Evaluation of Environmental Benefits and Impacts of Compost and Industry Standard Erosion and Sediment Control Measures used in Construction Activities

by

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(Under the Direction of Carl F. Jordan)

ABSTRACT

Soil erosion is considered the biggest contributor to nonpoint source pollution in the United States according to the federally mandated National Pollution Discharge Elimination System. Soil loss rates from construction sites are 10-20 times that of agricultural lands. Nearly 70% of the nation's Municipal Solid Waste is organic material and could be composted if source separated. Georgia leads the nation in poultry production, generating approximately 1.36 metric tons of poultry litter annually in addition to over 1.81 million metric tons per year of food processing waste, 2.26 million metric tons per year of wood waste, and almost 362,000 metric tons per year of municipal biosolids. It is important to divert these materials from landfills by developing off-site uses and markets for these materials. The use of surface applied organic amendments has been shown to reduce runoff and erosion. Four types of compost blankets, hydroseed, silt fence and a bare soil (control) were applied in field test plots. Treatments were seeded with common bermuda grass. A rainfall simulator applied rainfall at an average rate equivalent to the 50 yr/1 hr storm event, and runoff samples were collected and analyzed for solids, nutrients and runoff quantity. Three simulated rain events were conducted: immediately after treatment application, at vegetation establishment, and at vegetation maturity. Vegetative growth and soil quality characteristics were also evaluated. Results showed compost provided a quicker vegetative cover than hydroseed; however, due to weed invasion hydroseed produced the greatest biomass after one year. In the short term, hydroseeding was not very effective at reducing runoff compared to compost, and compost reduced runoff more over time than hydroseeding or a bare soil. Compost showed greater infiltration of rainfall compared to hydroseed. All treatments proved better than the control at reducing solids loss. Total solids loads were as much as 350% greater from the conventional methods compared to the composts during the first storm and as much as 36 times greater during the second storm. Materials high in inorganic N released greater amounts of nitrogen in storm runoff; however, these materials showed reduced N loss over time. Hydroseeding generated higher P concentrations and loads compared to compost in storm runoff, particularly during the first storm. Compost blankets showed increased soil microbial biomass compared to hydroseed treated soils, and increased surface soil total C, compared to bare soils, an indication of improved soil quality. Soils treated with hydroseed experienced elevated levels of soil phosphorus near the surface throughout the study.

INDEX WORDS: Compost, mulch, hydroseed, silt fence, storm water runoff, erosion control, solids loss, nutrient loss, nutrient loading, soil quality, vegetative growth, rainfall simulation

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PREFACE

The original idea for this research project was developed in the fall of 2000. It's purpose, at the time, was to evaluate the erosion control capability of poultry litter compost and to a provide a catalyst to increase it's market demand as an effective erosion control measure. Frequent field reports appearing in trade journals were reporting successful applications using compost for erosion control; however, scientific research supporting these claims was almost nonexistent. The original project grew to include not just poultry litter compost, but also a variety of composted materials as well as mulch from wood and yard waste. This project was conducted in the summer of 2001 and is presented as the second chapter of this dissertation reprinted by permission from the Journal of Soil and Water Conservation on June 7, 2004. The culmination of the proliferation of demonstration sites showing the anecdotal and empirical benefits of using compost to control runoff and erosion, the early development of state approved specifications, and our own education from "field practitioners" helped lead us in to the next, much larger phase, of this project.

Results from this "preliminary research" conducted in the summer of 2001 demonstrated that compost can be beneficial in controlling erosion, but nutrient loss may be an issue and mulch may do a better job at reducing soil loss in the short term. However, we knew this was not telling the whole story of how compost can be beneficial in this type of application. For example, we did not follow any specifications (which is considered crucial to the industry), in some cases the composts used were not mature and were of low quality, vegetation was not used, the rain events we simulated were at a rate and duration that rarely happens outside of hurricanes, we only conducted one rainfall event, and we did not compare it to any current industry standard or best management practice (BMP).

This set the stage for a research project that would incorporate the inherent weaknesses of the first project and take a systems approach at evaluating quality composted materials with conventional BMPs, over a longer period of time. In addition, the research site was prepared to simulate a construction site. Conducting three storm events over a one year time period and using vegetation growth, runoff, solids loss, nutrient loss, and soil quality as overall performance parameters, this research has helped to answer many of the questions the preliminary research project did not – in addition to raising new ones. This second, and much larger phase of the research is summarized in chapter three while the appendices provide most of the detail and discussion for each section in this very abbreviated chapter. Cheers!

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

In response to public concern regarding potential groundwater pollution potential and reduction in landfill capacity the Georgia General Assembly established a statewide waste reduction goal of 25% to be achieved by 1996, enabled through the 1992 Georgia Solid Waste Management Act. As a first step, the state issued a ban on yard waste going to landfills on September 1st, 1996. At the time, yard waste accounted for 18% of the national average of the municipal solid waste (MSW) stream and was the second leading source of waste after paper and paperboard (US EPA, 1999).

Georgia leads the nation in poultry production, processing nearly 1.5 billion birds per year and generating approximately 1.36 million metric tons (1.5 million tons) of poultry litter annually (Faucette, 2001). Nutrient management in the highly eroded soils of the Georgia piedmont is increasingly important with the rapid growth of the poultry industry. Poultry litter is high in phosphorus and is typically applied at levels greater than crop phosphorus needs. Much of Georgia's soils already have elevated phosphorus indices (Weld, 2003) making on-farm land application and nutrient management extremely complicated. National Resource Conservation Service (NRCS) guidelines for nutrient management make on-farm application of poultry litter increasingly difficult for poultry producers. Since most poultry farms import more nutrients in feed than they export in meat and crops, increasing the off-farm use of poultry litter may be one of the few truly sustainable solutions to water quality problems.

In addition to the poultry industry, nearly 70% of Georgia's Municipal Solid Waste is organic material (according to national averages) and could be composted if source separated (US EPA, 1999). For example, Georgia currently produces over 1.81 million metric tons (2 million tons) of food processing waste (Magbunua, 2000), 2.26 million metric tons (2.5 million tons) of wood waste (Benson, 2000), and almost 362,000 metric tons (400,000 tons) of municipal biosolids (Governo, 2000) annually.

According to the United States Environmental Protection Agency (US EPA)(1999) organic waste in our landfills is the number one source of methane production in the US, a greenhouse gas 20 to 25 times more potent than carbon dioxide. By diverting organic materials from landfills we reduce potential ground water pollution from landfill leachate, reduce the amount of methane released to the atmosphere, reduce the need to expand existing landfills and construct new ones, and potentially improve soil quality by replacing organic matter and recycling nutrients if applied to our highly depleted soils. Therefore, it is important to divert these materials from landfills by developing off-site uses and markets for these materials.

Currently, 38 composting operations recycle approximately 501,008 metric tons (553,600 tons) per year of our state's organic wastes (Gaskin et al., 2002) successfully relieving pressure on landfills, however the increase in compost operations has created a need for new markets that can utilize large amounts of compost. Creating new markets and value-added products will increase utilization of compost, creating greater revenue generation and lead to a more sustainable composting industry and increased infrastructure. This will increase recycling of organic waste materials, and create a greater standard of living based on increased environmental quality in our communities. Every community has a need to reduce materials going to landfills. Producing and using compost locally can make the production of new compost products, like compost used for erosion and sediment control, local rather than having to haul them over long distances.

Soil loss from both agricultural and nonagricultural lands in the United States amounts to over 4 billion metric tons each year due to erosion (Brady and Weil, 1996). While erosion is a natural occurrence, anthropogenic activities can significantly increase erosion and sedimentation rates. For example, forestlands lose an average of 0.36 metric tons/ha (1 ton/acre) per year; agriculture loses an average of 5.5 metric tons/ha (15 tons/acre) per year while construction sites average 73.3 metric tons/ha (200 tons/acre) per year (GA SWCC, 2002).

Erosion removes very thin layers of fertile soil, rich in nutrients and organic matter, which reduces the ability of plants to establish, grow, and remain healthy in the soil. A reduction in plant growth and subsequent plant residue results in less soil cover allowing the erosion process to perpetuate and become worse. The danger to this process is that it can be imperceptible and eventually lead to infertile land void of topsoil (Risse and Faucette, 2001).

The most serious impacts of soil erosion occur once the sediment leaves the site and enters surface waters. When eroded sediment is transported from its site of origin to nearby surface waters it also carries fertilizers, pesticides, fuels and other contaminants and substances commonly spilled at construction sites that readily attach to soil particles (Risse & Faucette, 2001). For example, total annual loss of nitrogen, phosphorus and potassium due to soil erosion is estimated to be over 38 million Mg. Most of this is in the soil organic matter lost with the sediment (Brady and Weil, 1996). As a result, sediment can be five times as high in organic matter and nitrogen as in the original topsoil (Brady and Weil, 1996). It is estimated that the annual cost to society for on-site loss of soil, nutrients, water and yield reduction due to soil erosion is over $27 billion per year (Brady and Weil, 1996).

The US EPA has declared that sediment contamination of our surface waters is the biggest threat to our nation's water resources. Surface water that is loaded with sediment can lead to reduced drainage capacity, increased flooding, decreased aquatic organism populations, decreased commercial and recreational fishing catches, clogged and damaged commercial and industrial irrigation systems, increased expenditures at water treatment plants to clean the water, and decreased recreational and aesthetic value of water resources (Risse and Faucette, 2001). In addition to sediment build up in US river systems, another 1.5 billion Mg of sediment are deposited in the nation's reservoirs annually (Brady and Weil, 1996). The Clayton County Water Authority in Georgia paid over $30,000 to dredge one reservoir in 2001 while the Metro Atlanta area pays an estimated $4,000,000 per year to treat highly turbid water (Pihera, personal communication 2002). It is estimated that the national cost to society due to sedimentation of eroded soil is over $17 billion per year, bringing the total cost of erosion and sedimentation to society in the United States to over $44 billion per year (Brady and Weil, 1996).

Soil erosion is considered the biggest contributor to nonpoint source pollution in the United States according to the federally mandated National Pollution Discharge Elimination System (NPDES) (US EPA, 1997). The US Environmental Protection Agency is moving ahead with major new regulations to control erosion and runoff from farms, construction sites, and roads in an effort to make over 20,000 rivers, lakes, and estuaries safe for swimming and fishing (US EPA, 2000).

In 1987, amendments to the federal Clean Water Act mandated that construction sites must control storm water, erosion, and sediment originating from their site (US EPA, 2000a). In 1990, NPDES Phase 1 Rules mandated that all construction sites over 2.03 ha (5 acres) were required to have land-disturbing permits and pollution prevention plans (US EPA, 2000a). In

2003, the federally mandated NPDES Phase II went into effect extending the storm water management plan requirement to any land-disturbing activity over 0.4 ha (1 acre) (US EPA, 2000a). This system affects 30 counties and 54 municipalities across Georgia (Kundell, personal communication 2003). In August 2000, Georgia's Erosion and Sediment Control Act was amended to support NPDES Phase II, which created one of the nation's toughest regulations on soil erosion and sedimentation originating from construction sites, according to US EPA officials. The new regulations label development zones as "point sources" requiring better erosion control practices, new permitting programs, increased monitoring, and more site inspections by state and local officials.

In the new Erosion and Sediment Control Law, construction sites are prohibited from impacting any warm water stream by more than 25 Nephelometric Turbidity Units (NTU) and any trout stream by more than 10 NTUs (GA Soil and Water Conservation Commission, 2002). In addition, construction contractors are responsible for collecting and reporting storm water runoff samples from their sites. Samples must be collected from the first 1.25 cm (½ inch) rain event after clearing and grading, and again either after 90 days or after major soil disturbances have commenced (Shahlaee, personal communication 2003). The state can and has levied penalties up to $2,500 (USD) per day per violation of compliance with the new Erosion and Sediment Control Law (GA Soil and Water Conservation Commission, 2002). In addition, violators can also be held in noncompliance with the federal Clean Water Act can be fined up to $100,000 (USD) day (GA Soil and Water Conservation Commission, 2002).

Construction and development projects, where topsoil is cleared of vegetation or moved, are particularly subject to erosion problems. These project zones often present a significant challenge in reestablishing vegetation to protect the soil due to reduced soil quality and fertility.

In many cases the existing topsoil has been totally removed making the challenge even greater. In addition, heavy machinery and constant traffic compact the soil creating a “hard pan” that decreases infiltration, increases runoff, and prevents plant establishment and growth (Brady and Weil, 1996).

The Federal Highway Administration (FHA) regulates storm water and erosion and sediment control for highway construction projects. They also develop erosion and sediment control guidelines for state departments’ of transportation (DOTs) through the Intermodal Efficiency Act of 1991 and the Transportation Equity Act for the 21st Century of 1998 (Federal Highway Administration, 1997) and are held to the same standards in the Clean Water Act and the NPDES permit program.

Although soil loss rates from construction sites are 10-20 times that of agricultural lands (US EPA, 2000a), much less research has been done in this area. Turbidity and concentration of suspended solids from storm runoff are the most commonly cited water quality impacts during and immediately following highway construction projects (Barrett et al., 1995). Ehrhart et al. (2002) reported that suspended sediment concentrations in storm water sampled from construction site sediment basin effluent pipes were as much as 17 times higher than measurements taken upstream. This Pennsylvania study also concluded that suspended sediments remained high 100 meters downstream (Ehrhart et al, 2002).

While little research has been done on erosion and water quality impacts from construction sites, what has been done evaluates silt fences, hydroseeding, sedimentation ponds, check dams, synthetic fiber mats, and sediment barriers (Barrett et al., 1995). Currently, the most common erosion control methods employed in Georgia include silt fences, hydroseeding, geotextile blankets and straw mats. Several recent studies and field projects have suggested that recycled organic material and/or compost applications can be a superior and cost effective alternative to current erosion and sediment control best management practices (BMPs). For example, the Georgia Department of Transportation and Georgia Soil and Water Conservation Commission only require that straw mats and mulches provide 70-75% soil cover (GA Soil and Water Conservation Commission, 2002), but Adams (1966) claims a 90% cover is needed for appreciable differences in infiltration rates. Compost blankets when applied correctly provide nearly 100% surface coverage. Studies by Adams (1966) and Meyer et al (1972) found that significant rilling can develop under straw mats, where most soil loss occurs, while no rilling developed under wood mulches. While synthetic blankets and mats provide a ground cover they do not protect the structural stability of the slope, as rilling and gullying are common underneath these measures. Compost blankets are designed and applied so that when runoff occurs it moves over the surface of the blanket, not underneath. Heavier mulch materials, like compost, are much less likely to blow off slopes in windy conditions compared to straw mulch, thus protecting the soil from wind erosion (Meyer et al, 1972). Finally, compost filter berms may have less of an impact on wildlife migration patterns than silt fence, since filter berms can be easily scaled or traversed by terrestrial organisms.

Aside from the minimal effects of soil erosion from splashing, if runoff can be reduced or prevented, then so too can soil erosion. As much as one-third of precipitation can be lost to surface runoff and lead to subsequent erosion of the soil (Brady and Weil, 1996). The use of surface applied organic amendments has been shown to reduce runoff and erosion (Adams, 1966; Meyer et al., 1972; Laflen et al., 1978, Vleeschauwer et al., 1978, Foster et al., 1985). Land application of animal manure has been shown to decrease runoff by up to 62% and soil loss up to 65% in agricultural operations where manure is added annually and subject to natural rainfall conditions (Gilley and Risse, 2000). Poultry litter applications can reduce soil erosion and runoff on bare soils with moderate 7% slopes, and can greatly reduce runoff on grassed slopes (Giddens and Barnett, 1980). In addition, increasing the application rate of manure and litter can decease runoff and soil loss rate (Giddens and Barnett, 1980; Gilley and Risse, 2000).

In forested landscapes, surface layers of organic matter reduce the energy of raindrop impact and allow water to percolate into the soil, reducing surface runoff and erosion (Jordan, 1998). In addition, increasing water percolation in the soil can help to recharge groundwater supplies, as 20% of all water used in the US comes from these sources (Brady and Weil, 1996). Because of better soil contact and reduced susceptibility to movement from wind or water, wood mulches are superior to hay and straw mats (Holmberg, 1983; Lyle, 1987). Shredded bark and straw mulches will intercept and dissipate the energy of raindrops and prevent soil surface crusting; they also break up overland flow of runoff and hold more water at the soil surface allowing more water to infiltrate the soil (Adams, 1966; Gorman et al., 2000). Runoff from mulched soils can be reduced to only a fraction of that from unmulched soils and can nearly eliminate soil erosion (Epstein et al., 1966; Meyer et al., 1972; Laflen et al., 1978; Foster et al., 1985; Meyer, 1985; Mills, et al., 1986). Adams (1966) found that soils covered with mulch averaged less than 0.36 metric tons/ha (1 ton/acre) of soil loss compared to 7.4 metric tons/ha (20.2 tons/acre) from uncovered soils, during a 21 cm (8.5-inch) storm event. Meyer et al (1972) found on highway construction slopes of 20% and 45 meters (150 feet) long during a 6 cm (2.5 inch) storm event wood mulches yielded less than 1.8 metric tons (2 tons) per hectare soil loss compared to over 36 metric tons (40 tons) per hectare soil loss from other measures. In addition, berms made from mulch can act to filter moving sediment from storm runoff preventing it from leaving construction sites and reaching nearby surface waters (GA Soil and Water Conservation Commission, 1993).

In the last ten years compost has been used for slope stabilization, erosion and sediment control, storm water filtration, and vegetative establishment applications (Tyler, 2001). Composted wood waste has been shown to increase water infiltration and water holding capacity by improving soil structure (Demars et al., 2000). Applications of composted municipal solid waste can provide efficient control of storm runoff by dissipating the impact of water droplets and reducing runoff flow velocity (Agassi, 1998). MSW compost has been shown to absorb approximately 85% of applied rainfall compared to 42% and 52% from control plots (Agassi, 1998). Runoff rates were significantly lower on newly constructed highway embankments when using compost instead of topsoil (Glanville et al, 2001; Glanville et al, 2002). Once incorporated in the soil, compost can increase water infiltration up to 125% (Demars, 1998).

By increasing infiltration and reducing runoff, compost can reduce and potentially prevent soil erosion from occurring. Compost used for erosion control in a French vineyard reduced soil loss by two orders of magnitude (Ballif & Herre, 1988). In Portland, Oregon yard waste composts used for erosion control in residential construction projects exhibited reduced erosion and improved water quality over conventional erosion and sediment control measures (Portland Metro, 1994). Ettlin and Stewart (1993) found that slopes up to 42% could effectively use yard waste compost for slope stabilization and erosion control. Compost applications at four-inch depths will effectively control erosion on 45% slopes up to 3 years (Michaud, 1995). A study conducted by the Connecticut Department of Transportation found composts and mulches reduced soil erosion ten-fold compared to bare soil surfaces on a 2:1 slope (Demars and Long, 1998). Furthermore, Demars and Long (1998) report that when compared to silt fences, compost is 99% more effective in keeping sediment out of nearby surface waters, and 38% more effective than hydroseeding. By protecting the soil surface, compost blankets in general have been demonstrated to prevent soil particle dislodgement and subsequent erosion (Demars et al., 2000; CA Environmental Protection Agency, 2000; Portland Metro, 1994). Tyler (2001) states that one of the reasons composts perform so well is they are often high in organic materials that are more flexible, lighter, and absorb more water than soils; this helps in allowing the water to infiltrate the soil underneath. Further, he states the variety of particle sizes in compost blankets create an interlocking cover that allows water to travel on top while trapping the movement of soil particles (Tyler, 2001).

