
	Poultry ECC	DI-C15	1,530	130
		DI2-C14	1,780	870
		DI3-C6	1,460	260
COMPOSTED BIOSOLIDS	Biosolids Clay	DI-C3	1,400	720
		DI2-C5	10,600	800
		DI3-C11	995	35
	Biosolids Sand	DI-C12	1,720	180
		DI2-C3	790	2,200
		DI3-C7	1,140	210
	Biosolids ECC	DI-C16	14	30
		DI2-C6	4,740	1,810
		DI3-C10	1,390	110

Table A-3. Leachate Study with Deionized Water LCRA Analytical Results

			Metals			Bacteria	
		Parameter	Copper	Lead	Zinc	Enterococci	Fecal Coliform
		Units	mg/L	mg/L	mg/L	MPN/100 mL	MPN/100 mL
		Sample ID					
COMPOSTED FEEDLOT	Feedlot Clay	DI-C11	0.06	ND	0.23	72	<100
		DI2-C13	ND	ND	ND	<1	<1
		DI3-C4	0.24	ND	0.38	>2400000	14,900
	Feedlot Sand	DI-C5	0.04	ND	ND	>48000	<100
		DI2-C10	ND	ND	0.05	>240000	<100
		DI3-C3	0.19	ND	0.71	>240000	280
	Feedlot ECC	DI-C8	0.22	ND	0.76	>120000	<100
		DI2-C8	0.14	ND	0.52	>240000	4,500
		DI3-C5	0.08	ND	0.36	>240000	<20
COMPOSTED DAIRY MANURE	Dairy Clay	DI-C10	0.19	ND	0.82	>120000	<1
		DI2-C4	ND	ND	ND	200	<1
		RDI-C4	ND	ND	ND	<10	<10
		RDI2-C7	ND	ND	ND	30	<10
		DI3-C15	ND	ND	0.04	230	65
	Dairy Sand	DI-C6	0.19	ND	0.18	>120000	3,000
		DI2-C11	0.09	ND	0.24	>240000	<100
		RDI-C2	0.03	ND	0.22	1,600	1,420
		RDI2-C6	0.02	ND	0.17	2,000	1,500
		DI3-C13	0.02	ND	0.13	170	40
	Dairy ECC	DI-C7	ND	ND	ND	9	<2
		DI2-C15	0.34	ND	0.32	>48000	1,300
		RDI-C5	ND	ND	0.15	3,700	<20
		RDI2-C8	ND	ND	0.10	300	<20
		DI3-C12	ND	ND	0.15	2,900	170

Table A-3. Leachate Study with Deionized Water LCRA Analytical Results

			Nitrogen				Phosphorus
		Parameter	Nitrate-N	Nitrite-N	Ammonia	TKN	Total P
		Units	mg/L	mg/L	mg/L	mg/L	mg/L
		Sample ID					
COMPOSTED FEEDLOT	Feedlot Clay	DI-C11	NR	ND	1.18	38.3	7.96
		DI2-C13	0.11	ND	ND	0.32	ND
		DI3-C4	79.8	ND	329	222	2.31
	Feedlot Sand	DI-C5	NR	ND	68.4	74.1	1.37
		DI2-C10	131	ND	ND	23.7	1.81
		DI3-C3	23	ND	29.3	221	72.9
	Feedlot ECC	DI-C8	NR	ND	40.1	232	13.1
		DI2-C8	49.5	ND	54.4	196	52.5
		DI3-C5	20.1	ND	13.2	123	31.4
COMPOSTED DAIRY MANURE	Dairy Clay	DI-C10	NR	ND	17.1	224	17.3
		DI2-C4	0.12	ND	ND	0.58	ND
		RDI-C4	95.8	ND	0.03	19.4	0.56
		RDI2-C7	91.5	ND	ND	10.4	0.75
		DI3-C15	73.4	ND	0.03	22.4	0.82
	Dairy Sand	DI-C6	NR	ND	95.5	193	16.7
		DI2-C11	71	ND	34.3	199	21.9
		RDI-C2	74.8	ND	0.2	20.1	8.09
		RDI2-C6	59.6	ND	0.13	17.4	7.21
		DI3-C13	103	ND	0.2	29.1	7.82
	Dairy ECC	DI-C7	NR	ND	ND	1.38	ND
		DI2-C15	0.49	ND	38.6	72.8	29.6
		RDI-C5	88.7	ND	0.11	19.8	5.45
		RDI2-C8	66.8	ND	0.06	15.2	4.24
		DI3-C12	62	ND	0.17	32	8.08