Perhaps the best way to reduce runoff and control erosion is to establish permanent vegetation as quickly as possible. Because of their dense cover characteristics undisturbed forests and grassed areas provide the best natural protection against soil loss; they are nearly equal in their capacity (Brady and Weil, 1996). The foliage of these vegetative covers can intercept between 5 and 40% of total precipitation never allowing it to even touch the soil surface, thus reducing runoff and potential soil loss (Brady and Weil, 1996). Grain sorghum reduces soil erosion compared to plots with no surface cover from 0.97 metric tons/ha (2.64 tons/acre) to 0.34 metric tons/ha (0.92 tons/acre), mainly because of raindrop interception by leaves and the binding actions of the fibrous roots near the soil surface (Adams, 1966). In addition, a layer of organic litter on the soil surface insulates the soil and reduces evaporation, creating a better environment for germination and root growth for establishing vegetation (Adams, 1966; Jordan, 1998). Field studies by the University of California Cooperative Extension staff found that compost out-performed conventional and slow-release fertilizers in turf grass applications in the following areas; improved turf color throughout the year, delayed onset of dormancy, lower weed populations, and consistently higher quality turf grass ratings (Block, 2000). A project sponsored by the Federal Highway Administration and the US EPA reported superior vegetative growth of compost over hydromulch and fertilizer on highway construction embankments (US EPA, 1997). The Texas Department of Transportation and the Texas Natural Resources Conservation Commission (TNRCC) found that composted dairy and cattle manure substantially increased vegetative growth and reduced soil erosion on roadway slopes (Block, 2000; US EPA, 2000). When comparing vegetative growth and erosion, Storey et al. (1995) found compost amended slopes outperformed synthetic chemical tackifiers and shredded wood on sandy soils. A study performed by Iowa State University found compost applied to highway roadsides established vegetation equal to topsoil, while outperforming topsoil in weed control (Richard et al, 2002).

It is important to delineate the advantage of compost over mulches in the ability to grow vegetation. Mulches can often have a detrimental effect on plant growth because of nitrogen immobilization (Meyer et al, 1972) while compost often has a carbon to nitrogen ratio optimum for plant uptake and can provide a slow release of nutrients (Maynard, 2000; Granberry et al, 2001) that sustains prolonged healthy plant growth.

One of the advantages in using compost for erosion control applications is its ability to maintain vegetation permanently because of its ability to increase soil organic matter and overall soil quality. Aside from studies already mentioned that demonstrate how compost can contribute to increased soil structure, water holding capacity, water infiltration and reduced soil erosion, it has also been shown to act as a slow release nutrient source (Maynard, 2000; Granberry et al, 2001), disease suppressant (De Cuester and Hoitink, 1999; Graham, 1998), pH buffer (Maynard, 2000), and source of beneficial soil organisms (Zibilske, 1999). Soil erosion studies have also shown that soil quality characteristics such as bulk density and aggregate stability can affect soil loss (Bradford and Foster, 1996) and additions of organic amendments can increase aggregate stability by resisting the beating action of rain and reducing soil erosion even when runoff occurs (Adams, 1966; Piccolo and Mbagwu, 1990; Brady and Weil, 1996). The ability of compost to positively influence these soil quality parameters is tantamount to its ability to maintain vegetation permanently which can insure reduced erosion and sedimentation.

While many states report having demonstration sites utilizing compost for erosion and sediment control, few have established specifications on what type or quality of compost to use and how to apply the material. The Departments of Transportation in Texas, Maine, Oregon, California, Connecticut, Washington, Idaho, and Michigan all have existing specifications on the use of compost for erosion control (Alexander, 2003). The Oregon Department of Environmental Quality, the Pennsylvania Division of Waterways, Wetlands and Erosion Control, and the Coalition of Northeastern Governors also have specifications for using compost in erosion and sediment control (Alexander, 2003). The American Association of State Highway Transportation Officials (AASHTO) has recently released provisional specifications that have been approved for the adoption by state departments of transportation (Alexander, 2003). The University of Georgia has a set of recommended guidelines based on most of these specifications (Risse and Faucette, 2001).

The Georgia Department of Transportation has recently approved some compost products as an erosion and sediment control measure but has not released final specifications on how to apply the material. The Georgia Soil and Water Conservation Commission (1993) which has been charged with approving and publishing best management practices (BMPs) for construction sites and land disturbing activities is considering the approval of compost as a BMP in the next addition of the state Manual for Erosion and Sediment Control, commonly referred to as the "Greenbook".

While 9 states have approved specifications as of 2002, very little research has evaluated the environmental impacts of different types of composts compared to industry standard measures of controlling soil erosion and preventing sedimentation. Scientific investigations in using compost for erosion control should seek to answer the following questions: how much can compost increase rain water infiltration and reduce storm water runoff volume; what is the optimum water content for composts to effectively be applied, reduce runoff and establish vegetation; what turbidity and suspended solids levels can be expected from the application of compost blankets; and are there water quality concerns related to nutrient loading from storm water runoff from compost blankets? If so, what types of composts should be avoided and/or how much buffer area should be maintained between compost application and surface waters; how effective are compost berms in filtering chemical spills and petroleum products in storm water runoff; and on how steep of a slope can compost be applied? In addition, what type of compost establishes erosion control vegetation the quickest and provides the best long-term vegetative cover; what is the optimum range of particle size distibution for water infiltration, runoff reduction, particle movement entrapment, and vegetation establishment and growth? And, what is the optimum depth for compost blankets and dimensions for compost filter berms - seeded and unseeded; what is the maximum concentrated flow velocity a compost blanket and compost filter berm can withstand; and what is the most cost effective way to apply compost blankets and filter berms? Finally, and possibly most important, is it cost competitive with industry standard erosion and sediment control measures?

As is usually the case, industry needs and consumer demand will steer the research. Most current specifications for compost address some of these issues, while none address them all. When developing specifications it is important to incorporate current research that addresses optimum application procedures, economic feasibility and environmental impacts.

There is very limited literature on the cost to apply compost in erosion and sediment control applications. Rexius Products of Eugene, Oregon constructs compost filter berms for $1.50 per linear 30 cm (1 ft) (Alexander, 1999). A Texas highway erosion control project utilizing compost cost the state $17,000 compared to standard measures employing topsoil, seeding and erosion control blankets that would have cost $30,000 (Block, 2000).

The ultimate goal of this research is to determine the environmental benefits and impacts of using compost for erosion and sediment control in construction site applications. Specifically, to determine the water quality impacts from nutrient and sediment loading, runoff volumes, and vegetative establishment and growth over 12 months compared to recognized industry standards - hydroseeding and silt fence. In addition, the research will measure the effects on soil quality and the overall cost to apply compost blankets and filter berms compared to conventional measures. Results from this study will be used by the Georgia Soil and Water Conservation Commission and a joint project by the US Department of Transportation, American Association of State Highway Transportation Officials and the US Composting Council in developing new specifications.

General Description of Compost Blankets and Compost Filter Berms

There are two basic methods for using compost in erosion and sediment control; *compost blankets* and *compost filter berms.* Generally, compost blankets are used to prevent soil erosion from occurring and filter berms are used to prevent moving sediments from leaving a designated area or from entering surface waters. In most cases, both methods can be used in combination.

Generally, a mix of *fine* and *course* grades of compost is best for controlling erosion (Risse and Faucette, 2001). The fine compost (passing through a 0.6 – 1.25 cm (**¼ - ½ in)** screen) will penetrate the soil surface and increase water infiltration and water holding capacity. In addition, the fine compost is important for rapid vegetation establishment and long term soil and plant health. The long-term nutrient value that compost supplies generally comes from the fine compost. Coarse grades of compost (passing through a 5 – 7.5 cm (**2-3 in)** screen) although harder to plant into, help to prevent splashing of raindrops directly on the soil surface and are less likely to be disturbed by storm runoff. The coarse grades also perform as filters by "stopping" or "catching" soil particles already in motion (Risse and Faucette, 2001).

Compost blankets or mats are surface applications of specified high quality composts on areas with erosive potential (Risse and Faucette, 2001). Compost blankets can be used to prevent erosion on disturbed areas such as construction sites, state DOT development (and planting) projects, exposed stream banks, and any disturbed or excavated land area with a 2:1 slope or less. The primary purpose of the compost blanket is to protect the soil surface until vegetation is established (Risse and Faucette, 2001). Therefore, it is important to insure that the compost material will encourage plant growth and that the slope is seeded with or directly following the compost application. Field demonstrations conducted in Georgia have shown that application rates should be between 2.5 to 7.5 cm (1 to 3 in) in depth, while some gradual slopes may require as little as 1.9 cm (¾ in). Particle sizes should be a mix of fine grade and coarse grades. Coarse grades may be larger if rapid vegetation establishment is not a primary goal.

Finally, a mixture ratio of 3:1 (fine: coarse) has been shown to work well in some of these field demonstrations.

Compost filter berms are contoured runoff and erosion filtration devices usually used for steeper slopes with high erosive potential (Risse and Faucette, 2001). The filter berm allows runoff water to flow through while filtering sediment and pollutants from the water. Filter berms also slow the flow down, allowing soil particles to settle out. Berm size and construction may vary based on slope steepness and the amount of expected rainfall; larger berms are recommended for steeper slopes and areas with greater runoff potential. Compost berms are typically contoured to the base of the slope but a second berm may be used on the shoulder contour of steeper slopes to prevent concentrated flow from running onto the compost blanket. Berms may be windrow or trapezoidal (allows maximum water penetration) in shape and should be placed uncompacted on bare soil immediately after soil disturbance. Windrow shaped berms (as used in this study) should be between 30 to 60 cm (1 to 2 ft) high and 75 to 120 cm (2.5 to 4 ft) wide (Risse and Faucette, 2001). Trapezoidal berms should be approximately 60 cm (2 ft) high, 60 to 90 cm (2 to 3 ft) wide at the top, and at least 120 cm (4 ft) wide at the base (Risse and Faucette, 2001). Compost filter berms are not recommended for use in runoff channels, ditches, or gullies. Particle sizes should be a mix of fine and coarse grades of compost with no particle sizes exceeding 7.5 cm (3 in) in length (Risse and Faucette). The mixture ratio should include a greater fraction of coarser grade compost (1:1) compared to compost blankets if vegetation establishment on the berm is not a primary goal, or if there is a high runoff quantity potential (Risse and Faucette, 2001).

Specifications for Compost Material and Compost Application in Erosion and Sediment Control

Specifications for compost use in erosion and sediment control applications are a relatively new development. Certainly composts can vary considerably in quality and often a product that claims to be compost, really may not have undergone the necessary biological processes. Specifications attempt to standardize high quality composts and formulate them in a manner that will provide optimum performance when applied correctly. Specifications may include: particle size, moisture content, nutrient content, organic matter content, pH, soluble salt content, heavy metals content, human made inert contents, stability and maturity indices, application rates, sand/silt/clay content, and/or certification by a third party.

For the purposes of this research, the recommended specifications developed by the University of Georgia were used. These recommendations, developed in the spring of 2001, were based on the specifications developed by Texas, Oregon, Connecticut, and California; interviews with the researchers and field professionals that developed these specifications; and trial and error in field demonstration projects in Georgia. Table 1.1 shows the recommended specifications developed by the University of Georgia (Risse and Faucette, 2001). Since this study was conducted, updated specifications have been developed for the American Association of State Highway Transportation Officials (Alexander, 2003) and are recommended for use in future projects.

Table 1.1: University of Georgia Recommended Specifications for Compost Use in Erosion and Sediment Control.

Parameter	Compost Blanket	Filter Berm
Particle size	0.9-1.25 cm (3/8 -1/2 in) screen & 5-7.5 cm (2-3 in) screen (3:1)	0.9-1.25 cm (3/8-1/2 in) & 5-7.5 cm (2-3 in) (1:1)
Moisture content	20-50%	20-50%
Soluble salt	< 6.0 mS/cm	< 8.0 mS/cm
Organic matter	40-70%	40-70%
pH	6.0-8.0	6.0-8.0
Nitrogen content	0.5-1.5%	0.5-1.5%
Human made inerts	0.0-1.0%	0.0-1.0%
Heavy Metals	US-EPA part 503	US-EPA part 503
Application rate/size	1.9-7.5 cm (¾ -3 in) depth	30-60 cm (1-2 ft) H x 75-120 cm (2.5-4 ft) W, 30-60 cm (1-2 ft) H x 120 cm (4 ft) B x 60-90 cm (2-3 ft) T
Respirometry (stability)	<1.0 mg/O_2 mg/VS hr^{-1}	<1.0 mg/O_2 mg/VS hr^{-1}
Germ. Index (maturity)	> 80%	> 80%

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CHAPTER 2

RUNOFF, EROSION, AND NUTRIENT LOSSES FROM COMPOST AND MULCH BLANKETS UNDER SIMULATED RAINFALL[1]

[1]Faucette, L.B.,L.M. Risse, M.A. Nearing, J.W. Gaskin , and L.T. West. Accepted by the Journal of Soil and Water Conservation

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Runoff, Erosion, and Nutrient Losses from Compost and Mulch Blankets under Simulated Rainfall

Abstract

Control of soil erosion and associated nonpoint source pollution is essential to improving water quality. The use of compost or mulch blankets as a soil cover can help control soil erosion and provide sustainable alternatives to disposal for many biomass resources. The objective of this study was to investigate the amounts of runoff, erosion, and nutrient losses obtained under simulated rainfall using a variety of compost and mulch materials. Treatments included aged poultry litter, two different types of poultry litter compost, municipal solid waste compost, biosolids compost, food waste compost, yard waste compost, three different types of wood mulch, and bare soil. Results indicated that all of the treatments except for aged poultry litter were effective at reducing total solids loss in the runoff. Nutrient losses from most of the compost treatments, however, were higher than those from bare soil or mulch treatments. Treatments with lower respiration rates and nitrate-nitrogen concentrations tended to have less erosion and transport of solids. Nitrate-nitrogen content, respiration rates, soluble salt, sodium, and potassium contents were good indicators of ammonium and phosphorus losses.

Keywords: Compost, erosion control, mulch, nutrient loss, runoff, water quality

Sediment has been identified as one of the most important nonpoint source pollutants of streams, lakes, and estuaries. Sediment is recognized as a pollutant that has an impact on aquatic organisms, habitat, and is also a carrier of other nonpoint source pollutants (Ermine and Ligon, 1988). While sources of sediment and other nonpoint source pollutants include agriculture and forestry, other land uses such as construction, development, and roads are being recognized as the major contributors in urban and developing areas. In fact, soil loss rates from construction sites are typically 10-20 times those from agricultural land (USEPA, 1997). Amendments in 1987 to the Clean Water Act label construction activities as “point sources” under the National Pollution Discharge Elimination System, requiring improved erosion control practices and new permitting programs (USEPA, 2003). In addition, road construction and maintenance are commonly recognized as significant sources of sediment requiring substantial investment in erosion control and vegetation establishment.

Currently, common erosion control practices for construction projects and road development in Georgia consist of silt fences, hydroseeding, and establishing vegetation. Demonstration projects and experimental research have suggested that the use of compost and mulch applications could improve upon existing erosion control technologies (Demars et al., 2000, Glanville et al., 2001, Mitchell, 1997). The use of compost and mulches in erosion control has additional benefits of being a more sustainable method of dealing with “waste” materials. With agricultural byproducts such as animal manure, it represents a method of improving the nutrient balance on the farm through the development of off-farm uses. Utilization of other organic byproducts such as municipal biosolids, wood waste, food processing residuals, and municipal solid waste could also be improved through composting if value added markets were available. Using these organic materials to rebuild soils and control soil erosion offers significant advantages over landfilling provided it is done in an environmentally sound manner. Additionally, many of these organic by-products are generated near urban and developing areas where the need for erosion control technologies is often greatest.

Conventional methods to control sediment include silt fencing and riprap; while hydroseeding, wood fiber mats, coconut hull fiber mats and straw mats are conventional means to prevent soil erosion from occurring. Surface applied organic mulches to protect the soil surface can significantly reduce both runoff and soil erosion (Adams, 1966; Meyer et al., 1972; Laflen et al., 1978; Vleeschauwer et al., 1978; Foster et al, 1985; Agassi et al., 1998). The mechanisms behind these reductions include less soil crust formation in the underlying soil, dissipation of the energy associated with raindrop impact, and a reduction in the shear forces exerted on the soil surface. Surface layers of organic matter reduce the energy of raindrop impact and allow water to percolate into the soil, reducing surface runoff and erosion. The rougher surface created by mulches and some composts also allows for greater water storage and percolation and lower runoff velocities (Kramer and Meyer, 1969). Composted wood waste has also been shown to increase water infiltration and water holding capacity by improving soil structure (Demars et al., 2000). Applications of animal manure to soil surfaces can also reduce runoff and soil erosion. However, the mechanisms behind these reductions are not well defined (Gilley and Risse, 2001; Giddens and Barnett, 1980). In addition, a layer of organic litter on the soil surface insulates the soil and reduces evaporation creating a better environment for germination and root growth and therefore improved vegetative cover (Jordan, 1998). Establishment of vegetative cover can then provide for long-term protection of the soil surface.

Studies conducted on 10.6 m by 3.1 m (35 ft by 10.2 ft) plots at a 2:1 slope by the Connecticut Department of Environmental Protection and Transportation showed that blankets of both yard waste mulch and yard waste compost reduced erosion by an order of magnitude and that the compost treatments performed as well or better than the conventional treatment of hay and seed (Demars et al., 2000). In Texas, Storey et al. (1996) compared compost amended plots and plots mulched with shredded wood to commonly used synthetic chemical tackifiers. They found that the compost amended plots reduced erosion as well or better than the other treatments with the greatest reductions occurring on sandy soils. Glanville et al.

(2001) compared three types of compost to bare soil and traditionally treated soils on new highway embankments in Iowa. They found that runoff from all three compost plots was significantly lower than the control and runoff from bio-industrial and yard waste compost was significantly lower than from plots amended with topsoil; however, plots amended with composted biosolids were not significantly different. All of the composts produced significantly less interrill erosion than topsoil amended plots. While differences in the growth of the planted cover crop were statistically indistinguishable, weed growth was significantly lower on some of the compost treatments.

Although erodibility is defined as a soil property and is quantified in terms of sediment loss, composts and mulches should display a similar property relative to the total solids lost from a surface cover. Very few people have investigated the measurement of erodibility on composts or mulches. Westerman et al. (1983) studied the erodibility of layer manure and broiler litter on sand and clay soils. They found that the addition of manure or litter resulted in increased transport of total solids and nutrients in the runoff, yet the erodibility of the manure was between that of the sand and clay. Many of the previously mentioned studies have attempted to quantify the total solids lost from compost or mulch blankets but few have related these data to the characteristics of the cover material. The erodibility of composts and mulches should be an important factor in their ability to control erosion.

The overall goal of this project is to develop a better understanding of the characteristics of composts and mulches as related to their use in erosion control technologies. Specifically, the objectives of this work were to test the runoff quantity, sediment loss and nutrient loss of various compost and mulch materials used as blankets under simulated rainfall and to correlate the physical and chemical properties of the materials to the measured losses.

Methods and Materials

Eleven treatments including three poultry litter composts, a municipal solid waste compost, a food waste compost, a yard waste compost, a biosolids/peanut hull compost, three grades of wood mulches and a bare soil control were selected for use in this study (Table 1.1). Compost is defined as organic material that has undergone a controlled, microbiological heat process and has decomposed to a biologically stable, humus rich material (Alexander, 1996). Mulch is simply a ground woody material generally derived from wood waste or yard debris. It has a relatively wide carbon to nitrogen ratio, a low nutrient content and has not gone through a controlled biological heat process. These treatments were selected based on their commercial availability in Georgia. Each of the materials was supplied by a commercial vendor and was tested as supplied. The bare soil control was obtained from a construction site that had undergone extensive grading and soil relocation. The site was originally mapped as an eroded Cecil sandy clay loam soil. Approximately, 1.81 metric tonnes (2 tons) of fill material was removed from the site, and passed through a 1.27 cm (0.5 in) screen to remove rocks and large aggregates. Initial plans called for three replicates of each treatment; however, due to limited supplies fewer replicates were used with several of the materials (Table 1.1).

Tables 1.2, 1.3 and 1.4 present the physical and chemical properties of each treatment. Bulk density, aggregate size, soluble salts, and respiration rate were measured at the University of Georgia Bioconversion laboratory using procedures outlined in Test Methods for the Examination of Compost (USCC, 1997). The remaining parameters were measured at the University of Georgia Agricultural and Environmental Services Laboratory using EPA or AOAC approved procedures (University of Georgia, 2004). Metals were analyzed and all of the treatments were below the pollutant concentration levels as specified in USEPA part 503 Table 4 (USEPA 1993).

Table 1.1. Treatment Names and Descriptions.

Treatment Name	Description/Primary feedstocks	Replicates
PLC1	Poultry Gold Compost/ Composted poultry litter	2
PLC2	Sargents Nutrients Compost/ Composted poultry litter	2
PL	Aged Poultry Litter/ Layer manure from underhouse storage	2
MSC	Cobb County Compost/ Municipal solid waste compost, biosolids	2
BSC	Erthfood Compost/ Biosolids, peanut hulls	3
FWC	Creative Earth Compost/ Food residuals, ground wood waste	2
YWC	UGA Compost/Yard waste, ground wood waste, some manure	3
WMf	Woodtech Superfine Mulch/Finely ground wood mulch	2
WMm	Woodtech Medium Hardwood Mulch/Medium ground wood mulch	3
WM2	Rockdale County Mulch/Coarse ground yard waste and waste wood	2
Soil	Bare soil control	3

Table 1.2. Physical Characteristics of Composts and Mulches.

Treatment	Moisture Content (%)	Volatile Solids (%)	Bulk Density (kg/m^3)	Respir. Rate ($g\ O_2/g\ VS/h$)
PLC1	24	14	799	0.06
PLC2	27	25	751	0.10
PLC3	36	13	724	0.07
PL	26	26	877	0.34
MSC	41	36	461	0.04
BSC	21	46	562	0.04
FWC	51	18	751	0.05
YWC	42	27	615	0.05
WMf	26	33	446	0.06
WMm	32	67	213	0.02
WM2	48	47	363	0.03
Soil	18	5	1453	0.14

Table 1.3. Particle Size Distribution of Composts and Mulches.

Treatment	Aggregate Size (%<25mm)	Aggregate Size (%<16 mm)	Aggregate Size (%<6.3 mm)	Aggregate Size (%<3.35 mm)	Aggregate Size (%<2.26 mm)	Aggregate Size (%<1.4 mm)	Aggregate Size (%<1 mm)	Aggregate Size (%<.710 mm)	Aggregate Size (%<.500 mm)	Aggregate Size (%<.125 mm)
PLC1	100	100.0	97.1	87.7	80.2	64.5	50.5	31.8	16.0	0.1
PLC2	100	99.7	93.0	83.4	75.1	58.5	47.4	37.6	28.1	5.3
PL	100	99.35	95.2	84.8	76.1	57.8	44.0	32.1	21.0	1.5
MSC	100	99.85	97.5	90.3	80.1	56.1	37.9	23.7	14.4	0.5
BSC	100	100	91.1	67.4	54.8	42.6	35.9	29.3	21.8	2.2
FWC	100	100	94.8	77.4	65.4	46.7	34.1	23.5	15.3	0.6
YWC	100	100.0	90.7	77.4	67.1	46.8	31.9	18.5	10.9	0.1
WMf	100	98.9	94.9	82.7	73.2	55.9	45.7	36.1	27.4	3.6
WMm	96.2	90.4	43.0	21.5	13.7	6.0	3.7	2.4	2.0	0.6
WM2	98	89.94	63.4	43.9	34.3	21.5	13.5	8.5	5.9	0.1
Soil	100	100.0	99.2	90.7	84.3	71.5	61.5	49.2	38.3	1.9

Table 1.4. Chemical Characteristics of Composts and Mulches.

Treatment	pH	Soluble Salts (dS/m)	C:N Ratio	Total N (%)	(NO_3-N) (mg/kg^{-1})	(NH4-N) (mg/kg^{-1})	Total P (mg/kg^{-1})	K (mg/kg^{-1})	Al (mg/kg^{-1})	Ca (mg/kg^{-1})	Mg (mg/kg^{-1})	Na (mg/kg^{-1})	Zn (mg/kg^{-1})
PLC1	7.2	5.87	15	0.56	732	56	9,009	7,835	13,300	51,540	3,454	1,330	192
PLC2	8.3	7.13	27	0.62	200	357	9,015	8,450	19,170	38,750	2,800	2,217	213
PL	7.1	20.60	9	1.74	4,876	35	13,830	14,990	2,347	29,810	3,494	4,660	261
MSC	8.3	5.03	23	1.18	210	1	3,186	2,571	9,357	18,270	1,718	2,700	372
BSC	4.9	7.65	13	1.09	1,460	116	8,086	4,872	11,670	6,028	1,705	283	202
FWC	7.7	0.80	29	0.46	1	63	622	2,622	11,760	3,715	1,093	151	41
YWC	5.0	0.11	36	0.39	74	245	351	1,868	19,240	483	1,043	44	39
WMf	6.0	0.25	113	0.16	21	21	192	1,076	11,280	1,954	651	50	21
WMm	5.6	0.20	637	0.09	1	42	74	578	756	1,065	204	28	8
WM2	7.0	0.24	139	0.18	4	28	141	773	2,383	1,761	275	42	27
Soil	5.0	0.11	9	0.08	88	172	351	1,868	19,240	483	1,043	44	39

Each replicate was placed in a 92 cm by 107 cm (36.2 in by 42.1 in) stainless-steel frame that was 15 cm (5.9 in) deep. These frames were attached to a plywood base that was placed at a 10% slope and equipped with a flume on the downslope end. The bottom of this flume was 5 cm (2 in) below the lip of the frame giving each collector an effective depth of 10 cm (4 in) with a 5 cm (2 in) border above the soil surface. Three 2.5 cm (1 in) holes were drilled in the plywood base to allow for seepage; however, little seepage occurred during the testing period. Five centimeters of soil was placed in the bottom of each collector and covered with cheese cloth and an additional 5 cm (2 in) of compost or mulch material was added for each run (except for the bare soil treatment). Between each run, the compost or mulch material was removed; the collector and soil surface rinsed, and the next treatment would be loaded into the collector. While the surface of the material was smoothed to ensure that it was flush with the flume edge and at a constant slope, no attempts were made to pack the compost, mulch, or soil treatments to an equal density. Prior to the initial run and to loading the treatments, the subsoil was pre-wet to saturation to insure that soil conditions would not influence the amount of runoff generated. Figure 1.1 shows the experimental set up.

Figure 1.1. Rainfall Simulator and Experimental Setup.

An eight-nozzle (V-jet nozzle operating at 4.2 kg/cm^2) Norton rainfall simulator obtained from the USDA National Soil Erosion Research Laboratory was used for this study. The simulator covered approximately a 6 m by 2 m (19.8 ft by 6.6 ft) area uniformly with rainfall. Therefore, four collectors fit under the simulator for each rainfall event and a total of seven runs were used in the study. Two runs used only three treatments. The treatments were randomly distributed throughout these runs. Actual rainfall rates were measured using 10 gages for each run. Average measured rainfall rates were 16 $\pm$ 0.7 cm/h (6.3 $\pm$ 0.3 in/h). The high rate of rainfall exceeds the 1-hour, 100-year storm event for Athens, Georgia (US Department of Commerce, 1961); however, it was our intention to evaluate these treatments under a "worst-case" scenario, because most erosion occurs during these large events. Since there was similar variability in rainfall rates within the runs as between them, no attempt was made to correct for rainfall rate. As soon as runoff began, which ranged from 3 minutes (soil) to 23 minutes (mulch) after rainfall was started, an initial sample of approximately 500 ml (16.9 oz) of runoff was collected. Additional samples were then collected at 5-minute intervals until a total time of 60 minutes had elapsed. An analysis of the data revealed that almost all the plots appeared to reach steady-state conditions during this period as the runoff rates were fairly constant near the end of the sampling period.

The runoff rate at 5-minute intervals during the simulation was plotted and the total runoff amount was calculated by summing the area under the runoff curve. In addition, each bottle was oven dried at 105°C until constant weight was achieved to determine the total solids content and total amount of solids lost from the plot. Volatile solids (VS), total solids (TS), total phosphorus (TP), ortho-phosphorus (PO_4), total nitrogen (TN), nitrate-nitrogen (NO_3-N), and ammonium-nitrogen (NH_4-N) were analyzed for the first flush sample and at the end of the run (steady-state sample). The TS and VS were measured using methods 2540 B Total Solids Dried at 103-105° C and method 2540 Fixed and Volatile Solids Ignited at 550° C (USEPA, 1983). Nitrate-nitrogen and total nitrogen were measured using EPA standard method 353.2 (colorimetric, automated, cadmium reduction), ammonium-nitrogen using EPA standard method 350.1 (colorimetric, automated phenate), and phosphorus using EPA standard method 365.1 (colorimetric, automated, ascorbic acid) (USEPA, 1983). A persulfate digest for water (Qualls, 1989) was used as a pretreatment for determination of total nitrogen and phosphorus. Total nutrient loads were estimated by averaging the concentrations of the first flush and steady state and multiplying by the runoff volume.

SAS version 8.2 (SAS, 2001) was used for the statistical analyses. Analysis of variance (PROC ANOVA) using Duncan's Multiple Range test for significant differences with unequal cell sizes was used to determine any significant differences between the treatments ($p \leq 0.05$). Correlation analysis (PROC CORR) was used to determine which of the physical and chemical treatment parameters were correlated to the measured runoff, total solids, and nutrient concentrations and loads.

Results and Discussion

Table 1.5. Mean Runoff, Solids and Nutrient Loss Data.

Treatment	Runoff Volume (L)	Total Solids Loss (g)	TN Load (mg)	NO_3-N Load (mg)	NH_4-N Load (mg)	TP Load (mg)	PO_4 Load (mg)
PLC1	74 ab	552 bc	4128 bc	2343 bc	138 b	10046 b	7588 b
PLC2	44 bcd	208 cd	1272 cd	751 c	45 b	1589 b	1253 c
PL	83 a	1221 a	1327 cd	14 c	6573 a	30266 a	23755 a
MSC	47 bcd	236 cd	645 d	410 c	194 b	294 b	242 c
BSC	53 abcd	154 d	8113 a	6301 a	241 b	2693 b	2217 c
FWC	37 cd	139 d	628 d	840 c	33 b	219 b	213 c
YWC	63 abcd	111 d	744 d	321 c	57 b	199 b	170 c
WMf	35 d	102 d	64 d	6 c	15 b	28 b	23 c
WMm	48 abcd	144 d	97 d	20 c	7 b	32 b	16 c
WM2	66 abcd	74 d	434 d	32 c	94 b	357 b	304 c
Soil	71 abc	646 b	150 d	42 c	20 b	52 b	57 c

* Treatments with the same letter are not significantly different at $p \leq 0.05$.

There was significant variability in the runoff volume and total solids loss between the treatments (Table 1.5). The poultry litter treatment had a runoff volume that was significantly higher than three of the composts (MSC, FWC, PLC2) and one of the mulches (WMf). This was probably due to the fact that the poultry litter appeared to be somewhat hydrophobic. At the end of the rainfall simulation, it was noted that the wetting front had not advanced through the layer of poultry litter. The poultry litter at the upper end of these plots was still dry after one hour of intense rainfall. None of the other treatments exhibited this and most appeared totally saturated. Although not significantly different, the composted poultry litters had less runoff and behaved more like the other treatments. The composting process appeared to reduce the hydrophobic properties of the poultry litter. The fine and medium mulches had the lowest runoff volumes. Although not significantly correlated to particle size distribution, mulches had the most storage volume (pore space) and took the longest to generate runoff due to the higher infiltration rate. The second wood mulch treatment (WM2) did not display these lower runoff rates. This may be due to the fact that this mulch contained post consumer wood waste, more hardwood that appeared to absorb less water and had a higher initial moisture content.

Compared to the bare soil, most of the compost and mulch treatments had less runoff and total solids loss (Figure 1.2). This indicates that almost all of the treatments were effective in reducing erosion.

There were very few differences in runoff among the compost treatments. In fact, these treatments only varied from 55% to 102% of the runoff observed on the bare soil treatment and overall there was only an average of 20% less runoff on the treated plots than the bare soil control. The point at which runoff began and the time to reach a semi steady-state condition appeared to vary from treatment to treatment but the steady-state rates were similar. Under these test conditions, the rainfall rate was much greater than the infiltration rate of the soil layer beneath the treatment. Therefore, excess water would pond on the soil surface in the cover treatment until it reached the lip of the flume and began to run off.

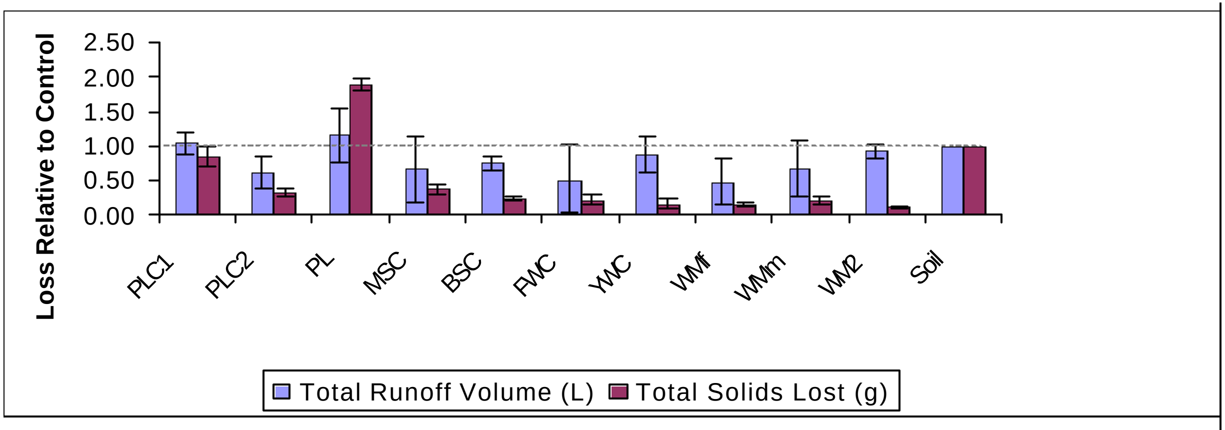

Figure 1.2. Total Runoff Volume and Total Solids Loss Relative to that from the Bare Soil Control.

Near the end of the simulation, when most of the cover treatment was saturated, all of the treatments with the exception of the poultry litter and mulches had similar runoff rates, but the differences were not significant. The runoff rates only varied from 17 to 26 ml/s (0.6 oz to 0.9 oz/s) and this could probably be attributed to differences in the rainfall rates and plot preparation. Under field conditions where the treatments are given time to influence vegetation and soil properties or with lower rainfall rates, greater differences in runoff rates and volumes would be expected.

The sediment loss data exhibited more differences between treatments. The total solids concentration over time was highly variable. In general, the first flush of runoff, when runoff rates were lower, had higher total solids concentrations, which generally decreased over time in an erratic manner. Due to the high variability between measurements, total solids lost, which aggregates the data, is probably a better indicator of performance than the first flush or steady-state concentration. Total solids loss for the poultry litter treatment was significantly higher than any other treatment. Total solids loss on the bare soil was significantly higher than all but one of the compost treatments (PLC1). Generally, the mulch treatments had the lowest total solids loss although these were not statistically different than many of the compost treatments. During the simulation, the poultry litter treatment and the bare soil control were the only treatments that displayed rill formation indicating erosion by flow stresses rather than just raindrop impact and sheet flow. By protecting the soil surface, all of the treatments, except the aged poultry litter, visually appeared to reduce or eliminate the impacts of concentrated flow and rill erosion.

Table 1.5 shows the nutrient loss data for each treatment. The biosolids compost had significantly higher total nitrogen and nitrate losses than any other treatment, even though the poultry litter had higher total nitrogen and nitrate contents in the initial analysis of materials. The poultry litter had significantly higher ammonium losses than any other treatment even though many other treatments had higher ammonium contents in the initial analysis. This indicates that the nutrients in some of the compost treatments were more available to runoff than equivalent concentrations in other treatments. The mulch and bare soil treatments generally had lower total nitrogen, nitrate, and ammonium losses; however, these were often not statistically significant. The phosphorus losses were significantly higher for the poultry litter treatment. Even though this was the only statistically significant difference, many of the compost treatments had phosphorus losses one or two orders of magnitude greater than the bare soil or mulch treatments. The high nutrient levels may be due to the fact that this simulation was conducted under worst case conditions including first flush following application with little opportunity for available nutrients to move into the soil, no vegetation, and very intense prolonged rainfall. Nevertheless, this does indicate that the environmental impacts of nutrient losses from these treatments must be weighed against the environmental benefits of reduced runoff and soil erosion. Future work should investigate the changes in nutrient losses over time from each of these treatments.

All of the physical and chemical characteristics in Tables 1.2, 1.3 and 1.4 were correlated against all measured outputs in Table 1.5, but only those that were highly correlated ($r>0.70$, $p\leq0.05$) are reported (Table 1.6). None of the independent variables measured were well correlated with total runoff volumes. Total solids loss was correlated with the respiration rate, nitrate-nitrogen, soluble salt, potassium and sodium contents of the treatment. Treatments with lower respiration rates and nitrate concentrations tended to show a reduction in the loss of total solids. The bare soil and poultry litter had the highest respiration rates (respiration rate is measured per gram of volatile solids and the bare soil had a very low amount of volatile solids and higher respiration rate) and the highest loss of total solids. Likewise, nitrate-nitrogen content, respiration rates, soluble salt, sodium, potassium, and total nitrogen contents were good indicators of ammonium and phosphorus losses. The fact that respiration rate was correlated to the total solids loss may be an indication that the biological processes involved in the composting process do influence the ability of the materials to resist detachment and movement. This was especially evident in the poultry litter composts, where those that had lower respiration rates showed reduced solids loss. This relationship warrants further research, as it could be an important component for standards involving compost use in storm water management applications. Soil erosion studies have indicated that particle size has a significant impact on erodibility (Foster et al, 1985, Wischmeier and Smith, 1978); however, the aggregate size analysis in this study was not well correlated to the erosion observed.

Table 1.6. Results from Correlation Analysis. All variables were tested against the complete list of parameters in Tables 1.2, 1.3 and 1.4. This table lists all the variables with significant correlation (r>0.70) or the most highly correlated variable.

Independent Variable	Variable with Significant Correlation (Correlation Coefficient)*
Total runoff volume	Res. (0.59)
Total solids loss	Res. (0.92), NO_3-N (0.83), SS (0.78), K (0.78), Na (0.72)
Total N loss	P (0.45)
Nitrate-N loss	P (0.33)
Ammonium N loss	NO_3-N (0.96), Res. (0.92), SS (0.88), K (0.88), Na (0.72), Total N (0.72)
Total P loss	NO_3-N (0.96), SS (0.91), K (0.89), Res. (0.88), Na (0.79), P (0.79), Total N (0.72), Mg (0.72)

PO_4 loss	NO_3-N (0.96), SS (0.91), K (0.89), Res. (0.88), Na (0.80), P (0.79), Total N (0.72), Mg (0.71)

*SS= Soluble Salts, Res.= Respiration rate, BD= Bulk density

Summary and Conclusions

All of the treatments tested, except for the poultry litter treatment, were effective at reducing total solids lost compared to a bare soil under these simulated conditions. The poultry litter treatment had significantly more runoff than did the mulch treatments. The poultry litter treatment also lost significantly more total solids than any other treatments. The bare soil lost significantly less total solids than the poultry litter treatment, but significantly more than all of the other treatments except for one of the poultry litter composts. In all cases, composted poultry litter treatments had less runoff, erosion, and nutrient loss than did aged poultry litter. The mulch treatments had lower total solids loss and less runoff than most of the composts; however, these differences were often not statistically significant. Losses of nutrients tended to be higher for the poultry litter and biosolids compost treatments. Total nitrogen loads were significantly higher for the biosolids compost treatment and two of the poultry litter composts were significantly higher than the other treatments. Total phosphorus losses were significantly higher for the poultry litter. Treatments with lower respiration rates, nitrate-nitrogen, soluble salt, potassium, and sodium concentrations tended to have less erosion and transport of solids. Nitrate-nitrogen content, respiration rates, soluble salt, sodium, potassium, and total nitrogen contents were good indicators of ammonium and phosphorus losses. Further work is needed to better quantify the relationships between the physical and chemical properties of the treatments and the runoff, erosion, and nutrient losses. The goal of a soil cover should be to provide short-term protection with little environmental impact while vegetation is being established. Ultimately, the vegetation establishment is an equally important goal and the nutrients in the compost treatments should aid in this process. Further work is ongoing to investigate similar compost and mulch materials to determine which are effective at establishing and maintaining long-term vegetative cover and soil quality. Ultimately, the results from both studies should be combined to develop decision aids in the selection of compost and mulch materials for erosion control.