Table A-3. Leachate Study with Deionized Water LCRA Analytical Results.

			Solids	
		Parameter	TDS	TSS
		Units	mg/L	mg/L
		Sample ID		
COMPOSTED FEEDLOT	Feedlot Clay	DI-C11	3,580	920
		DI2-C13	9	13
		DI3-C4	10,900	50
	Feedlot Sand	DI-C5	1,200	240
		DI2-C10	2,970	2,800
		DI3-C3	5,470	170
	Feedlot ECC	DI-C8	10,100	210
		DI2-C8	7,400	150
		DI3-C5	3,780	150
COMPOSTED DAIRY MANURE	Dairy Clay	DI-C10	7,420	920
		DI2-C4	36	8
		RDI-C4	1,660	10
		RDI2-C7	1,740	15
		DI3-C15	1,380	40
	Dairy Sand	DI-C6	1,940	180
		DI2-C11	8,190	880
		RDI-C2	1,680	470
		RDI2-C6	1,700	320
		DI3-C13	432	465
	Dairy ECC	DI-C7	18	66
		DI2-C15	995	450
		RDI-C5	1,700	350
		RDI2-C8	1,400	240
		DI3-C12	1,190	360

Table A-4. Leachate Study with Highway Runoff LCRA Analytical Results

			Metals			Bacteria	
		Parameter	Copper	Lead	Zinc	Enterococci	Fecal Coliform
		Units	mg/L	mg/L	mg/L	MPN/100 mL	MPN/100 mL
		Sample ID					
CONTROLS	Blank	HR1-C8	0.01	ND	0.13	1,200	>20000
		HR2-C12	ND	ND	0.12	2,100	1,000
		HR3-C7	ND	ND	0.13	860	1,000
	Clay Only	HR1-C10	ND	ND	ND	230	500
		HR2-C9	ND	ND	ND	100	1,400
		HR3-C1	ND	ND	0.09	1,300	3,000
	Sand Only	HR1-C10	0.03	ND	0.16	3,700	15,700
		HR2-C1	0.02	ND	0.14	1,800	1,000
		HR3-C9	0.03	ND	0.2	1,300	2,000
COMPOSTED POULTRY LITTER	Poultry Clay CMT	HR1-C15	0.14	ND	ND	1,000	8,500
		HR2-C15	0.07	ND	ND	1,300	3,700
		HR3-C6	0.06	ND	ND	2,000	700
	Poultry Sand CMT	HR1-C6	0.51	ND	0.69	3,100	>20000
		HR2-C8	0.53	ND	0.60	>2400000	4,000
		HR3-C4	0.46	ND	0.57	2,000	2,000
	Poultry ECC	HR1-C5	0.13	ND	0.23	6,600	>20000
		HR2-C10	0.06	ND	0.15	3,500	2,000
		HR3-C5	0.06	ND	0.15	2,900	6,500
COMPOSTED BIOSOLIDS	Biosolids Clay CMT	HR1-C13	0.03	ND	ND	310	3,000
		HR2-C16	0.02	ND	ND	1,200	2,000
		HR3-C13	0.02	ND	ND	850	600
	Biosolids Sand CMT	HR1-C3	0.19	ND	0.35	15,000	>20000
		HR2-C6	0.16	ND	0.25	2,800	3,000
		HR3-C15	0.13	ND	0.23	4,100	2,000
	Biosolids ECC	HR1-C7	0.09	ND	0.22	4,400	>20000
		HR2-C3	0.04	ND	0.12	4,100	3,000
		HR3-C12	0.06	ND	0.18	4,500	9,500

Table A-4. Leachate Study with Highway Runoff LCRA Analytical Results

			Nitrogen				Phosphorus
		Parameter	Nitrate-N	Nitrite-N	Ammonia	TKN	Total P
		Units	mg/L	mg/L	mg/L	mg/L	mg/L
		Sample ID					
CONTROLS	Blank	HR1-C8	0.46	0.1	0.09	1.61	0.15
		HR2-C12	0.54	0.07	0.05	0.17	0.07
		HR3-C7	0.54	0.39	0.03	1.1	0.11
	Clay Only	HR1-C10	3.14	0.08	ND	1.05	0.04
		HR2-C9	3.23	0.07	ND	1.03	ND
		HR3-C1	2.54	0.1	ND	0.52	0.53
	Sand Only	HR1-C10	1.11	0.08	0.09	2.75	1.16
		HR2-C1	1.19	0.09	0.1	2.32	1.15
		HR3-C9	0.97	0.08	ND	1.97	1.32
COMPOSTED POULTRY LITTER	Poultry Clay CMT	HR1-C15	5.38	ND	33.9	75.1	15.5
		HR2-C15	6.82	ND	39.2	53.9	14.7
		HR3-C6	2.82	ND	42	71.2	8.31
	Poultry Sand CMT	HR1-C6	1.55	ND	46	103	31.3
		HR2-C8	2.43	ND	92.6	135	19.2
		HR3-C4	1.42	ND	72	353	22
	Poultry ECC	HR1-C5	0.63	0.24	14.5	29.4	5.66
		HR2-C10	0.6	0.15	14.1	35.4	2.81
		HR3-C5	0.53	0.25	13.5	34.9	3.02
COMPOSTED BIOSOLIDS	Biosolids Clay CMT	HR1-C13	3.51	0.18	29.3	52.1	0.71
		HR2-C16	2.07	0.12	24.7	42.4	0.63
		HR3-C13	2.29	ND	26.4	170.0	0.41
	Biosolids Sand CMT	HR1-C3	1.12	0.2	67.7	113	8.52
		HR2-C6	1.76	ND	208.0	270	2.93
		HR3-C15	1.34	ND	101.0	192	1.1
	Biosolids ECC	HR1-C7	0.58	0.14	22.8	33.1	1.23
		HR2-C3	0.65	0.12	22.0	32.7	1.29
		HR3-C12	0.62	0.12	54.3	60.2	2.15

Table A-4. Leachate Study with Highway Runoff LCRA Analytical Results

			Solids	
		Parameter	TDS	TSS
		Units	mg/L	mg/L
		Sample ID		
CONTROLS	Blank	HR1-C8	290	520
		HR2-C12	185	260
		HR3-C7	395	120
	Clay Only	HR1-C10	195	ND
		HR2-C9	335	80
		HR3-C1	190	2,900
	Sand Only	HR1-C10	830	825
		HR2-C1	350	3,720
		HR3-C9	610	2,730
COMPOSTED POULTRY LITTER	Poultry Clay CMT	HR1-C15	1,800	15
		HR2-C15	1,270	55
		HR3-C6	1,530	50
	Poultry Sand CMT	HR1-C6	2,420	985
		HR2-C8	2,340	3,100
		HR3-C4	2,100	1,460
	Poultry ECC	HR1-C5	725	75
		HR2-C10	590	525
		HR3-C5	685	305
COMPOSTED BIOSOLIDS	Biosolids Clay CMT	HR1-C13	1,250	10
		HR2-C16	875	65
		HR3-C13	1,060	20
	Biosolids Sand CMT	HR1-C3	1,650	400
		HR2-C6	1,510	1,790
		HR3-C15	1,460	535
	Biosolids ECC	HR1-C7	525	285
		HR2-C3	540	500
		HR3-C12	685	190

Table A-4. Leachate Study with Highway Runoff LCRA Analytical Results.