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CHAPTER 3

EVALUATION OF ENVIRONMENTAL BENEFITS AND IMPACTS OF COMPOST AND INDUSTRY STANDARD EROSION AND SEDIMENT CONTROL MEASURES USED IN CONSTRUCTION ACTIVITIES

In response to public concern regarding potential groundwater pollution potential and reduction in landfill capacity the Georgia General Assembly established a statewide waste reduction goal of 25% to be achieved by 1996, enabled through the 1992 Georgia Solid Waste Management Act. Nearly 70% of Georgia's Municipal Solid Waste is organic material and could be composted if source separated (US EPA, 1999). Georgia leads the nation in poultry production, generating approximately 1.36 metric tons (1.5 million tons) of poultry litter annually (Faucette, 2001) in addition to over 1.81 million metric tons (2 million tons) per year of food processing waste (Magbunua, 2000), 2.26 million metric tons (2.5 million tons) per year of wood waste (Benson, 2000), and almost 362,000 metric tons (400,000 tons) per year of municipal biosolids (Governo, 2000). By diverting organic materials from landfills we reduce potential ground water pollution from landfill leachate, reduce the amount of methane released to the atmosphere, reduce the need to expand existing landfills and construct new ones, and potentially improve soil quality by replacing organic matter and recycling nutrients to our highly depleted soils. Therefore, it is important to divert these materials from landfills by developing off-site uses and markets for these materials.

The US EPA has declared that sediment contamination of our surface waters is the biggest threat to our nation's water resources. Soil erosion is considered the biggest contributor to nonpoint source pollution in the United States according to the federally mandated National

Pollution Discharge Elimination System (US EPA, 1997). Soil loss rates from construction sites can be 10-20 times that of agricultural lands (US EPA, 2000). For example, forestlands lose an average of 0.36 metric tons/ha (1 ton/acre) per year; agriculture loses an average of 5.5 metric tons/ha (15 tons/acre) per year while construction sites average 73.3 metric tons/ha (200 tons/acre) per year (GA SWCC, 2002). In 2003, the federally mandated NPDES Phase II went into effect extending the storm water management plan requirement to any land-disturbing activity over 0.4 ha (1 acre). The new regulations label development zones as “point sources” requiring better erosion control practices, new permitting programs, increased monitoring, and more site inspections by state and local officials.

The use of surface applied organic amendments has been shown to reduce runoff and erosion (Adams, 1966; Meyer et al., 1972; Laflen et al., 1978, Vleeschauwer et al., 1978, Foster et al., 1985). In forested landscapes, surface layers of organic matter reduce the energy of raindrop impact and allow water to percolate into the soil, reducing surface runoff and erosion (Jordan, 1998). Because of better soil contact and reduced susceptibility to movement from wind or water, wood mulches are superior to hay and straw mats (Holmberg, 1983; Lyle, 1987). Shredded bark and straw mulches will intercept and dissipate the energy of raindrops and prevent soil surface crusting; they also break up overland flow of runoff and hold more water at the soil surface allowing more water to infiltrate the soil (Adams, 1966; Gorman et al., 2000).

In the last ten years compost has been used successfully for slope stabilization, erosion and sediment control, storm water filtration, and vegetative establishment applications. Compost used for erosion control in a French vineyard reduced soil loss by two orders of magnitude (Ballif and Herre, 1988). In Portland, Oregon yard waste composts used for erosion control in residential construction projects exhibited reduced erosion and improved water quality over conventional erosion and sediment control measures (Portland Metro, 1994). Ettlin and Stewart (1993) found that slopes up to 42% could effectively use yard waste compost for slope stabilization and erosion control. Compost applications at four-inch depths will effectively control erosion on 45% slopes up to 3 years (Michaud, 1995). A study conducted by the Connecticut Department of Transportation found composts and mulches reduced soil erosion ten-fold compared to bare soil surfaces on a 2:1 slope (Demars and Long, 1998). Furthermore, Demars and Long (1998) report that when compared to silt fences, compost is 99% more effective in keeping sediment out of nearby surface waters, and 38% more effective than hydroseeding. For a more exhaustive literature review see Chapter 1.

MATERIALS AND METHODS

Epstein (1997) and Storey et al. (1995) define compost as a relatively stable decomposed organic material resulting from the accelerated biological degradation of organic material under controlled, aerobic conditions. Storey et al. (1995) adds that it is the disinfected and stabilized product of the decomposition process that is used or sold for use as a soil amendment, artificial topsoil, or growing medium amendment.

Seven treatments were randomly assigned and applied to 1 m by 4.8 m cleared and 10% graded field test plots: a biosolids compost blanket with compost filter berm; a yardwaste compost blanket with compost filter berm; a municipal solid waste compost (MSW) and mulch blanket with mulch filter berm; a poultry litter compost, mulch and gypsum blanket and mulch filter berm; hydroseed and silt fence; hydroseed and mulch filter berm; and a bare soil (control) plot. Table 2.1 shows the layout of the test plots. Compost blankets were manually applied at 3.75 cm (1.5 inch) depths over the entire area of the plot. Filter berms were 60 cm (2 ft) wide by

30 cm (1 ft) high and situated at the base of the slope across the width of the plot. Each treatment, excluding the control plots, were seeded with a grass seed mix specified by the G DOT as an erosion and sediment control vegetative measure for slopes 3:1 or less for the Athens, Georgia region. The compost treatments were physically, biologically and chemically characterized prior to application in the test plots (Table 2.2 and 2.3). Complete sampling and analytical procedures can be found in Appendix A.

Table 2.1: Test plot layout by treatment.

Test Plot Number	Treatment	Abbreviation
1	Bare soil (control)	BS-1
2	Biosolids compost blanket and filter berm	BC-2
3	Poultry litter compost/mulch/gypsum blanket w/ mulch filter berm	PL-3
4	Yardwaste compost blanket and filter berm	YW-4
5	Hydroseed and silt fence	HS-5
6	Bare soil (control)	BS-6
7	Hydroseed and mulch filter berm	HM-7
8	MSW compost/mulch blanket w/ mulch filter berm	MS-8
9	Poultry litter compost/mulch/gypsum blanket w/ mulch filter berm	PL-9
10	Biosolids compost blanket and filter berm	BC-10
11	Hydroseed and silt fence	HS-11
12	MSW compost/mulch blanket w/ mulch filter berm	MS-12
13	Bare soil (control)	BS-13
14	Hydroseed and mulch filter berm	HM-14
15	MSW compost/mulch blanket w/ mulch filter berm	MS-15
16	Hydroseed and silt fence	HS-16
17	Yardwaste compost blanket and filter berm	YW-17
18	Poultry litter compost/mulch/gypsum blanket w/ mulch filter berm	PL-18
19	Biosolids compost blanket and filter berm	BC-19
20	Hydroseed and mulch filter berm	HM-20
21	Yardwaste compost blanket and filter berm	YW-21

Table 2.2: Physical, chemical and biological characterization of treatments.

Treatment	Bulk Density (g/cm^3)	Bulk Density (lbs/yd^3)	% Inerts	Stability - 0_2 uptake (mg O_2/g VM Hr^{-1})	Germination Index (%)
Biosolids compost	0.51	1292.5	< 1%	0.02	96
Yard waste compost	0.5	1122.9	< 1%	0.09	100
Poultry litter compost w/ mulch & gypsum	0.59	1316.8	< 1%	0.06	100
MSW compost w/ mulch	0.32	743.2	< 1%	0.1	100
Mulch (fines & medium grade)	0.18	670.5	< 1%	0.05	86
Soil	2.23	3,758.8	< 1%	nd	nd

Treatment	Water (%)	pH	SS (mS/cm)	OM g kg^{-1} (550 C)	C:N	C	N	NH_4	NO_3	P
Biosolids compost	31.3	7	1.62	202	17	100900	5830	2480	1960	4470
Yard waste compost	40.66	7.8	0.645	193	19	97500	5010	40	70	3240
Poultry litter compost w/ mulch & gypsum	32.2	7.2	5.93	212	22	131500	5980	70	240	4290
MSW compost w/ mulch	45.7	8.1	4.96	360	20	175200	8660	140	180	1910
Mulch (fines & medium grade)	32.4	7.2	0.544	497	101	268900	2670	180	100	960
Soil	Nd	4.7	Nd	Nd	18	250	14	0.74	0.053	348

Treatment	Al	B	Ca	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	Pb	S	Si	Zn
Biosolids compost	9480	8	3046	12.56	46.7	6780	1794	755.8	108.7	1.74	124.1	6.5	< 2.5	1393	190.8	117.1
Yard waste compost	11600	11.8	8147	11.96	< 0.5	11360	3241	1976	374.8	< 0.5	177.9	7.31	< 2.5	805.8	215.4	65.82
Poultry litter compost w/ mulch & gypsum	9000	19.3	16610	6.76	10.95	5191	4292	1215	88.75	< 0.5	180.8	2.59	< 2.5	9463	132.6	45.59
MSW compost w/ mulch	11690	32.5	1443	22.72	74.89	11260	2465	1332	213.4	1.33	2944	17.64	78.93	2118	170.1	248.3
Mulch (fines & medium grade)	8558	4.14	1713	5.9	< 0.5	5418	963.4	540.7	125.2	< 0.5	137.7	3.18	< 2.5	189	253.1	20.22
Soil	nd	nd	173	nd	Nd	Nd	130	23	15	50	nd	nd	nd	nd	nd	0.17

All nutrients and metals expressed in mg kg^{-1}.

Table 2.3: Particle size characterization of treatments.

Sieve Size	Unit	MSWC	%	PLC	%	Mulch	%	YWC	%	BSC	%
25	**mm**	0	100	4.9	99.5	2.4	99.3	0	100	0	100
16		1.1	99.8	6.2	98.8	17.1	94.6	2.7	99.6	0	100
9.5		38.9	91.6	17	97.0	37.1	84.4	16.1	97.2	14.6	98.1
6.3		34.5	84.4	36.8	93.0	61.6	67.4	41.8	91.0	134.3	80.7
4		35.4	77.0	53.4	87.2	64.1	49.7	65	81.4	166.6	59.1
3.35		19.8	72.9	23.4	84.7	23.8	43.1	27.5	77.3	46.3	53.1
2.36		46.3	63.2	47.2	79.6	35.5	33.3	54.6	69.2	68.9	44.1
2		31.9	56.5	31	76.2	36.1	23.4	34.3	64.1	27.5	40.6
1.4		61.9	43.6	71.9	68.4	18.4	18.3	84.2	51.6	51.1	33.9
1.18		27.6	37.8	35.3	64.6	5.6	16.7	19.5	48.7	24.3	30.8
1		34.5	30.6	41.9	60.1	9.3	14.2	34.6	43.6	28	27.1
850	mm	19.8	26.4	23.5	57.6	1.9	13.6	20	40.6	17.5	24.9
710		32	19.7	50.5	52.1	11.5	10.5	44.7	34.0	37.8	20.0
600		16.1	16.4	46.1	47.1	3.6	9.5	34	29.0	27.4	16.4
500		13.2	13.6	49.1	41.8	4.8	8.1	33.1	24.1	25.6	13.1
250		40.2	5.2	228.3	17.1	19.1	2.9	112.3	7.4	78.5	2.9
125		19.4	1.2	120.2	4.1	8.2	0.6	40.6	1.4	20.9	0.2
Pan		5.5	0	38.1	0	2.2	0	9.3	0	1.5	0
Total (g)		**478.1**		**924.8**		**362.3**		**674.3**		**770.8**	

Research test plots were at Spring Valley Farm in Athens/Clarke County, Georgia, USA at 33° 57’ N latitude and 83° 19’ W longitude. Today Spring Valley Farm is a research and education site for Agroecological and Agroforestry production practices. Prior to this the farm was used extensively for pasture and intensive cotton production for over 100 years. These practices have left the research site area devoid of topsoil, and low in soil fertility and overall soil quality. The research site was surrounded by open and unmanaged pasture with scrub vegetation. The soil was originally classified as an eroded Pacolet Sandy Clay Loam (USDA, 1968) and has a high soil erodibility factor (K value) of approximately 0.36 (Wischmeier and Smith, 1978). The area receives an average annual rainfall of 1214.7 mm, with January through March as the wettest period. The average annual high temperature for the area is 22° C, the average low is 11°C, with a mean annual temperature of 17°C (Weather Channel, 2004).

The land was cleared of vegetation and topsoil to simulate a construction site soil surface. A 10% grade was applied to the exposed subsoil (Bt horizon). Test plot borders were installed to prevent cross contamination of plots. Fifteen cm (6 in) stainless steel was used to avoid potential metal contamination in the runoff. The borders were trenched 7.5 cm (3 in) into the soil. Seven and a half centimeters of the border extended above ground. The plots were sized to fit the greatest effective rainfall distribution from the rainfall simulator. Preliminary tests showed this to be 1.0 m (3.3 ft) wide by 4.8 m (16 ft) long, for an effective area of 4.8 m^2 (53 ft^2). A removable flume was installed at the base of each plot prior to each simulated rainfall event. Nine rain gauges were installed in each plot to measure rainfall quantity. Three each were placed 1.2 m (4 ft), 2.4 m (8 ft) and 3.6 m (12 ft) from the top of the plot. Gauges were also spaced evenly across the width of the plot.

The rainfall erosion index (R value), a value used to account for the erosive effects of storms using rainfall intensity and total rainfall data, is relatively high for this region of the United States, between 250 and 300, making it highly susceptible to soil erosion (USDA, 1995). A rainfall simulator was calibrated to produce a 7.75 cm (3.1 in) per hour storm event for one-hour duration. This is equivalent to the one-hour storm event for a 50-year return for the Athens, Georgia region, based on historical rainfall records (US Department of Commerce, 1961). It was our intention to evaluate these treatments under a “worst-case” scenario, because most erosion occurs during these large events.

A Norton Rainfall Simulator with 4 variable speed V-jet oscillating nozzles was used to simulate storm events. Water pressure to the nozzles was maintained at 0.42 kg/cm^2 (6 psi) during rain events. A 7569 liter (2000 gal) tanker truck was used to supply and pump water to the rainfall simulator. Municipal tap water was used in the study. The water was monitored and tested for NO_3-N (0.673 mg L^{-1}) and $P0_4$-P (0.093 mg L^{-1}) contents prior to use in the study.

Three simulated rainstorms were conducted; at the beginning of the experiment, at 3 months and one year. These time intervals were chosen based on the predicted establishment of the vegetation. The first storm event was intended to provide information on the performance of the treatments prior to vegetation establishment. The second storm event was intended to provide information on how the performance of the treatments changed when vegetation was newly established. The final storm event was to provide information on how the treatments reacted once vegetation was fully established. A stainless steel border was inserted at the base of each plot between storm events to maintain the structure and integrity of the plot.

The week prior to the first simulated storm event the research site received no natural rainfall, while 31 mm (1.22 in) of rain fell on the plots during the week of the simulated storm events. During the three months between the second and third storm event the site only received 90.7 mm (3.57 in) of natural rainfall, with only 16.8 mm (0.66 in) falling in the third month. These extremely dry conditions likely affected vegetation growth. The week prior to the second storm the research site received no natural rainfall, while during the weeklong simulated storm trials the site received 6.9 mm (0.27 in) of natural rain. The week before the final storm event the research site received 102.4 mm (4.03 in) of natural rain and 35.8 mm (1.41 in) during the week of storm simulations. This led to saturated field conditions during the final simulated storm event.

Two vegetative growth analyses were conducted; at three months (as vegetation was establishing) and one year (vegetation mature). Three soil analyses were conducted; at the beginning of the experiment, at 6 months and 18 months. Complete sampling and analytical procedures can be found in Appendix B.

Analyses for storm water included: rainfall amount, antecedent soil water, time until start of runoff, time until steady state of runoff, runoff volume, runoff rate, rainfall infiltration, rainfall infiltration to runoff ratio, total sediment loads, sediment loss ratios, total N concentration and load, NO_3-N concentration and load, NH_4-N concentration and load, total P concentration and load, dissolved reactive P concentration and load, and total P load to dissolved reactive P load ratios. Vegetation analysis included: percent cover at three months and twelve months; number of weed species and weed plants at three months and number of weed species and percent cover of weeds at twelve months; and Bermuda grass, weed and total biomass at twelve months. Soil analysis included: bulk density, water infiltration rate, extractable organic carbon, total C, total N, C:N ratio, total P, plant available P, K, Ca, Mg, Zn, pH, and organic matter at 0 to 5 cm and 0 to 15 cm depths. Complete sampling and analytical procedures can be found in Appendix B.

SAS version 8.2 (SAS, 2001) was used for statistical analysis. Analysis of variance (PROC ANOVA) used Duncan's Multiple Range test for significant differences between cells was used to determine any significant differences between treatments ($p \leq 0.05$). Correlation analysis (PROC CORR) was used to determine which of the independent variables, including: physical, chemical, and biological treatment parameters (as expressed in tables 2.2, 2.3, and 2.4), and all reported vegetation and rainfall characteristics were correlated to the response variables, including: all results from vegetation, runoff, solids loss, nutrient loss, and soil quality parameters. For more detail on the materials and methods see Appendix B.

A survey was conducted in Georgia in 2001 to determine which compost operations could potentially enter the erosion and sediment control market and what they would charge for installation of compost blankets (per yd^2) and filter berms (per linear ft). Price was based on a 3.75 cm (1.5 in) deep compost blanket and 0.3 m high by 0.6 m wide (1 ft by 2 ft) compost filter berm. Prices are compared to industry standard measures and are presented as the total installed price (material cost + installation cost). All information was collected by telephone survey and/or site visits.

RESULTS AND DISCUSSION

Vegetative Growth

Based on this study and under these environmental conditions, compost did better than hydroseeding and bare soil at providing a quick vegetative cover (Table 2.4). However, in the long term hydroseeding may be a better option. The caveat was that the better long term performance of the hydroseeding was due to the invasion of weeds, not the intended vegetation (Table 2.5). From a practical standpoint to control erosion this was a good result, but from an industry or commercial standpoint this may be undesirable. Additionally, this may provide evidence that some composts can suppress the growth of weeds. It should also be noted that wherever vegetation has not been established by hydroseeding, soil erosion will continue to occur and potentially get worse over time; unlike compost which still covers the soil surface in areas where vegetation may not have established. Composts with high germination rates, total nitrogen, total phosphorus, and potassium concentrations lead to a quicker vegetative cover (Table 2.6). Additionally, plenty of rainfall or moisture may be required. High nutrient, biologically stable, mature composts that get plenty of rainfall will provide the best and quickest cover. However, composts with high ammonium nitrogen, high nitrate nitrogen, and low C:N ratios appear to create greater weed growth, in number of species, number of plants, and biomass.

For erosion control professionals deciding on which measure to use for vegetation establishment, compost provides a quicker vegetative cover with less weed growth – particularly under conditions of heavy rainfall and drought (as experienced in this study), while hydroseeding (utilizing Bermuda grass seed) may require additional applications to provide sufficient and permanent vegetative cover without weed proliferation. See Appendix B for more results and discussion.

Table 2.4: Average percent cover by treatment at three months and twelve months, n=3.

Treatment	3 months	SD	12 months	SD
PLC/Mulch/Gypsum	64a	28	73a	22
Biosolids Compost	57a	6	86a	15
MSW Compost/Mulch	59a	20	72a	16
Yardwaste Compost	62a	19	68a	17
Hydroseed/Mulch Berm	22b	7	86a	2
Hydroseed/Silt Fence	22b	16	81a	20
Bare Soil (not seeded)	17b	14	24b	15

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Multiple Range test.

Table 2.5: Average biomass of Bermuda grass, weed, and total vegetation in g/m^2 ($10.8\ ft^2$) and ratio of average Bermuda grass biomass to average weed biomass by treatment at 12 months, n=3.