			Metals			Bacteria	
		Parameter	Copper	Lead	Zinc	Enterococci	Fecal Coliform
		Units	mg/L	mg/L	mg/L	MPN/100 mL	MPN/100 mL
		Sample ID					
COMPOSTED FEEDLOT	Feedlot Clay	HR1-C14	0.23	ND	0.43	2,000	10,300
		HR2-C13	0.08	ND	0.14	>2400000	1,100
		HR3-C2	0.07	ND	0.13	2,000	2,200
	Feedlot Sand	HR1-C4	0.09	ND	0.32	9,800	13,600
		HR2-C5	0.1	ND	0.34	100,000	1,000
		HR3-C3	0.11	ND	0.37	1,000	2,000
	Feedlot ECC	HR1-C9	0.06	ND	0.23	3,000	>20000
		HR2-C4	0.02	ND	0.18	3,900	2,000
		HR3-C10	0.02	ND	0.22	2,800	2,000
COMPOSTED DAIRY MANURE	Dairy Clay	HR1-C12	ND	ND	ND	2,000	3,800
		HR2-C14	ND	ND	ND	1,300	4,000
		HR3-C16	ND	ND	ND	630	1,600
	Dairy Sand	HR1-C2	0.04	ND	0.16	6,600	>20000
		HR2-C7	0.01	ND	0.06	4,300	4,000
		HR3-C14	0.04	ND	0.19	3,100	5,300
	Dairy ECC	HR1-C11	0.02	ND	0.1	8,800	>20000
		HR2-C2	0.01	ND	0.12	2,000	3,000
		HR3-C11	0.01	ND	0.16	4,600	4,000

Table A-4. Leachate Study with Highway Runoff LCRA Analytical Results

			Nitrogen				Phosphorus
		Parameter	Nitrate-N	Nitrite-N	Ammonia	TKN	Total P
		Units	mg/L	mg/L	mg/L	mg/L	mg/L
		Sample ID					
COMPOSTED FEEDLOT MANURE	Feedlot Clay	HR1-C14	66.4	ND	92.3	175	19.3
		HR2-C13	79.8	ND	20.7	135	33.9
		HR3-C2	49.7	ND	22.8	44.5	7.01
	Feedlot Sand	HR1-C4	36.4	ND	22.2	150	39.4
		HR2-C5	59.0	ND	19.1	107	26.2
		HR3-C3	49.2	ND	28.7	91.8	16.2
	Feedlot ECC	HR1-C9	20.7	ND	9.74	79.3	19.6
		HR2-C4	13.3	ND	5.1	29.9	2.72
		HR3-C10	8.5	ND	3.34	56.5	5.37
COMPOSTED DAIRY MANURE	Dairy Clay	HR1-C12	100	ND	0.14	10.5	0.66
		HR2-C14	151	ND	0.24	9.66	0.34
		HR3-C16	115	ND	0.15	0.64	0.12
	Dairy Sand	HR1-C2	133	ND	0.18	14.2	4.88
		HR2-C7	91.9	ND	0.15	8.48	2.09
		HR3-C14	104	ND	0.09	2.36	1.69
	Dairy ECC	HR1-C11	50.5	ND	0.59	10.6	1.46
		HR2-C2	16.8	0.17	0.17	4.95	0.5
		HR3-C11	21.2	0.18	0.25	6.18	0.67