Treatment	Bermuda	SD	Weed	SD	Total	SD	Bermuda:weed
PLC/Mulch/Gypsum	244a	230.2	80.6bc	25.0	324.6ab	206.3	3.03:1
Biosolids Compost	128.5a	111.4	168.9b	74	297.4ab	173.1	0.76:1
MSW Compost/Mulch	191.5a	256.9	65.1bc	10.7	256.6ab	247.1	2.94:1

Yardwaste Compost	148a	139.0	43.2c	13.1	191.2ab	149.5	3.43:1
Hydroseed/Mulch Berm	199.5a	69.8	286a	71.4	485.5a	32.2	0.70:1
Hydroseed/Silt Fence	158.8a	105.7	287a	78.7	445.7a	27.4	0.55:1
Bare Soil (not seeded)	0a	0	76.7bc	63	76.7b	63	0

Treatments with same letter are not significantly different at α = 0.05 using Duncan's Multiple Range test.

Table 2.6: Results from correlation analysis. This table lists all variables with significant correlation ($r>0.70$, $\alpha = 0.05$, $n = 21$).

Response Variable	**Independent Variable (treatment) with Correlation Coefficient**
Vegetative cover at 3 months	Germination rate (0.71), K (0.71), rainfall amount from 1st storm (0.70), N (0.69), compost - P (0.68)
# of weed species at 3 months	NH_4 (0.81), NO_3 (0.82), # of weed plants (0.92)
# of weed plants at 3 months	NH_4 (0.84), NO_3 (0.85), # of weed species (0.94)
Weed cover at 12 months	Weed biomass at 12 months (0.81), total biomass at 12 months (0.72)
Weed biomass at 12 months	C:N ratio (0.78), weed cover at 12 months (0.87), total biomass at 12 months (0.76)

Storm Water Runoff and Solids Loss

MSW compost was the best tool at reducing runoff volume in the short and long term. It also appeared that hydroseeding was not very effective at reducing runoff compared to a bare soil, while compost was effective (Table 2.7). Additionally, compost reduced runoff more over time than hydroseeding or a bare soil. Support for this is evident in the amount of rainfall that infiltrated each treatment, again the composts outperformed hydroseeding, and the MSW compost did particularly well. All of the treatments allowed for better infiltration than the control. Based on the time it takes for runoff to commence, compost may be a better tool to prevent runoff from occurring during small storm events (Table 2.8). The MSW compost was particularly effective in this area. Based on correlation analysis, general characteristics of high quality compost such as a high biological stability rating, high germination rate, and a neutral pH are good indicators that there will be greater infiltration and less runoff (Table 2.9). This is likely since these characteristics lead to good vegetation establishment, which in turn can lead to greater infiltration and less runoff. Additional parameters that provide good vegetative growth, such low bulk density, adequate N, P, and K and to some extent the particle size distribution of the compost, are important to increasing infiltration and reducing runoff. This provides compelling evidence that compost may be well suited for a variety of storm water management applications, particularly where it can eliminate runoff, thus preventing most erosion from ever occurring. For erosion control professionals deciding on which measure to use for managing storm water and reducing runoff, compost is a better tool than hydroseeding for increasing infiltration and reducing storm runoff. For more results and discussion see Appendix C.

Table 2.7: Total runoff volume (mm) by treatment at day one, three months, and twelve months, n=3.

	DAY ONE		THREE MONTHS		TWELVE MONTHS	
Treatment	AVG	SD	AVG	SD	AVG	SD
PLC/Mulch/Gypsum	32.0ab	12.7	5.0c	4.9	15.9c	7.0
Biosolids Compost	38.1ab	7.9	9.6c	6.9	21.6bc	17.0
MSW Compost/Mulch	22.5b	13.1	1.8c	Nd	21.9bc	2.2
Yardwaste Compost	33.0ab	5.6	8.1c	4.1	25.0abc	7.0
Hydroseed/Mulch Berm	36.7ab	5.8	20.2bc	2.4	34.2ab	9.9
Hydroseed/Silt fence	30.0ab	11.6	32.3ab	28.3	27.6abc	5.1
Bare Soil (not seeded)	42.3a	5.6	45.9a	20.6	40.8a	8.9

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 2.8: Average time (minutes) until start of runoff and steady state conditions by treatment at day one, three moths, and twelve months, n=3.

	DAY ONE		THREE MONTHS		TWELVE MONTHS	
Treatment	RO Start	RO Steady state	RO Start	RO Steady state	RO Start	RO Steady state
PLC/Mulch/Gypsum	12.0bc	40.3a	41.0ab	55.3a	21a	44.3ab
Biosolids Compost	8.3bcd	26.7ab	32.7b	56.0a	23.7a	40.3a
MSW Compost/Mulch	20.0a	40.0a	51.7a	>60.0a	14.3a	37.7ab
Yardwaste Compost	13.0b	31.3ab	33.3b	54.0a	14.7a	34.7ab
Hydroseed/Mulch Berm	7.3cde	25.7ab	14.3b	31.0b	9.0a	27.3ab
Hydroseed/Silt fence	6.0de	22.7ab	8.0b	19.7b	10.3a	33.7ab
Bare Soil (not seeded)	2.7e	9.3c	6.3b	19.7b	3.7a	18.7b

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 2.9: Results from correlation analysis. This table lists all variables with significant correlation (r>0.70, α = 0.05, n = 21).

Response Variable	**Independent Variable (treatment) wi th Correlation Coefficient**
Time to runoff start, Storm #1	N (0.83), pH (0.77), stability (0.72), moisture content (0.77), Na (0.76), Mg (0.70), B (0.81), Cd (0.72), Cr (0.72), Ni (0.74), Zn (0.76)
Time to runoff steady state, Storm #1	N (0.75), K (0.72), pH (0.74)
Rain infiltration volume, Storm #1	Particle size >4mm (7.0), pH (0.74), germination rate (0.70), Al (0.72), N (0.74), K (0.72), Mg (0.84), Mn (0.70)
Time to runoff start, Storm #2	Particle size >25mm (0.71), Particle size >16mm (0.82), Particle size >9.5mm (0.77), Particle size >6.3mm (0.72), pH (0.73), germination rate (0.80), percent vegetative cover (0.91)
Time to runoff steady state, Storm #2	Particle size >25mm (0.77), Particle size >16mm (0.89), Particle size >9.5mm (0.82), Particle size >6.3mm (0.74), pH (0.74), germination rate (0.84), Zn (0.70), percent vegetative cover (0.90)
Rain infiltration volume, Storm #2	N (0.74), pH (0.81)
Runoff rate, Storm #2	N (0.86), P (0.81), K (0.76), Mo (0.81), Mg (0.75)

Solids Loss

All treatments proved better than the control at reducing solids loss (Table 2.10). While the differences were not significant, it appeared that the composts provided better erosion control than the industry standards, particularly in the short term, as solids loads were as much as 350% greater from the conventional methods during the first storm event. In addition, compost blankets continued to outperformed the industry standards three months after the initial application, although not statistically significant, solids loads were as much as 36 times greater from the industry standard treatments compared to compost. This study also lends some evidence that compost blankets may provide better protection from soil erosion than these industry standards during storms preceded by drought. After one year, however, the industry standards performed as well as the composts at reducing solids loss. The comeback of the hydroseeded plots, after obvious seed wash during the first storm event, can be partly attributed to the prolific growth characteristic of the vegetation chosen (Bermuda grass) for this study.

While the compost treatments consistently showed a near 100% reduction (no less than 97%) in solids loss compared to the control, the industry standards maintained solids loss reductions no less than 95%. In addition, although differences were not statistically significant, the hydroseed with mulch filter berm consistently yielded less solids loss compared to silt fence throughout the entire study. Finally, it appears that the bulk density and organic matter content of compost is correlated to solids loading (Table 2.11). For erosion control professionals deciding on which measure to use to provide the greatest protection against solids loss, compost generally outperforms hydroseeding and silt fence – particularly in short term applications, and mulch filter berms can provide better solids filtration than silt fence. For more results and discussion see Appendix C.

Table 2.10: Average total solids loads (g/m^2) and total solids loss ratio (treatment to control) by treatment at day one, three months, and twelve months, n=3.

	DAY ONE			THREE MONTHS			TWELVE MONTHS		
Treatment	AVG	SD	RATIO	AVG	SD	RATIO	AVG	SD	RATIO
PLC/Mulch/Gypsum	158.9b	91.3	0.025	14.6b	8.3	0.003	10.8b	4.5	0.010
Biosolids Compost	105.8b	13.0	0.016	18.9b	13.2	0.003	8.8b	6.4	0.008
MSW Compost/Mulch	191.9b	107.8	0.030	6.0b	nd	0.001	17.8b	6.8	0.016
Yardwaste Compost	88.5b	45.3	0.014	13.7b	6.6	0.002	17.1b	6.2	0.015
Hydroseed/Mulch Berm	265.1b	32.3	0.041	78.1b	21.7	0.014	10.9b	6.1	0.010
Hydroseed/Silt Fence	307.9b	127.8	0.048	219.6b	72.0	0.039	14.5b	6.7	0.013
Bare Soil (not seeded)	6428.1a	2182.7		5464.2a	3290.4		1109.7a	987.7	

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 2.11: Results from correlation analysis. This table lists all variables with significant correlation (r>0.70, α = 0.05, n = 21).

Response Variable	**Independent Variable (treatment) with Correlation Coefficient**
Total sediment concentration, Storm #1	Bulk density (0.93)
Total sediment load, Storm #1	Bulk density (0.90), organic matter (0.78)
Total sediment concentration, Storm #2	Bulk density (0.87), organic matter (0.71)
Total sediment load, Storm #2	Bulk density (0.73), organic matter (0.77)
Total sediment concentration, Storm #3	Bulk density (0.76)
Total sediment load, Storm #3	Bulk density (0.75)

Nutrient Loss

Materials high in ammonium N and nitrate N will release greater amounts of each form of nitrogen in storm runoff, in both concentration and load (Table 2.12 and 2.13). These materials showed reduced N loss over time, particularly after the first storm event; however, high N content composts and hydroseeding applications may still have elevated levels of N in the runoff during the next large storm event. Over time, N losses from composts and hydroseed treated soils were negligible. Additionally, composts high in ammonium N may be more susceptible to weed growth. It does not appear that mulch filter berms substantially reduce total N or nitrate N in runoff from hydroseed applications; however, there may be evidence that mulch berms can filter ammonium N from storm water runoff. For professionals utilizing compost blankets it is recommended that composts have a high percentage of organic N content relative to inorganic N.

Soil application of hydroseeding can lead to high P concentrations and loads in storm runoff; however, this may only be a concern for the first storm event after application (Table 2.14 and 2.15). Generally, composts pose a much lower risk than hydroseeding, particularly during a storm that occurs just after application. It appears that composts with high P concentrations can have elevated P losses in runoff, even after the first storm event, but unlikely after a second large storm. Additionally, it appears that blending ground gypsum wallboard (calcium sulfate) may reduce P losses from compost blankets, although more testing is needed to draw conclusions. Composts with low P concentrations are the best insurance for reducing P losses and preventing P from entering surface waters. In addition, composts high in organic matter and C may reduce P loading. It does not appear from this study that mulch filter berms substantially reduce P losses from hydroseed applications. Finally, compost high in ammonium N, nitrate N and/or exhibiting relatively prolific weed growth may indicate that P loading could be an issue, according to correlation analysis. For more results and discussion see Appendix D.

Table 2.12: Average total N concentration (mg L^{-1}) and average total N load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n=3.

	DAY ONE			THREE MONTHS			TWELVE MONTHS		
Treatment	AVG	SD	LOAD	AVG	SD	LOAD	AVG	SD	LOAD
PLC/Mulch/Gypsum	28.64cd	10.36	841.9cde	3.38b	2.95	24.5b	2.15ab	1.16	39.9b
Biosolids Compost	106.63a	6.6	4060.9a	25.79a	6.36	254.3a	1.96ab	0.24	41.8b
MSW Compost/Mulch	88.7b	14.98	2014.1b	4.08b	7.07	22.7b	2.11ab	0.14	46.5b
Yardwaste Compost	14.42de	6.97	450.5de	6.11b	2.60	38.5ab	1.35b	0.09	34.2b
Hydroseed/Mulch Berm	38.49c	10.68	1391.2cb	4.57b	1.75	89.8ab	1.25b	0.07	43.3b
Hydroseed/Silt Fence	38.26c	7.83	1008.3cd	8.13b	2.61	188.2ab	1.45ab	0.12	40.1b
Bare Soil (not seeded)	1.83e	0.57	76.7e	2.06b	0.19	92.0ab	2.44a	0.66	102.9a

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 2.13: Average nitrate N concentration (mg L^{-1}) and average nitrate N load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n=3.

	DAY ONE			THREE MONTHS			TWELVE MONTHS		
Treatment	AVG	SD	LOAD	AVG	SD	LOAD	AVG	SD	LOAD
PLC/Mulch/Gypsum	17.20b	3.57	526.8bc	0.68c	0.98	2.9a	0.32cd	0.09	4.7c
Biosolids Compost	67.37a	2.89	2568.3a	11.82a	5.78	126.1a	0.43abc	0.10	9.7bc
MSW Compost/Mulch	0.10c	0.08	3.4d	1.53c	2.65	8.5a	0.26d	0.09	5.7c
Yardwaste Compost	2.77c	0.93	88.2cd	1.45c	1.46	6.8a	0.34bcd	0.02	8.4bc
Hydroseed/Mulch Berm	21.79b	4.53	796.4b	3.25bc	2.74	64.3a	0.45ab	0.01	15.4ab
Hydroseed/Silt Fence	15.05b	12.22	644.3b	6.96b	1.56	171.6a	0.49a	0.09	13.8abc
Bare Soil (not seeded)	1.28c	0.47	53.4cd	1.42c	0.52	60.1a	0.49a	0.05	20.1a

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 2.14: Average total P concentration (mg L^{-1}) and average DRP load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n=3.

	DAY ONE			THREE MONTHS			TWELVE MONTHS		
Treatment	AVG	SD	LOAD	AVG	SD	LOAD	AVG	SD	LOAD
PLC/Mulch/Gypsum	3.073b	1.403	86.7c	1.582b	1.374	16.2a	1.039b	0.029	16.5ab
Biosolids Compost	4.125b	0.265	156.7bc	6.298a	0.592	53.9a	1.962a	0.498	46.2a
MSW Compost/Mulch	2.192b	0.251	33.2c	0.450b	0.779	7.5a	0.532bc	0.278	11.9b
Yardwaste Compost	2.152b	0.279	70.1c	1.610b	0.567	10.3a	0.479c	0.112	12.5b
Hydroseed/Mulch Berm	25.867a	13.241	924.7a	1.420b	0.309	27.7a	0.485c	0.145	17.5ab
Hydroseed/Silt Fence	22.398a	6.077	483.0b	1.635b	0.563	41.0a	0.704bc	0.364	20.5ab
Bare Soil (not seeded)	0.015b	0.003	0.6c	0.490b	0.046	22.0a	0.642bc	0.257	26.9ab

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 2.15: Average DRP concentration (mg L^{-1}) and average DRP load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n=3.

	DAY ONE			THREE MONTHS			TWELVE MONTHS		
Treatment	AVG	SD	LOAD	AVG	SD	LOAD	AVG	SD	LOAD
PLC/Mulch/Gypsum	2.68b	1.261	75.3c	1.293b	1.121	13.4a	0.863b	0.022	13.7b
Biosolids Compost	3.722b	0.406	141.2bc	5.935a	0.480	51.4a	1.652a	0.348	37.8a
MSW Compost/Mulch	0.204b	0.079	2.7c	0.235bc	0.407	3.9a	0.332c	0.068	7.4b
Yardwaste Compost	1.738b	0.246	56.5c	1.176b	0.355	7.7a	0.366c	0.117	9.7b
Hydroseed/Mulch Berm	24.194a	12.753	865.6a	1.059bc	0.434	20.3a	0.382c	0.140	13.8b
Hydroseed/Silt Fence	19.240a	5.461	412.0b	1.015bc	0.452	26.7a	0.444c	0.162	12.8b
Bare Soil (not seeded)	0.013b	0.001	0.54c	0.009c	0.015	0.33a	0.466c	0.056	19.4ab

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Soil Quality

Compost blankets can increase soil extractable organic carbon (used to estimate soil microbial biomass) compared to hydroseed treated soils, and increase surface soil total C, compared to bare soils, which can be in indication of improved soil quality (Table 2.16 and 2.17). Soils treated with hydroseed may experience elevated levels of soil phosphorus near the surface for a short and prolonged time period. This may be beneficial to plant growth (including weeds) but it may contribute to increased phosphorus in storm runoff and nearby surface waters. It also appears that some composts, and the application of hydroseed can increase soil potassium, calcium and pH near the soil surface which can be beneficial to plant growth; while other composts may increase pH, organic matter, calcium and magnesium at deeper soil horizons, particularly over a longer period of time. For more detailed results and discussion see Appendix E.

Table 2.16: Average soil extractable organic carbon (mg kg^{-1}) from by treatment at six months and eighteen months, n=3.

	SIX MONTHS		EIGHTEEN MONTHS		ONE YR CHANGE
Treatment	AVG	SD	AVG	SD	AVG
PLC/Mulch/Gypsum	19.09a	17.08	57.4b	16.96	38.31bc
Biosolids Compost	18.46a	12.32	58.88b	0.37	40.42ab
MSW Compost/Mulch	32.71a	8.09	93.95a	13.46	61.24a
Yardwaste Compost	27.02a	12.33	41.2b	9.4	14.18d
Hydroseed/Mulch Berm	30.74a	15.99	58.74b	24.63	28.0bcd
Hydroseed/Mulch Berm	30.74a	15.99	58.74b	24.63	28.0bcd
Hydroseed/Silt Fence	28.36a	14.69	48.34b	11.44	19.98bcd
Bare Soil (not seeded)	33.74a	22.38	50.78b	12.8	17.04cd

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 2.17: Selected soil chemical characteristics from 0-5 cm (0-2 in) by treatment at day one, six months and eighteen months, n=3.

	DAY ONE						SIX MONTHS						EIGHTEEN MONTHS						1.5 YR CHANGE
Characteristic	Total C (mg kg^{-1})		Total N (mg kg^{-1})		C:N Ratio		Total C (mg kg^{-1})		Total N (mg kg^{-1})		C:N Ratio		Total C (mg kg^{-1})		Total N (mg kg^{-1})		C:N Ratio		Total C (mg kg^{-1})
Treatment	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg
PLC/Mulch/Gypsum	5833	3900	593	331	9.34	3.16	8250	3748	585	177	13.77ab	2.2	14270	12830	670	680	25.89	10.1	8437a
Biosolids Compost	5543	3711	476	205	10.31	4.37	7667	4219	553	298	13.83ab	0.56	7380	4490	370	180	18.84	3.82	1837ab
MSW Compost/Mulch	7143	2467	627	319	11.99	2.38	9367	1762	583	127	16.1a	0.68	9580	1210	480	130	20.58	2.92	2437ab
Yardwaste Compost	3503	3679	353	181	8.22	4.96	7033	3350	470	286	15.7ab	1.9	7480	2206	290	180	30.58	12.0	3977ab
Hydroseed/Mulch Berm	5023	3705	400	175	11.2	4.87	4800	400	367	116	12.59ab	2.36	8050	2110	310	130	27.44	5.81	3027ab
Hydroseed/Silt Fence	7347	3709	560	275	12.84	0.90	6033	560	490	150	11.79b	3.26	8500	3170	400	220	22.99	4.91	1153ab
Bare Soil (not seeded)	7350	1247	526	101	14.04	0.64	6367	526	393	140	16.2a	2.52	5950	1160	260	28	24.95	0.88	-1400b

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 2.17 (cont.): Selected soil chemical characteristics from 0-5 cm (0-2 in) by treatment at day one, six months and eighteen months, n=3.

	DAY ONE				SIX MONTHS				EIGHTEEN MONTHS				1.5 YR CHANGE	
Characteristic	Total P (mg kg^{-1})		Plant available P (mg kg^{-1})		Total P (mg kg^{-1})		Plant available P (mg kg^{-1})		Total P (mg kg^{-1})		Plant available P (mg kg^{-1})		Total P (mg kg^{-1})	Plant available P (mg kg^{-1})
Treatment	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	Avg
PLC/Mulch/ Gypsum	415.33	69.86	29.67	25.11	463ab	165	44ab	15	479ab	100	12ab	10	63.67b	-17.67
Biosolids Compost	389.67	71.74	32.67	24.83	433ab	34	76ab	35	486ab	84	16ab	12	96.33b	-16.67
MSW Compost/ Mulch	398.33	58.35	29.0	8.89	463ab	120	48ab	24	534ab	222	7ab	3	135.67ab	-22.0
Yardwaste Compost	449.33	83.05	16.67	13.28	475ab	80	41ab	20	501ab	92	4b	2	51.67b	-12.67
Hydroseed/ Mulch Berm	441.67	75.22	20.67	15.31	590a	46	141a	108	728a	141	32ab	28	286.33a	11.33
Hydroseed/ Silt Fence	402.33	33.5	35.67	26.31	568a	121	139a	56	691a	166	47a	47	288.67a	11.33
Bare Soil (not seeded)	347.67	30.09	32.67	8.5	358b	83	25b	17	325b	56	7ab	2	-22.67b	-25.67

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 2.17 (cont.): Selected soil chemical characteristics from 0-5 cm (0-2 in) by treatment at day one, six months and eighteen months, n=3.

	DAY ONE				SIX MONTHS				EIGHTEEN MONTHS			
Characteristic	K (mg kg^{-1})		Ca (mg kg^{-1})		K (mg kg^{-1})		Ca (mg kg^{-1})		K (mg kg^{-1})		Ca (mg kg^{-1})	
Treatment	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
PLC/Mulch/Gypsum	143.33	25.17	210	40	142.0	25.24	211.33	38.5	160ab	86.2	464.3abc	254.3
Biosolids Compost	133.33	25.17	206.67	25.17	132.33	25.77	204.0	25.94	81b	43.3	158bc	62.2
MSW Compost/Mulch	133.33	5.77	213.33	65.06	132.33	4.16	212.0	65.51	135.7ab	50.0	573.3ab	96
Yardwaste Compost	140.0	26.46	190	60.83	137.67	28.54	189.67	60.96	152.7ab	14.0	420.3abc	86.2
Hydroseed/Mulch Berm	156.67	25.17	186.67	20.82	157.67	26.76	186.0	18.68	206ab	99.2	629.7ab	471.3
Hydroseed/Silt Fence	150.0	40.0	216.67	32.15	150.0	44.0	217.67	29.87	235.7a	111.8	868.7a	358.6
Bare Soil (not seeded)	130.0	17.32	173.33	30.55	131.67	15.37	170.33	32.19	90.3b	52.4	64.3c	39.7

	DAY ONE				SIX MONTHS				EIGHTEEN MONTHS			
Characteristic	pH		OM (g kg^{-1})		pH		OM (g kg^{-1})		pH		OM (g kg^{-1})	
Treatment	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
PLC/Mulch/Gypsum	5.58	0.27	4.95	1.05	6.44a	0.3	4.63	2.91	6.4bc	0.16	5.37	0.88
Biosolids Compost	5.54	0.22	4.69	0.44	5.86bc	0.14	4.3	1.83	6.16c	0.23	4.56	0.24
MSW Compost/Mulch	5.67	0.17	4.35	1.09	6.52a	0.33	4.77	2.06	7.03a	0.23	5.69	2.43
Yardwaste Compost	5.54	0.11	4.36	0.36	6.17abc	0.14	5.23	1.43	6.46bc	0.08	4.99	0.57
Hydroseed/Mulch Berm	5.6	0.11	4.67	0.26	6.31ab	0.46	4.4	1.46	6.65ab	0.27	4.28	0.62
Hydroseed/Silt Fence	5.66	0.26	4.59	0.51	6.17abc	0.16	4.03	1.2	6.77ab	0.10	5.03	1.44
Bare Soil (not seeded)	5.6	0.37	3.91	0.76	5.68c	0.16	4.01	1.18	6.42bc	0.39	3.95	1.04

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Results from Infrastructure and Market Survey in Georgia

Currently, five composting operations in Georgia have used their products in erosion and sediment control applications at nearly 15 demonstration sites. Four companies have established themselves as compost applicators for erosion and sediment control. Three county government agencies in Metro Atlanta have requested demonstration sites to be set-up in their county. The Georgia Department of Transportation has approved the use of compost for erosion and sediment control and is currently developing appropriate specifications. The American Association of State Highway Transportation Officials has approved specifications that can be adopted by all fifty state DOTs. The Georgia Soil and Water Conservation Commission is considering including compost in its next edition of *Erosion and Sediment Control in Georgia.*

A market survey of Georgia's 38 composting facilities found 11 could potentially enter the erosion control market. Compost blankets ranged from \$0.69/m^2 to \$3.63/m^2 (\$0.83/yd^2 to \$4.32/yd^2). Filter berms ranged from \$0.23 to \$0.61/linear meter (\$0.74 to \$2.00/linear ft). Hydroseed is the least expensive erosion control method costing \$0.38/m^2 (\$0.45/yd^2) while rip-rap is the most expensive at \$9.61/m^2 (\$31.50/yd^2). The most comparative methods, straw mats and geotextile blankets, cost slightly more than compost blankets. The filter berms were cost competitive with class A silt fences and less expensive than class C silt fences, which are specified more often. In addition, silt fences have an associated maintenance, removal, and disposal cost, creating a life cycle cost that could be *more than double* a compost filter berm. While compost blankets are more expensive than hydroseed, hydroseeding often *requires more than one application* to achieve the minimum 70% cover required by the G DOT. For more information on market infrastructure and educational outreach see Appendix F.

SUMMARY AND CONCLUSIONS

It is inappropriate to conclude which treatment works best because every situation in the field is different, and specific characteristics of a particular compost or an industry standard method may fit with a specific challenge in the field. However, there were evident trends from the results that cannot be ignored. First, stable and mature composts will consistently provide the best results for each of the parameters examined in this study, additionally, it is important to follow approved specifications and in *some cases these specifications may be improved* – although that is not in the scope of this study.

In very broad terms, mature composts that meet specifications provide better vegetative growth, less runoff, less solids loss from erosion, less nutrient loss and increased soil quality. Phosphorus loading from hydroseed should be a major concern to erosion control and water quality specialists, while compost as well as hydroseed with high mineral N should be used with caution and are not recommended for use near surface water. Conversely, compost with low total N and P and/or high organic N and P contents should pose little threat to water quality. Finally, it may be worthwhile to reexamine existing compost specifications based on these results, particularly regarding nutrient content and their potential loss in runoff.

FUTURE RECOMMENDATIONS

Developing an expansive market infrastructure through continual research, demonstration projects, product and application specifications, and supporting product certification are the cornerstones to a successful and sustainable composting industry seeking to recycle ever more organic waste. The following is a list of recommendations for the sustainable development of compost in erosion and sediment control applications and markets:

1. Research. As a relatively new technology there is a tremendous amount of research that can be done in this area. Here are a few ideas: how close to surface water can compost blankets be applied; what is the optimum particle size ratio for filter berms to filter sediment from storm water; is compost effective in areas on concentrated water flow; what is the optimum particle size ratio and lowest possible nutrient content of a compost blanket that can still provide a rapidly established and permanent vegetative cover; how steep of a grade can compost blankets be applied to; and will the addition of a tackifier significantly increase the physical stability of a compost blanket on a steep slope.

2. Demonstration sites. There is no better training and educational tool than to see how it works in the field. Strategically located demonstration sites can expose a large audience and significant stakeholders to this emerging technology.

3. Education. Educational and technical assistance through workshops, trainings, conferences, multi-media and personnel communication to architects, engineers, regulators, inspectors and other related professionals and stakeholders is essential to the widespread adoption of this material.

4. Development and Adoption of Specifications. During the short time period this study was conducted the development and adoption of specifications for this application has grown significantly. The Georgia Department of Transportation has developed and adopted new specifications (with assistance from this project), the Georgia Soil and Water Conservation Commission is considering following suit. The American

Association of State Highway Transportation Officials, supported by the Federal Highway Administration, has adopted specifications (with assistance from this project) that have been sent to the DOTs of the fifty states. The continued adoption of these specifications throughout state and federal agencies that deal with erosion and sediment control is essential.

5. Marketing. Compost operators need to be aggressive in marketing their material to this market. This may include hiring a marketing specialist and/or sales personnel, researching and making bids for erosion control jobs with the DOT, meeting with building architects who specify which erosion control measures will be employed on a particular project, and leading/participating in education and outreach activities.

6. Being Competitive. This application normally requires very large volumes of material per project with compost that can be blended with less expensive mulch or “overs” materials. With this in mind compost operators can charge less for their compost relative to other markets. If composters do not reduce their cost, on a cubic yard or tonnage basis, to a level that is competitive with industry standard measures, it will likely never be adopted on a large scale. If composters can demonstrate that their product is less expensive than standard measures, the financial rewards could be overwhelming. In addition, small operations may enter partnerships to fulfill the quantity demanded for large storm water projects.

7. Quality Products. Providing consistent, high quality compost that meets specification is essential to the growth of this application. One or two bad applications or failures can devastate the adoption of this technology. Most specifications include quality standards as insurance to all parties and the industry a whole.
8. Establishment of Storm Water Utilities. Storm water utilities that charge counties or municipalities based on the quantity of impervious surface under their jurisdiction could lead to a greater awareness and demand for the use of compost in storm water applications.

9. Polluter Pays Program. Erosion Control enforcement agencies could charge violators based on the turbidity unit increase to the ambient upstream flow of a designated surface water. This may help push the adoption of more effective best management practices (BMPs), including compost.

10. Erosion and Sediment Control (E&SC) Plan Fee Waiver. The EPD could offer reduced fees or no fee waivers to contractors or submitters of E&SC and storm water management plans that specify recycled materials in their plans, which helps the state achieve another goal – 25% waste reduction.

11. Evaluation of Current E&SC BMPs. Many industry and field specialists feel that some currently approved BMPs do not perform well in erosion and sedimentation applications. Quantitative research that comparatively evaluates currently approved BMPs may show

the ineffectiveness of many of these measures, particularly once compared to one another.

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CHAPTER 4

SUMMARY AND CONCLUSION

It is inappropriate to conclude which treatment works best because every situation in the field is different, and specific characteristics of a particular compost or an industry standard method may fit with a specific challenge in the field. However, there were evident trends from the results that cannot be ignored. First, stable and mature composts will consistently provide the best results for each of the parameters examined in this study. Additionally, it is important to follow approved specifications and in *some cases these specifications may be improved* – although that is not in the scope of this study.

Composts with high germination rates, total nitrogen, total phosphorus, and potassium concentrations lead to the quickest vegetative cover. However, composts with high ammonium nitrogen, high nitrate nitrogen, and low C:N ratios can create greater weed growth. Further testing would show if this was because these composts were not thoroughly composted or if high nutrient content leads to greater weed growth. Hydroseeding (utilizing Bermuda grass seed) may require additional applications to provide sufficient and permanent vegetative cover to prevent weed proliferation and to sufficiently cover the soil, particularly after rain events that produce runoff.

Compost provides greater infiltration and less runoff than hydroseed treated soils, as hydroseed treated soils performed similarly to bare soil prior to vegetation establishment.

General characteristics of high quality compost that provide good vegetative growth, such as low bulk density, high maturity, near neutral pH, adequate N, P, and K and the particle size distribution of the compost, are important to increasing infiltration and reducing runoff. This provides compelling evidence that compost may be well suited for a variety of storm water management applications, particularly in small to medium storms where it can eliminate runoff, thus preventing most erosion from ever occurring.

Compost provides better protection from solids loss than hydroseed and silt fence; however, the difference is reduced over time, particularly if weeds are left unchecked in hydroseed treated areas. Composts with low bulk density and high organic matter may be better suited to reduce solids loss, although further testing is needed. Mulch filter berms can provide better filtration of solids in storm water compared to silt fence.

Materials high in total N and total P are likely to lose more of each nutrient to storm runoff; however, these nutrient concentrations will diminish over time. Because hydroseed is applied with inorganic N and soluble P it is more likely that these nutrients will be lost to storm runoff and consequently are in more reactive forms that lead to eutrophication. In addition, hydroseed is likely to cause P build up in soil, which can lead to elevated P loss in runoff over a prolonged time period. Composts high in inorganic N are likely to lose higher concentrations of N to runoff, therefore it is recommended that composts have a much higher percentage of organic N of the total N content. Additionally, high concentrations of C, organic matter and Ca (as added gypsum) in compost may reduce P loss in runoff.

Compost blankets can increase soil microbial biomass, total C, potassium, calcium and pH in surface soil; and pH, organic matter, calcium and magnesium at deeper soil horizons.

Hydroseed can increase soil phosphorus, potassium, calcium and pH near the soil surface. The increase in surface soil P may lead to increase P loss in runoff over a prolonged period of time.

In very broad terms, mature composts that meet specifications provide quicker vegetative growth, less runoff, less solids loss from erosion, less nutrient loss and increased soil quality. Manufacturing compost that meets locally prescribed specifications can be a challenge in itself. Finally, it may be worthwhile to reexamine existing specifications based on some of these results, particularly regarding nutrient content and potential losses.

APPENDIX A

MATERIALS AND METHODS

Compost Definition

Composting is the controlled, biological process of decomposition and recycling of organic materials into a humus rich soil amendment (Risse and Faucette, 2001). It includes mixing of organic waste materials with attention to C, N, water, and aeration for optimum microbial aerobic conditions to achieve a desired heat followed by a decline in temperatures until biological stability is reached. Epstein (1997) and Storey et al. (1995) define compost as a relatively stable decomposed organic material resulting from the accelerated biological degradation of organic material under controlled, aerobic conditions. Storey et al. (1995) adds that it is the disinfected and stabilized product of the decomposition process that is used or sold for use as a soil amendment, artificial topsoil, or growing medium amendment.

Treatments

Seven treatments were randomly assigned and applied to 1 m by 4.8 m test plots: a biosolids compost blanket with compost filter berm; a yardwaste compost blanket with compost filter berm; a municipal solid waste compost (MSW) and mulch blanket with mulch filter berm; a poultry litter compost, mulch and gypsum blanket and mulch filter berm; hydroseed and silt fence; hydroseed and mulch filter berm; and a bare soil (control) plot. The compost and mulch blankets were blended on a 3:1(compost:mulch) volumetric basis. The poultry litter compost and mulch blanket included 5% (volumetric) ground gypsum from scrap wallboard. Each treatment was replicated three times, creating a total of 21 test plots. Table 2.1 presents the plot assignment of the treatments. The composts and mulch were chosen because they were readily and commercially available in Georgia. Hydroseeding and silt fence were chosen because they represent industry standard erosion and sediment control measures. All are considered quality products in their respective industries.

Compost blankets were manually applied at 3.75 cm (1.5 inch) depths over the entire area of the plot. Filter berms were 60 cm (2 ft) wide by 30 cm (1 ft) high and situated at the base of the slope across the width of the plot. The silt fence was Georgia Department of Transportation (G DOT) certified, trenched 15 cm (6 in) deep at the base of the slope and across the width of the plot. The hydroseed was a mixture of pelletized lime, 10-4.4-8.3 fertilizer (commercially recognized as 10-10-10), wood fiber, green pigment, water and Common Bermuda (*Cynodon dactylon*) grass seed. A certified professional mechanically applied the hydroseed.

Table 2.1: Test plot layout by treatment.

Test Plot Number	Treatment	Abbreviation
1	Bare soil (control)	BS-1
2	Biosolids compost blanket and filter berm	BC-2
3	Poultry litter compost/mulch/gypsum blanket w/ mulch filter berm	PL-3
4	Yardwaste compost blanket and filter berm	YW-4
5	Hydroseed and silt fence	HS-5
6	Bare soil (control)	BS-6
7	Hydroseed and mulch filter berm	HM-7

8	MSW compost/mulch blanket w/ mulch filter berm	MS-8
9	Poultry litter compost/mulch/gypsum blanket w/ mulch filter berm	PL-9
10	Biosolids compost blanket and filter berm	BC-10
11	Hydroseed and silt fence	HS-11
12	MSW compost/mulch blanket w/ mulch filter berm	MS-12
13	Bare soil (control)	BS-13
14	Hydroseed and mulch filter berm	HM-14
15	MSW compost/mulch blanket w/ mulch filter berm	MS-15
16	Hydroseed and silt fence	HS-16
17	Yardwaste compost blanket and filter berm	YW-17
18	Poultry litter compost/mulch/gypsum blanket w/ mulch filter berm	PL-18
19	Biosolids compost blanket and filter berm	BC-19
20	Hydroseed and mulch filter berm	HM-20
21	Yardwaste compost blanket and filter berm	YW-21

Each treatment, excluding the control plots, was seeded with a grass seed mix specified by the G DOT as an erosion and sediment control vegetative measure for slopes 3:1 or less for the Athens, Georgia region. This included a 1:1 mix of hulled and unhulled Common Bermuda (*Cynodon dactylon*) grass seed applied at 3.7 kg ha^{-1} (20 lbs/acre). Based on the size of the test plots each plot received 9.4 grams of grass seed. Grass seed was applied using a manually operated seed spreader. Each plot was covered with plastic after treatment application until the first rainfall simulation.

Background of Treatments

Each compost treatment was produced at its respective processing yard. No additional composting or curing was conducted after procurement.

The poultry litter compost was a blend of poultry litter, culled vegetables, municipal yard waste, wood fiber, peanut hay, and straw. The composting facility is an outdoor windrow operation that meticulously monitors temperature, moisture, aeration, and carbon dioxide respiration.

The biosolids compost was a blend of municipal biosolids and peanut hulls and was processed in large aerated static piles. The entire operation including curing, screening, and finished piles is under roof. Meticulous attention is paid to temperature levels, moisture, aeration, and screening. This facility adheres to EPA part 503 temperature requirements to kill pathogens and maintains a processing certification by the U.S. Composting Council's (USCC) Seal of Testing Assurance (STA) program.

The municipal solid waste (MSW) compost was a blend of MSW and municipal biosolids and was processed in large Bedminster rotational drums for one week and then processed in large aerated static piles. Next the material was screened to remove inert materials and contaminants. All three processes are managed indoors where temperature, leachate, moisture, and aeration are monitored and EPA part 503 temperature requirements are achieved. The compost is then transported to an outdoor facility where it is cured in windrows for several months prior to sale.

The yard waste compost was a blend of yard waste, animal bedding and paper bags. The materials are processed in outdoor windrows for approximately 6 to 9 months and screened prior to use.

The mulch consisted mostly of ground softwood and hardwood trees from land clearing debris, often referred to as green waste within the industry. It was a 1:1 blend of mulch screened to 0.6 cm (¼ in) minus (particles < screen size) and mulch screened to 5 cm (2 in) minus. This material was stored in large static piles where some heating occurred, but was not monitored.

The gypsum used in the poultry litter compost blanket was ground scrap wallboard from a residential construction site. The gypsum was used as a potential calcium additive to reduce phosphorus loss from the poultry litter compost. Scrap wallboard is a major byproduct of the construction industry in Georgia that is rarely recycled.

Physical, Chemical and Biological Characteristics of Treatments

The compost treatments were characterized after blending and prior to application in the test plots (Table 2.2 & Table 2.3). Bulk density levels ranged between 0.32 to 1.49 g/cm^3 (743 to 2512 lbs/yd^3). All treatments met US Composting Council guidelines for inerts percentage analysis for high quality composts (1997).

Respirometry analysis, used to determine biological stability, found all treatments were biologically stable. Unstable composts typically exhibit a stability index greater than 2.0 **mg O_2/g VM Hr^{-1}** (Epstein, 1997). The percentage of cucumber seeds that germinated was used to determine compost maturity, the point when organic materials have been sufficiently composted and cured, and therefore optimum for plant growth. All treatments exhibited a germination rate that was optimum for seed germination – above 80% (Barberis and Nappi, 1996).

Water contents of the treatments ranged between 31% and 45%, which may have affected the treatments ability to hold moisture and affect the runoff yield from each treatment. pH ranged from 7.0 in the biosolids compost to 8.1 in the MSW compost, which may have had an effect on vegetative growth and nutrient availability. Organic matter ranged from 23.3 g kg^{-1} in the bare soil control to 360 g kg^{-1} in the MSW compost. This may affect soil quality over time. The American Association of State Highway Transportation Officials (AASHTO) specifies that 5 mS/cm or less is acceptable for compost used for erosion control blankets (Alexander, 2003). The poultry litter compost did not meet this requirement. Elevated levels of soluble salts could have an effect on vegetative growth.