Table A-4. Leachate Study with Highway Runoff LCRA Analytical Results

			Solids	
		Parameter	TDS	TSS
		Units	mg/L	mg/L
		Sample ID		
COMPOSTED FEEDLOT MANURE	Feedlot Clay CMT	HR1-C14	8,750	40
		HR2-C13	8,790	110
		HR3-C2	6,100	45
	Feedlot Sand CMT	HR1-C4	5,600	85
		HR2-C5	8,700	270
		HR3-C3	7,560	290
	Feedlot ECC	HR1-C9	3,170	90
		HR2-C4	1,950	550
		HR3-C10	1,460	235
COMPOSTED DAIRY MANURE	Dairy Clay CMT	HR1-C12	1,690	5
		HR2-C14	2,540	185
		HR3-C16	2,080	90
	Dairy Sand CMT	HR1-C2	2,880	315
		HR2-C7	2,110	640
		HR3-C14	2,590	645
	Dairy ECC	HR1-C11	1,190	355
		HR2-C2	510	235
		HR3-C11	670	145

Table A-5. Extended Column Study Nitrate Concentration in the Leachate from Clay CMT

Equivalent Rainfall, months	Units	Nitrate - N Concentration in Clay CMT Mixtures				
		Clay Control	Composted Poultry Litter CMT	Composted Biosolids CMT	Composted Feedlot Manure CMT	Comoposted Dairy Cattle Manure CMT
1.5	mg/L	0.18	1.18	0.37	0.64	1.11
3.0	mg/L	0.30	0.16	0.15	1.23	2.43
4.5	mg/L	0.54	1.88	0.69	7.73	1.23
6.0	mg/L	1.10	20.1	12.2		1.11
7.5	mg/L	0.38	0.92	1.58		
9.0	mg/L		1.80	1.43		
10.5	mg/L	0.91	2.79	3.90		
12.0	mg/L	0.52	6.86	5.44		

Table A-6. Extended Column Study Nitrate Concentration in the Leachate from Sand CMT

Equivalent Rainfall, months	Units	Nitrate - N Concentration in Sand CMT Mixtures				
		Sand Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	0.2	1.08	0.56	43.1	91.4
3.0	mg/L	0.14	0.72	0.28	0.97	13.5
4.5	mg/L	0.22	10.6	24.5	0.97	2.97
6.0	mg/L	0.26	6.89	16.4	2.29	5.59
7.5	mg/L	0.17	1.34	4.78	2.44	4.23
9.0	mg/L	0.26	1.02	2.56	1.65	3.50
10.5	mg/L	0.32	0.75	1.51	1.50	3.41
12.0	mg/L	0.25	0.39	0.74	1.49	3.19

Table A-7. Extended Column Study Nitrate Concentration in the Leachate from ECC

Equivalent Rainfall, months	Units	Nitrate - N Concentration in ECC Mixtures			
		Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	51.7	30.5	71.6	163
3.0	mg/L	0.57	0.79	6.04	12.9
4.5	mg/L	8.64	16.2	1.41	1.54
6.0	mg/L	11.50	25.2	4.33	1.93
7.5	mg/L	7.48	8.30	2.83	2.17
9.0	mg/L	2.93	2.75	2.64	3.04
10.5	mg/L	1.04	2.20	2.75	3.28
12.0	mg/L	0.45	1.07	0.95	2.86

Table A-8. Extended Column Study Total Nitrogen Concentration in the Leachate from Clay CMT

Equivalent Rainfall, months	Units	Total N Concentration in Clay CMT Mixtures				
		Clay Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	0.88	120.28	288.37	231.64	247.11
3.0	mg/L	1.04	12.60	40.65	29.33	12.06
4.5	mg/L	0.74	20.65	20.50	82.93	4.51
6.0	mg/L	1.10	32.22	26.19	36.00	5.80
7.5	mg/L	1.37	1.83	2.85		2.29
9.0	mg/L	0.60	3.19	3.37		2.38
10.5	mg/L	1.24	4.11	5.57		
12.0	mg/L	0.86	8.19	6.74		

Table A-9. Extended Column Study Total Nitrogen Concentration in the Leachate from Sand CMT