A C:N ratio for finished compost of 20:1 or less is recommended to avoid N immobilization by soil microorganisms. The poultry litter compost blend was the only treatment that exceeded this guideline. Total C, total N, ammonium-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N), and total P levels ranged quite a bit between treatments and may effect vegetative growth and water quality of the storm runoff. No treatment had heavy metals levels that would be a concern and all met US EPA part 503 code 40 standards (1993).

Current literature suggests a range of particle sizes is optimum for filtering moving sediments and for holding the soil in place. While a higher ratio of larger particles may work better to filter moving sediments and be more resistant to dislodgment from rainfall impact, they may be less effective for plant establishment and growth. Field demonstration projects indicate that particle size may be the most important factor in compost's ability to keep sediment out of nearby surface waters.

Based on the University of Georgia recommended specifications all compost treatments adhered to the parameters for moisture content, soluble salt, nitrogen content, human made inerts, heavy metals, application rate/size, respirometry, and germination rate. All treatments, with the exception of the mulch filter berms, were below the minimum organic matter recommendation. All treatments, excluding the MSW compost, met the pH recommendation. All treatments had particle size distributions that were too high in small particles, i.e. greater than 3:1 for blankets and 1:1 for filter berms, according to the recommended specifications presented here.

Site Location and Description

Research test plots were at Spring Valley Farm in Athens/Clarke County, Georgia, USA at 33° 57' N latitude and 83° 19' W longitude. The plots are situated towards the west-northwest end of the farm property. Figure 1.1 depicts the location of the research site relative to Georgia. Figure 1.2 represents the location of the site within Clarke County and Figure 1.3 is a more detailed map of where the test plots are in relation to the farm.

Today Spring Valley Farm is a research and education site for Agroecological and Agroforestry production practices. Prior to this the farm was used extensively for pasture and intensive cotton production for over 100 years. These practices have left the research site area devoid of topsoil, and low in soil fertility and overall soil quality. The research site was surrounded by open and unmanaged pasture with scrub vegetation.

The soil was originally classified as an eroded Pacolet Sandy Clay Loam (USDA, 1968) and has a high soil erodibility factor (K value) of approximately 0.36 (Wischmeier and Smith, 1978). Table 2.4 shows the average percent sand, silt and clay and its soil type by treatment prior to treatment application. No significant differences were found. The area receives an average annual rainfall of 1214.7 mm, with January through March as the wettest period. The average annual high temperature for the area is 22° C, the average low is 11°C, with a mean annual temperature of 17°C (Weather Channel, 2004).

Table 2.2: Physical, chemical and biological characterization of treatments.

Treatment	Bulk Density (g/cm^3)	Bulk Density (lbs/yd^3)	% Inerts	Stability - 0_2 uptake (mg O_2/g VM Hr^{-1})	Germination Rate (%)
Biosolids compost	0.51	1292.5	< 1%	0.02	96
Yard waste compost	0.5	1122.9	< 1%	0.09	100
Poultry litter compost w/ mulch & gypsum	0.59	1316.8	< 1%	0.06	100
MSW compost w/ mulch	0.32	743.2	< 1%	0.1	100
Mulch (fines & medium grade)	0.18	670.5	< 1%	0.05	86
Soil	2.23	3758.8	< 1%	nd	nd

Treatment	Water (%)	pH	SS (mS/cm)	OM g kg^{-1} (550 C)	C:N	C	N	NH_4	NO_3	P
Biosolids compost	31.3	7	1.62	202	17	100900	5830	2480	1960	4470
Yard waste compost	40.66	7.8	0.645	193	19	97500	5010	40	70	3240
Poultry litter compost w/ mulch & gypsum	32.2	7.2	5.93	212	22	131500	5980	70	240	4290
MSW compost w/ mulch	45.7	8.1	4.96	360	20	175200	8660	140	180	1910
Mulch (fines & medium grade)	32.4	7.2	0.544	497	101	268900	2670	180	100	960
Soil	nd	4.7	Nd	nd	18	250	14	0.74	0.053	348

Treatment	Al	B	Ca	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	Pb	S	Si	Zn
Biosolids compost	9480	8	3046	12.56	46.7	6780	1794	755.8	108.7	1.74	124.1	6.5	< 2.5	1393	190.8	117.1
Yard waste compost	11600	11.8	8147	11.96	< 0.5	11360	3241	1976	374.8	< 0.5	177.9	7.31	< 2.5	805.8	215.4	65.82
Poultry litter compost w/ mulch & gypsum	9000	19.3	16610	6.76	10.95	5191	4292	1215	88.75	< 0.5	180.8	2.59	< 2.5	9463	132.6	45.59
MSW compost w/ mulch	11690	32.5	1443	22.72	74.89	11260	2465	1332	213.4	1.33	2944	17.64	78.93	2118	170.1	248.3
Mulch (fines & medium grade)	8558	4.14	1713	5.9	< 0.5	5418	963.4	540.7	125.2	< 0.5	137.7	3.18	< 2.5	189	253.1	20.22
Soil	nd	nd	173	nd	Nd	nd	130	23	15	50	nd	nd	nd	nd	nd	0.17

All nutrients and metals expressed in mg kg^{-1}.

Table 2.3: Particle size characterization of treatments.

Sieve Size	**Unit**	**MSWC**	**%**	**PLC**	**%**	**Mulch**	**%**	**YWC**	**%**	**BSC**	**%**
25	**mm**	0	100	4.9	99.5	2.4	99.3	0	100	0	100
16		1.1	99.8	6.2	98.8	17.1	94.6	2.7	99.6	0	100
9.5		38.9	91.6	17	97.0	37.1	84.4	16.1	97.2	14.6	98.1
6.3		34.5	84.4	36.8	93.0	61.6	67.4	41.8	91.0	134.3	80.7
4		35.4	77.0	53.4	87.2	64.1	49.7	65	81.4	166.6	59.1
3.35		19.8	72.9	23.4	84.7	23.8	43.1	27.5	77.3	46.3	53.1
2.36		46.3	63.2	47.2	79.6	35.5	33.3	54.6	69.2	68.9	44.1
2		31.9	56.5	31	76.2	36.1	23.4	34.3	64.1	27.5	40.6
1.4		61.9	43.6	71.9	68.4	18.4	18.3	84.2	51.6	51.1	33.9
1.18		27.6	37.8	35.3	64.6	5.6	16.7	19.5	48.7	24.3	30.8
1		34.5	30.6	41.9	60.1	9.3	14.2	34.6	43.6	28	27.1
850	mm	19.8	26.4	23.5	57.6	1.9	13.6	20	40.6	17.5	24.9
710		32	19.7	50.5	52.1	11.5	10.5	44.7	34.0	37.8	20.0
600		16.1	16.4	46.1	47.1	3.6	9.5	34	29.0	27.4	16.4
500		13.2	13.6	49.1	41.8	4.8	8.1	33.1	24.1	25.6	13.1
250		40.2	5.2	228.3	17.1	19.1	2.9	112.3	7.4	78.5	2.9
125		19.4	1.2	120.2	4.1	8.2	0.6	40.6	1.4	20.9	0.2
Pan		5.5	0	38.1	0	2.2	0	9.3	0	1.5	0
Total (g)		**478.1**		**924.8**		**362.3**		**674.3**		**770.8**	

Figure 1.1: Research site location in Athens, Georgia, USA.

Figure 1.2: Research site location in Clarke County, Georgia.

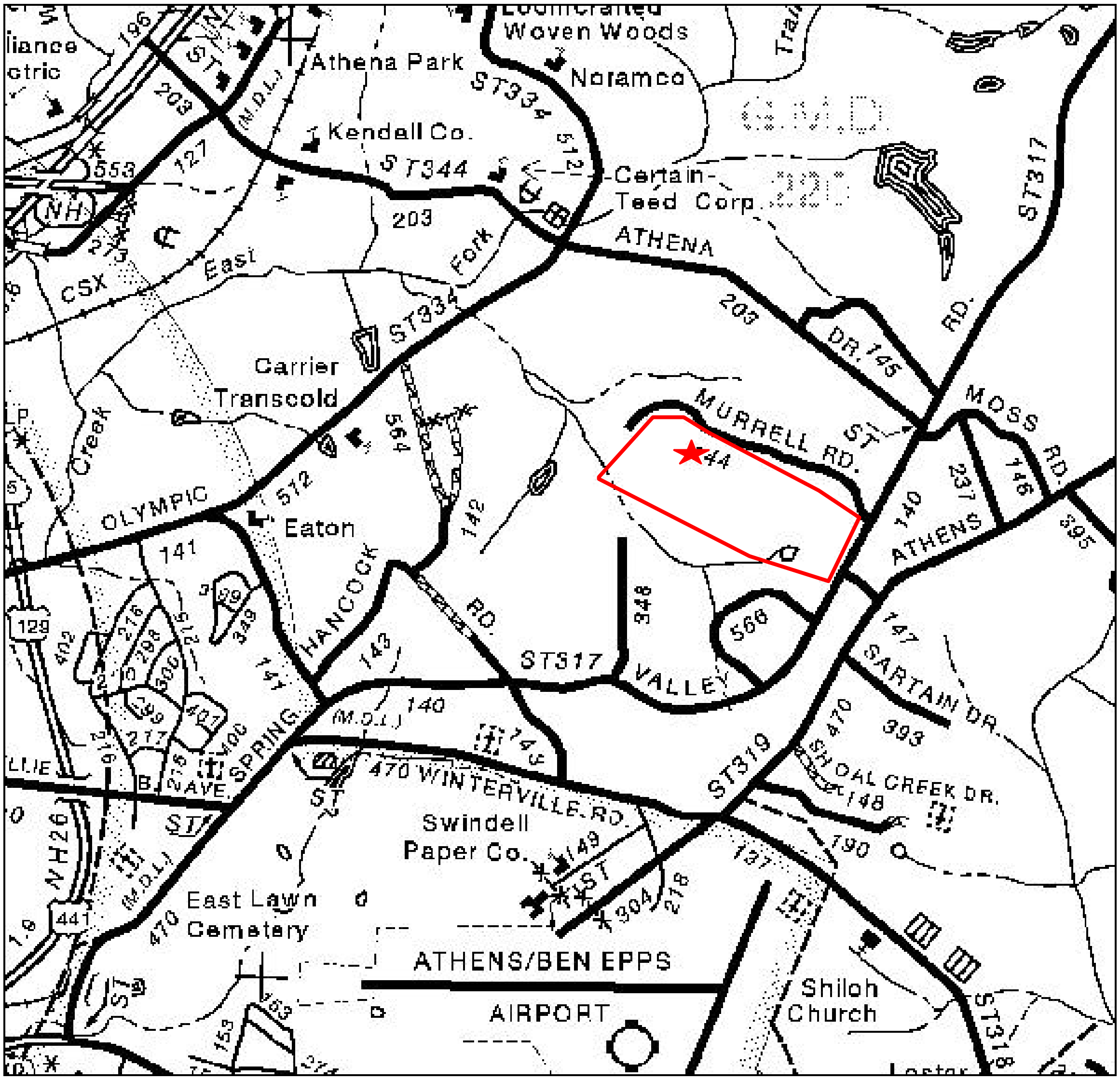

Figure 1.3: Research plots located on Spring Valley Farm.

Table 2.4: Average percent sand, silt, clay and predominant soil type from 0-15 cm by treatment prior to treatment application.

Treatment	Sand	Silt	Clay	Type
PLC/Mulch/Gypsum	60.67	8.67	30.67	Sandy clay loam
Biosolids Compost	61.33	8.67	30.0	Sandy clay loam
MSW Compost/Mulch	62.67	6.67	30.67	Sandy clay loam
Yardwaste Compost	53.33	11.33	35.33	Clay
Hydroseed/Mulch Berm	52.67	10.67	36.67	Sandy clay
Hydroseed/Silt Fence	64.0	8.0	28.0	Sandy clay loam
Bare Soil (not seeded)	66.0	8.67	25.33	Sandy clay loam

Treatments were not significantly different at $\alpha = 0.05$

Experimental Test Plots

The land was cleared of vegetation and topsoil to simulate a construction site soil surface. A 10% grade was applied to the exposed subsoil (Bt horizon). Test plot borders were installed to prevent cross contamination of plots. Fifteen cm (6 in) stainless steel was used to avoid potential metal contamination in the runoff. The borders were trenched 7.5 cm (3 in) into the soil. Seven and a half centimeters of the border extended above ground. The plots were sized to fit the greatest effective rainfall distribution from the rainfall simulator. Preliminary tests showed this to be 1.0 m (3.3 ft) wide by 4.8 m (16 ft) long, for an effective area of 4.8 m^2 (53 ft^2). A removable flume was installed at the base of each plot prior to each simulated rainfall event. Nine rain gauges were installed in each plot to measure rainfall quantity. Three each were placed 1.2 m (4 ft), 2.4 m (8 ft) and 3.6 m (12 ft) from the top of the plot. Gauges were also spaced evenly across the width of the plot. Figure 1.4 depicts the layout of the 21 research plots. Figure 1.5 shows the design of a research plot.

Figure 1.4: Experimental site layout with rainfall simulator.

Figure 1.5: Test plot design.

Rainfall Simulation and Natural Rainfall

The rainfall erosion index (R value), a value used to account for the erosive effects of storms using rainfall intensity and total rainfall data, is relatively high for this region of the United States, between 250 and 300, making it highly susceptible to soil erosion (USDA, 1995). A rainfall simulator was calibrated to produce a 7.75 cm (3.1 in) per hour storm event for one-hour duration. This is equivalent to the one-hour storm event for a 50-year return for the Athens, Georgia region, based on historical rainfall records (US Department of Commerce, 1961). It was our intention to evaluate these treatments under a "worst-case" scenario, because most erosion occurs during these large events. A Norton Rainfall Simulator with 4 variable speed V-jet oscillating nozzles was used to simulate storm events. Water pressure to the nozzles was maintained at 0.42 kg/cm^2 (6 psi) during rain events. A 7569 liter (2000 gal) tanker truck was used to supply and pump water to the rainfall simulator. Municipal tap water was used in the study. The water was monitored and tested for NO_3-N (0.673 mg L^{-1}) and $P0_4$-P (0.093 mg L^{-1}) concentration prior to use in the study.

Three simulated rainstorms were conducted; at the beginning of the experiment, at 3 months and one year. These time intervals were chosen based on the predicted establishment of the vegetation. The first storm event was intended to provide information on the performance of the treatments prior to vegetation establishment. The second storm event was intended to provide information on how the performance of the treatments changed when vegetation was newly established. The final storm event was to provide information on how the treatments reacted once vegetation was fully established. A stainless steel border was inserted at the base of each plot between storm events to maintain the structure and integrity of the plot.

The week prior to the first simulated storm event the research site received no natural rainfall, while 31 mm (1.22 in) of rain fell on the plots during the week of the simulated storm events. During the three months between the second and third storm event the site only received 90.7 mm (3.57 in) of natural rainfall, with only 16.8 mm (0.66 in) falling in the third month. These extremely dry conditions likely affected vegetation growth. The week prior to the second storm the research site received no natural rainfall, while during the weeklong simulated storm trials the site received 6.9 mm (0.27 in) of natural rain. The week before the final storm event the research site received 102.4 mm (4.03 in) of natural rain and 35.8 mm (1.41 in) during the week of storm simulations. This led to saturated field conditions during the final simulated storm event.

Rainfall Average and Distribution

Rainfall averages were calculated by averaging the rainfall depths for the nine rain gages. The rainfall distribution pattern was calculated by averaging the difference from each rain gage from the average rainfall for the entire test plot, for all 21 test plots, and for each storm event.

Soil Moisture

Antecedent soil moisture conditions were measured prior to the first and third rainfall simulation using time domain reflectometry (TDR) with a Tektronix Cable Tester (Ferre and Topp, 2002). Each plot used three TDR probes at intervals of 0.9 m (3 ft). The USDA Agricultural Research Service (1980) TACQ program was used to process and convert wavelengths to moisture content.

Sampling Procedures

Storm water runoff:

Runoff samples were collected from a flume placed at the base of each plot. The first sample was taken once water began to “trickle” from the flume aperture, the point determined to be the beginning of runoff. After the first sample was collected, samples were taken every five min until the 60-min storm was finished.

Runoff samples were analyzed for runoff quantity, runoff rate, total solids, total N, NH_4-N, NO_3-N, total P, and dissolved reactive P (DRP). Runoff quantity and solids samples used one 500 ml Nalgene bottle per time interval sample and were timed until the bottle was full. Nutrient samples used separate 500 ml Nalgene bottles and were filled for five seconds (s) duration. This created a single volume weighted sample for the event. Each five-s nutrient sample, taken every five-min, was placed in a 3.8 liter (1 gal) bottle for easy transportation.

Soil:

Soil samples were taken to evaluate the effects of the treatments on soil quality with special attention given to the Bt horizon (A was removed). Soil samples were taken at the beginning of the study (after clearing and grading but before application of treatments), at 6 months and at 18 months. At the 6 and 18 month sampling periods the compost treatment was removed prior to sampling the soil. Soil core samples were taken at 0-5 cm (0-2 in) and 0-15 cm (0-6 in) depths. Five randomly sampled replicates were taken for composite samples for each depth at each plot. The 0-5 cm (0-2 in) samples were analyzed for total N, total P, plant available P (Mehlich 1), K, Ca, Mg, pH, organic matter, and extractable organic carbon (as an indicator of soil microbial biomass). The 0-15 cm (0-6 in) samples were analyzed for total N, total P, plant available P (Mehlich 1), K, Ca, Mg, pH, and organic matter. Bulk density samples were taken from 0-7.5 cm (0-3 in), and replicated three times per plot. Soil sampling at six months did not include bulk density or the 0-15 cm (0-6 in) core sample analyses. It was assumed that little difference would be noticed from these tests after six months time. Water infiltration rate and extractable organic carbon tests were performed only at the six-mo and eighteen-mo sampling periods.

Vegetative growth and weeds:

Vegetative growth and weed analysis was performed at 3 months and 12 months, coinciding with storm events. Analysis included the percentage of vegetative cover of each plot area, total number of weed plants and species, and biomass of the vegetation. Harvest for biomass analysis was only conducted at the end of the study.

Percent vegetative cover was measured using a one meter (3.3 ft) wide by 4.8 m (16 ft) long grid with string lines set four inches apart on all sides. Vegetation was counted only if it was found directly under each intersect. A total of 480 intersects per plot were used in the calculation to obtain the percent cover.

Weeds (defined as any species other than Bermuda grass) may help control erosion and sediment loss but they are also regarded as a nuisance and undesirable in field applications. The total number of different weed species and the total number of weed plants were counted for each plot at three months and twelve months. Total number of weed species and number of plants were low enough at three months to manually count and identify for the plot as a whole. At twelve months, a grid measuring 9.3 dm^2 (1 ft^2) was randomly placed once in each third of each plot to sub-sample number of weed species, number of weeds and percent cover of weeds (i.e. excluding Bermuda grass). The sub-samples were averaged to obtain a composite for each plot.

Composite samples for biomass analysis were harvested using a 9.3 dm^2 (1 ft^2) sampling area replicated three times, once in each third of each plot. Vegetation was clipped and harvested at the soil surface. Harvested biomass was sorted into weed biomass and Bermuda grass biomass, and then oven dried separately. Biomass was calculated as dry weight divided by the area. The addition of the weed biomass and Bermuda grass biomass were used to calculate the total biomass.

Analytical Methods

Treatment characterization:

Physical and biological analyses of the treatments were performed at the University of Georgia's Bioconversion Research and Education Center laboratory. Water content (method 07.09-A), human made inert analysis (method 07.08), and germination rate (method 09.05-A) of the treatments followed the procedures outlined in the United States Composting Council's Test Methods for the Examination of Composting and Compost (USCC, 1997). Bulk density followed USDA guidelines for soil quality (1998), and biological stability (as oxygen uptake) was determined using methods described by Iannotti et. al (1993). Chemical characterizations were performed at the University of Georgia Agricultural and Soil, Plant and Water Laboratory using EPA or AOAC approved procedures (University of Georgia Soil, Plant and Water Analysis Lab, 2004). Total C and total N were determined by Micro-Dumas combustion, organic matter used the loss on ignition method, pH was from water, nitrate-N and ammonium-N used the colormetric autoanalyzer method, soluble salts were determined by conductivity and the remaining chemical elements were analyzed by ICP method (University of Georgia Soil, Plant and Water Analysis Lab, 2004). Metals were analyzed and all of the treatments were below the pollutant concentration levels as specified in US EPA part 503 Table 4 (USEPA 1993).