Equivalent Rainfall, months	Units	Total Nitrogen Concentration in Sand CMT Mixtures				
		Composted Sand Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	2.05	593.08	171.67	763.10	159.30
3.0	mg/L	0.57	88.69	44.86	122.19	17.29
4.5	mg/L	0.61	51.47	38.94	118.37	6.68
6.0	mg/L	0.76	13.73	20.84	25.84	16.39
7.5	mg/L	8.70	7.57	10.54	12.88	14.73
9.0	mg/L	0.80	6.20	7.70	13.05	16.00
10.5	mg/L	0.73	5.09	6.11	7.96	9.93
12.0	mg/L	0.72	3.21	3.76	6.01	7.19

Table A-10. Extended Column Study Total Nitrogen Concentration in the Leachate from ECC

Equivalent Rainfall, months	Units	Total Nitrogen Concentration in ECC Mixtures			
		Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	121.53	606.74	986.58	281.00
3.0	mg/L	109.92	72.63	209.04	29.40
4.5	mg/L	61.14	69.70	88.76	11.08
6.0	mg/L	20.30	30.69	23.60	8.07
7.5	mg/L	20.88	12.77	57.53	10.09
9.0	mg/L	14.73	6.62	50.24	8.28
10.5	mg/L	9.49	5.51	33.95	8.12
12.0	mg/L	5.42	4.03	14.05	5.80

Table A-11. Extended Column Study Phosphorus Concentration in the Leachate from Clay CMT

Equivalent Rainfall, months	Units	Phosphorus Concentration in Clay CMT Mixtures				
		Composted Clay Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	0.06	1.71	5.38	6.62	41.2
3.0	mg/L	0.08	3.38	1.32	6.20	1.94
4.5	mg/L	0.03	10.00	1.31	26.2	1.91
6.0	mg/L	0.05	6.60	1.41	13.5	1.92
7.5	mg/L	0.73	1.12	0.56		0.84
9.0	mg/L	0.06	1.01	1.07		0.74
10.5	mg/L	0.02	0.73	0.72		
12.0	mg/L	0.02	1.33	0.32		

Table A-12. Extended Column Study Phosphorus Concentration in the Leachate from Sand CMT

Equivalent Rainfall, months	Units	Phosphorus Concentration in Sand CMT Mixtures				
		Sand Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	0.62	63.7	3.00	65.8	4.06
3.0	mg/L	0.10	50.9	3.62	74.8	8.30
4.5	mg/L	0.57	21.7	2.65	25.8	6.09
6.0	mg/L	0.20	8.52	1.84	18.6	7.06
7.5	mg/L	3.39	8.47	3.13	10.4	6.47
9.0	mg/L	0.18	7.20	3.51	9.11	7.52
10.5	mg/L	0.20	5.50	3.45	6.49	5.15
12.0	mg/L	0.13	5.96	3.48	6.69	4.80

Table A-13. Extended Column Study Phosphorus Concentration in the Leachate from ECC

Equivalent Rainfall, months	Units	Phosphorus Concentration in ECC Mixtures			
		Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	0.30	6.86	44.6	5.12
3.0	mg/L	42.5	2.84	35.1	5.63
4.5	mg/L	22.4	2.11	13.4	2.57
6.0	mg/L	8.22	1.55	3.37	2.40
7.5	mg/L	11.90	1.68	16.50	4.18
9.0	mg/L	8.47	1.73	14.20	2.65
10.5	mg/L	7.29	1.33	11.60	2.22
12.0	mg/L	6.18	2.96	7.18	1.85

Table A-14. Extended Column Study Copper Concentration in the Leachate from Clay CMT

Equivalent Rainfall, months	Units	Copper Concentration in Clay CMT Mixtures				
		Composted Clay Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	0.39	0.08	0.27	0.20	0.43
3.0	mg/L	0.06	0.16	0.07	0.35	0.03
4.5	mg/L	ND	0.08	0.03	0.12	0.02
6.0	mg/L	ND	0.06	0.03	0.04	0.02
7.5	mg/L	0.03	0.02	0.01	0.02	0.02
9.0	mg/L	0.06	0.05	0.04		0.02
10.5	mg/L	ND	0.01	0.01		
12.0	mg/L	ND	0.02	ND		

Table A-15. Extended Column Study Copper Concentration in the Leachate from Sand CMT

Equivalent Rainfall, months	Units	Copper Concentration in Sand CMT Mixtures				
		Sand Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	0.02	0.50	0.12	0.15	0.07
3.0	mg/L	0.02	0.57	0.10	0.37	0.06
4.5	mg/L	0.02	0.25	0.04	0.08	0.06
6.0	mg/L	0.01	0.16	0.05	0.02	0.05
7.5	mg/L	0.02	0.11	0.05	0.01	0.04
9.0	mg/L	0.02	0.02	0.09	0.01	0.05
10.5	mg/L	0.01	0.07	0.04	ND	0.03
12.0	mg/L	0.01	0.08	0.04	ND	0.03

Table A-16. Extended Column Study Copper Concentration in the Leachate from ECC

Equivalent Rainfall, months	Units	Copper Concentration in ECC Mixtures			
		Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	0.04	0.30	0.16	0.15
3.0	mg/L	1.08	0.17	0.36	0.19
4.5	mg/L	0.22	0.04	0.10	0.02
6.0	mg/L	0.11	0.02	0.06	0.03
7.5	mg/L	0.16	0.02	0.08	0.03
9.0	mg/L	0.02	0.01	0.01	0.07
10.5	mg/L	0.10	0.02	0.04	0.01
12.0	mg/L	0.07	0.02	0.03	0.01

Table A-17. Extended Column Study Zinc Concentration in the Leachate from Clay CMT

Equivalent Rainfall, months	Units	Zinc Concentration in Clay CMT Mixtures				
		Clay Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	1.32	1.28	1.57	0.84	0.90
3.0	mg/L	0.33	0.97	2.75	1.01	0.65
4.5	mg/L	0.16	0.87	0.94	2.93	0.39
6.0	mg/L	0.20	0.93	1.05	1.92	0.51
7.5	mg/L	0.32	0.43	0.29	1.05	1.93
9.0	mg/L	ND	0.71	ND		1.64
10.5	mg/L	0.23	0.17	0.24		
12.0	mg/L	0.27	0.19	0.14		

Table A-18. Extended Column Study Zinc Concentration in the Leachate from Sand CMT

Equivalent Rainfall, months	Units	Zinc Concentration in Sand CMT Mixtures				
		Sand Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	0.46	0.85	0.70	1.27	0.39
3.0	mg/L	0.22	1.28	1.17	2.48	0.46
4.5	mg/L	0.29	0.80	0.84	1.06	0.49
6.0	mg/L	0.10	0.33	0.37	0.40	0.42
7.5	mg/L	0.09	0.28	0.29	0.28	0.45
9.0	mg/L	0.19	0.28	0.26	0.26	0.40
10.5	mg/L	0.14	0.18	0.24	0.20	0.29
12.0	mg/L	0.12	0.21	0.33	0.17	0.27

Table A-19. Extended Column Study Zinc Concentration in the Leachate from ECC

Equivalent Rainfall, months	Units	Zinc Concentration in ECC Mixtures			
		Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	0.76	3.02	2.18	0.54
3.0	mg/L	1.15	1.41	2.52	1.03
4.5	mg/L	0.81	1.09	1.41	0.31
6.0	mg/L	0.28	0.26	0.61	0.26
7.5	mg/L	0.3	0.18	0.54	0.26
9.0	mg/L	0.26	0.18	0.12	0.44
10.5	mg/L	0.24	0.23	0.38	0.22
12.0	mg/L	0.24	0.24	0.40	0.24

Table A-20. Extended Column Study TDS Concentration in the Leachate from Clay CMT

Equivalent Rainfall, months	Units	TDS Concentration in Clay CMT Mixtures				
		Clay Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	229	960	1730	2090	2830
3.0	mg/L	262	340	610	595	625
4.5	mg/L	334	585	455		475
6.0	mg/L	339	850	715		
7.5	mg/L	316	300	245	1440	510
9.0	mg/L		95.00	270		
10.5	mg/L	359	275	320		
12.0	mg/L	331	395	308		

Table A-21. Extended Column Study TDS Concentration in the Leachate from Sand CMT

Equivalent Rainfall, months	Units	TDS Concentration in Sand CMT Mixtures				
		Sand Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	445	2850	1400	8700	2420
3.0	mg/L	292	1870	830	4850	1110
4.5	mg/L	305	765	655	1420	525
6.0	mg/L	305	665	620	730	690
7.5	mg/L	360	490	455	530	575
9.0	mg/L	360	395	460	505	665
10.5	mg/L	375	415	415	405	570
12.0	mg/L	220	390	365	375	390

Table A-22. Extended Column Study TDS Concentration in the Leachate from ECC

Equivalent Rainfall, months	Units	TDS Concentration in ECC Mixtures			
		Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	1260	8810	15800	3830
3.0	mg/L	2060	1120	4990	985
4.5	mg/L	860	675	1620	480
6.0	mg/L	475.00	450	1200	660
7.5	mg/L	630	440	1440	625
9.0	mg/L	510	280	1220	465
10.5	mg/L	410	310	970	430
12.0	mg/L	450	385	745	335

Table A-23. Extended Column Study TSS Concentration in the Leachate from Clay CMT

Equivalent Rainfall, months	Units	TSS Concentration in Clay CMT Mixtures				
		Clay Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	53	10	495	230	325
3.0	mg/L	42	530	10	45	20
4.5	mg/L	4	45	45		40
6.0	mg/L	11	ND	10		
7.5	mg/L	8	1040	1480	30	15
9.0	mg/L		300	380		
10.5	mg/L	ND	21	33		
12.0	mg/L	4	25	74		

Table A-24. Extended Column Study TSS Concentration in the Leachate from Sand CMT

Equivalent Rainfall, months	Units	TSS Concentration in Sand CMT Mixtures				
		Sand Control	Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	1180	455	150	155	130
3.0	mg/L	79	135	20	110	55
4.5	mg/L	605	345	255	135	745
6.0	mg/L	330	340	175	85	920
7.5	mg/L	260	195	115	100	590
9.0	mg/L	160	100	55	55	310
10.5	mg/L	145	70	50	20	310
12.0	mg/L	100	60	55	20	235

Table A-25. Extended Column Study TSS Concentration in the Leachate from ECC

Equivalent Rainfall, months	Units	TSS Concentration in ECC Mixtures			
		Composted Poultry Litter	Composted Biosolids	Composted Feedlot Manure	Composted Dairy Cattle Manure
1.5	mg/L	25	30	525	185
3.0	mg/L	315	45	105	55
4.5	mg/L	340	290	105	530
6.0	mg/L	145	95	150	435
7.5	mg/L	220	160	95	360
9.0	mg/L	110	90	65	100
10.5	mg/L	70	75	30	60
12.0	mg/L	35	25	10	60

Table A-26. Erosion Control Study Water Quality Composted Dairy Manure clay CMT and ECC Slope = 3:1

Group	Parameter	Units	Composted Dairy Manure Blends	
			Clay CMT	ECC
Nitrogen	Nitrate-N	mg/L	9.27	0.73
	Nitrite-N	mg/L	ND	ND
	Ammonia	mg/L	0.532	0.35
	TKN	mg/L	7.07	8.98
Phosphorus	TP	mg/L	3.98	4.17
Metals	Copper	mg/L	0.07	0.06
	Lead	mg/L	ND	ND
	Zinc	mg/L	0.41	0.22
Bacteria	Enterocci	MPN/100mL	630	160
	Fecal Coliform	cfu/100 mL	<20	<20
Solids	TDS	mg/L	380	380
	TSS	mg/L	9040	645