Water quality:

For each rainfall run, the total weight of runoff and the time over which it was collected was recorded. Each bottle was oven dried at 105° C until constant weight was achieved to determine the total solids content and total amount of solids lost from the plot. The total solids were measured using methods 2540 B Total Solids Dried at 103-105° C (USEPA, 1983).

Laboratory analysis of the nutrients was conducted at the University of Georgia's Institute of Ecology Analytical Chemistry Laboratory for the first two rainfall events. Nitrate-N and total N were measured using EPA standard method 353.2 (colorimetric, automated, cadmium reduction), ammonia nitrogen using EPA standard method 350.1 (colorimetric, automated phenate), and total P and DRP using EPA standard method 365.1 (colorimetric, automated, ascorbic acid) (USEPA, 1983). A persulfate digest for water (Qualls, 1989) was used as a pretreatment for determination of total N and total P. The University of Georgia's Biological and Agricultural Engineering Water Quality Laboratory analyzed runoff nutrients from the final rainfall event. Standard procedural methods were the same as those followed by the Institute of Ecology except they were processed on a TRAACS automated sampler; DRP (Method No. US-781-86D-multitest MT1), nitrate-N (Method No. US-782-86C- Multitest MT1), and ammonium-N (Method No. US-780-86C-Multitest MT1) (Bran and Luebbe, 1996).

From these data, the steady state runoff rate was calculated by averaging the last three five-minute interval samples during the simulated storm. The time until steady state was achieved was measured once two time adjacent samples were equal in the elapsed time to fill the sample bottle. The total runoff volume was calculated by summing the averages of each two time adjacent samples. Total solid and nutrient loads were calculated by summing the average of each two time adjacent concentration samples multiplied by the average of the same two samples for runoff volume. Infiltration volumes were calculated as total rainfall volume subtracted by total runoff volume, where total rainfall volume was rainfall total multiplied by the total area of the plot. Total solid load ratios were calculated by dividing the treatment average by the control average. Results less than one show a benefit to erosion control by the treatment.

Soil quality:

Soil chemical characterizations for the 0-5 cm (0-2 in) core samples and were performed at the University of Georgia's Institute of Ecology Analytical Chemistry Lab. Total C and total N were determined by Micro-Dumas combustion (University of Georgia Institute of Ecology, 2004). Total P used an acid-persulfate digest (Nelson, 1987) and was determined using EPA standard method 365.1 (colorimetric, automated, ascorbic acid) (USEPA, 1983). Plant available P used EPA standard method 365.1 (colorimetric, automated, ascorbic acid), K used EPA standard method 258.1 (atomic absorption, direct aspiration), Ca used EPA standard method 215.1 (atomic absorption, direct aspiration) (USEPA, 1983); and all followed Mehlich I extraction methods (Mehlich, 1953). Organic matter was determined by ash free dry weight analysis (Jackson, 1958), and pH was from water (Peech, 1965). Full analytical methods and references can be found on their website (University of Georgia Institute of Ecology, 2004).

Soil texture and chemical analysis for the 0-15 cm (0-6 in) soil core samples were performed at the University of Georgia Soil, Plant and Water Analysis Lab. Total P, K, Ca, Mg, and Zn were extracted by Mehlich 1 extraction methods (Mehlich, 1953) and analyzed by ICP (Munter and Grande, 1981). Organic matter used the same method as the 0-5 cm samples (Jackson, 1958), pH was also from water (Peech, 1965) and soil texture used the Bouyoucos method (Bouyoucos, 1936). Full analytical methods and references can be found on their website (University of Georgia Soil, Plant and Water Analysis Lab, 2004).

Bulk density and water infiltration rate analysis followed test methods in the USDA Soil Quality Test Guide (1998). Extractable organic C extractions were performed by using 0.5ml K_2SO_4 on a 1:4 basis (soil:extractant), agitated for one hour, centrifuged, and the resulting supernatant was analyzed for extractable organic C (Ross, 1992; Christensen and Christensen, 1991). Extractable organic C analysis was performed with an ASI 5000A auto sampler according to EPA standard method 5310B (combustion-infared)(USEPA, 1983).

Statistical Analysis

SAS version 8.2 (SAS, 2001) was used for statistical analysis. Analysis of variance (PROC ANOVA) used Duncan's Multiple Range test for significant differences between cells was used to determine any significant differences between treatments ($p \leq 0.05$). Correlation analysis (PROC CORR) was used to determine which of the independent variables, including: physical, chemical, and biological treatment parameters (as expressed in tables 2.2, 2.3, and 2.4), and all reported vegetation and rainfall characteristics were correlated to the response variables, including: all results from vegetation, runoff, solids loss, nutrient loss, and soil quality parameters.

Compost Market Survey

A survey was conducted in Georgia in 2001 to determine which compost operations could potentially enter the erosion and sediment control market and what they would charge for installation of compost blankets (per yd^2) and filter berms (per linear ft). Price was based on a 3.75 cm (1.5 in) deep compost blanket and 0.3 m high by 0.6 m wide (1 ft by 2 ft) compost filter berm. Prices are compared to industry standard measures and are presented as the total installed price (material cost + installation cost). All information was collected by telephone survey and/or site visits.

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APPENDIX B

RESULTS AND DISCUSSION: VEGETATIVE GROWTH

Rapid vegetative establishment and permanent vegetative cover are perhaps the two most important factors in controlling erosion and sedimentation. Each test plot was evaluated for vegetative growth characteristics at the time of each simulated rainfall. Due to site construction, there was no vegetation at the time of the first simulated rain event but there was significant growth by the second and third rain events, at three months and one year after the start of the experiment, respectively.

Each treatment, except the control, was seeded with Common Bermuda Grass *(Cynodon dactylon)* at 3.7 kg/ha (20 lbs/acre) equivalent (specified by the GA Department of Transportation) and was evaluated for: percent cover at three months and twelve months; number of weed species and weed plants at three months and number of weed species and percent cover of weeds at twelve months; and Bermuda grass, weed and total biomass at twelve months. It was hypothesized that those treatments that established vegetation the quickest and fullest would be more effective at controlling soil erosion as well as reducing potential nutrient loss in storm runoff over time.

Percent Cover

Percent cover results for all treatments at three months were lower than expected due to extreme drought conditions over the 3-mo time period (90.7 mm of rain). No supplemental irrigation was used. After three months the poultry litter compost treatment had the highest percent cover of vegetation followed closely by the yard waste compost (Table 3.1). There were no significant differences in cover between the compost treatments. The bare soil control had the lowest cover, as it was the only treatment that was not seeded, followed closely by the hydroseeded treatments, as much of the seed washed of the plot during the first storm event. There was no significant difference between the control and the hydroseeded treatments, however the difference between these treatments and the compost treatments was statistically significant. Any vegetative cover found in the control plots was presumed to be from weed seeds blown-in from adjacent fields. Increased percent cover results from the compost treatments may be due to their ability to hold moisture better than the hydroseeded or bare soil treatments. This can be critical to plant growth during periods of drought as experienced during the first three months of this study. Additionally, recent evidence indicates that plants grown in highly weathered soils may rely more on easily soluble organic phosphorus (like that in compost) rather than inorganic phosphorus (like that in the hydroseed), since soluble inorganic P can react quickly with Fe and Al thus becoming insoluble and unavailable to plants.

After twelve months the biosolids compost had the highest percent cover, although it had the lowest percent cover of the compost treatments at three months. Interestingly, while the yard waste compost had nearly the highest percent cover at the three months it had the lowest after twelve months, excluding the control. This may be due to the low nutrient content of the yard waste compost. Both hydroseeded treatments improved remarkably from the three-month to the twelve-month sampling period. This may be due to the ability of Bermuda grass to spread rapidly over the soil surface, as it appeared that much of the hydroseed had washed down slope after the first rain event. The bare soil control remained the treatment with the lowest percent cover, although it did increase between the sampling periods. This was likely due to weed seeds blowing into the test plots between sampling periods. After twelve months only the control was significantly different from the remaining experimental treatments. There were no significant differences among the rest of the treatments at this time period. Figure 2.1 compares the percent cover of each treatment between the three-month and twelve-month sampling periods.

Table 3.1: Average percent cover by treatment at three months and twelve months, n=3.

Treatment	3 months	SD	12 months	SD
PLC/Mulch/Gypsum	64a	28	73a	22
Biosolids Compost	57a	6	86a	15
MSW Compost/Mulch	59a	20	72a	16
Yardwaste Compost	62a	19	68a	17
Hydroseed/Mulch Berm	22b	7	86a	2
Hydroseed/Silt Fence	22b	16	81a	20
Bare Soil (not seeded)	17b	14	24b	15

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

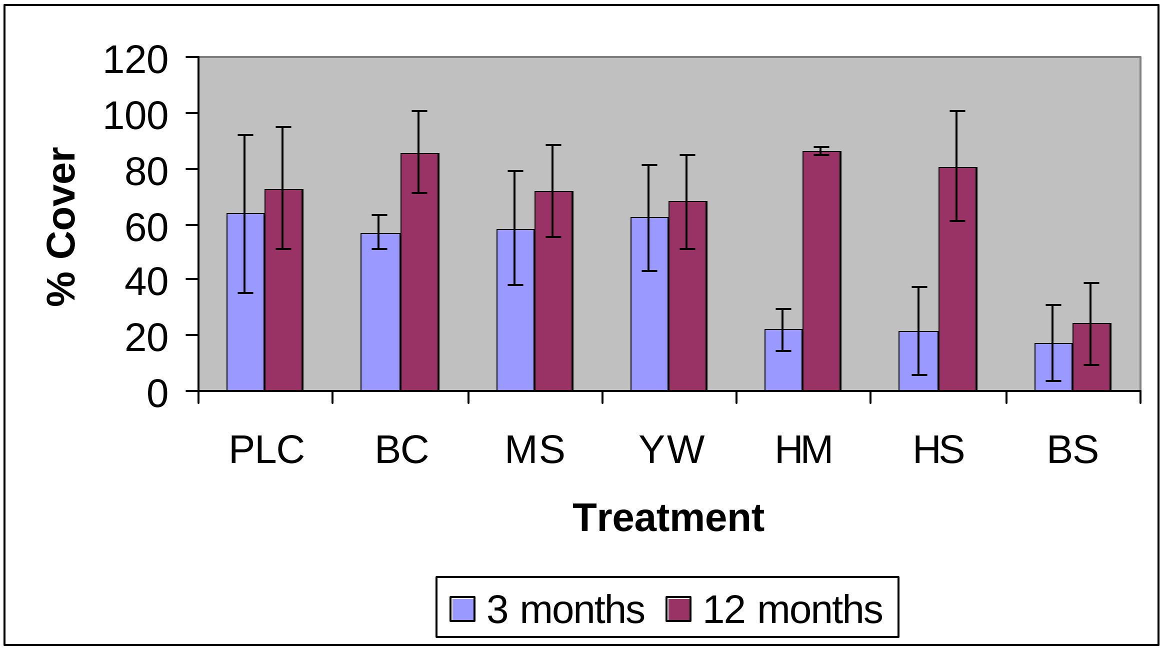


Figure 2.1: Comparison of average percent cover at three and twelve months by treatment, n = 3.

Number of Weed Species and Weed Plants

Weeds in compost blankets may aid in the control of erosion and sedimentation, however from a product and marketing standpoint it can significantly devalue the compost product. It was not determined whether the weeds that appeared in the composted treatments came from the compost or were from seeds that blew in from the surrounding field. Some of the weeds from these treatments were not identified in the surrounding field during the study period. The hydroseeded treatments and MSW compost treatments had the least number of weed species, while the yardwaste compost and control had the same number of weed species after three months (Table 3.2). The biosolids compost had the highest level of weed species followed by the poultry litter compost treatments. The increased levels of weed species in the biosolids and poultry litter compost treatments could have been a function of the compost processing or heightened nutrient levels in these composts that aided in weed species proliferation. The biosolids compost was the only treatment that was statistically significant in the number of weed species at three months.

Table 3.2: Average number of weed species per 0.093 m^2 (1 ft^2) by treatment at three months and twelve months and average number of weed plants by treatment at three months (total plot) and percent cover of weed plants by treatment at twelve months, n=3.

Treatment	**Weed species, 3 mo**	**SD**	**Weed species, 12 mo**	**SD**	**Weed plants (total #), 3 mo**	**SD**	**Weed plants (%), 12 mo**	**SD**
PLC/Mulch/Gypsum	< 1b	0	10ab	6	4bc	1	19b	10
Biosolids Compost	< 1a	0	8ab	4	15a	4	43ab	6
MSW Compost/Mulch	< 1b	0	12a	3	1c	1	28b	8
Yardwaste Compost	< 1b	0	11a	5	4bc	2	21b	9
Hydroseed/Mulch Berm	< 1b	0	10ab	2	0c	1	61a	27
Hydroseed/Silt Fence	< 1b	0	8ab	3	0c	1	69a	24
Bare Soil (not seeded)	< 1b	0	3b	4	6b	3	15b	13

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

After twelve months the control had the least number of weed species followed by the hydroseeded treatments. The MSW compost had the highest level of weed species and the biosolids compost had the lowest of the compost treatments followed by the poultry litter compost. The number of weed species was significantly higher among the MSW compost and yard waste compost compared to the control. This may provide evidence that the increased quantities of weed species at three months in the biosolids and poultry litter composts were originally from these treatments and did not blow in from the surrounding field. Figure 2.2 compares the number of weed species between treatments at twelve months.

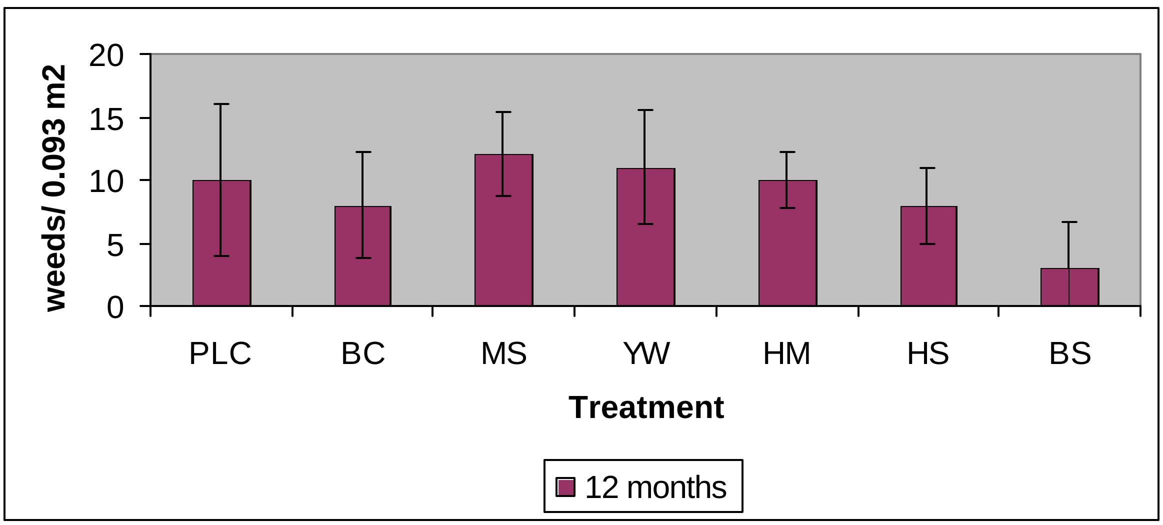


Figure 2.2: Average number of weed species per 0.093 m^2 (1 ft^2) by treatment at twelve months, n = 3.

The total number of weed plants was also counted in each plot at three months (Table 3.2). The results were similar to the number of weed species per treatment. The hydroseeded and MSW compost treatments had almost no weeds, while the biosolids compost had a comparatively large number of weed plants. Interestingly, the control plot had the second highest number of weeds per plot indicating that much of the weed growth was probably due to blown-in weed seeds from the surrounding field. Statistically, the biosolids compost had the greatest number of weeds per plot, followed by the control. While there were significant differences between the biosolids compost, the control, and the remaining five treatments, there was no significant difference among these remaining five treatments.

After twelve months, weeds had increased in number so high that determining the percent cover of weeds was more feasible (Table 3.2). At this sampling period the hydroseeded treatments had the greatest percent cover of weeds followed by the biosolids compost treatments. Both hydroseeded treatments were significantly greater than the control and most of the compost treatments. The poultry litter compost and yard waste compost had the lowest percent cover of weeds among the compost treatments, however the control had the lowest of any treatment. The results show that the majority of weed growth was probably due to blown-in weed seeds from the adjacent fields, particularly because of the increase in weeds from the three to twelve month sampling periods in the hydroseeded and the control treatments; however, the consistently high results reported from the biosolids compost treatment probably signify that some weed seeds were brought in with the compost. Figure 2.3 compares the number of weed plants at three months and the percent cover of weed plants at twelve months between treatments.

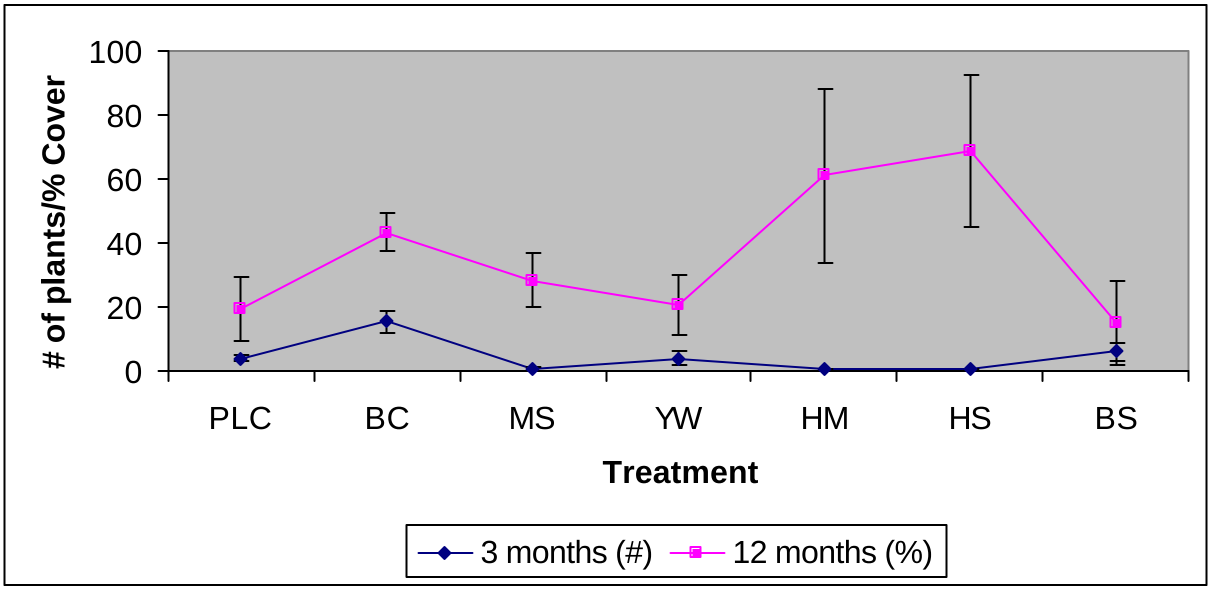


Figure 2.3: Average number of weed plants (total plot) at three months and percent cover of weed plants at twelve months by treatment, n = 3.

Biomass of Vegetative Cover

Above ground biomass samples were harvested in May of 2003, twelve months after the test plots were seeded with Bermuda grass. Biomass samples were divided into Bermuda grass and weed (defined as everything but Bermuda grass) samples before being analyzed. Total vegetative biomass was calculated as the addition of the two (Table 3.3).

The poultry litter compost treatment had the highest biomass of Bermuda grass, followed by the hydroseed with mulch berm and MSW compost treatments, respectively. The control was not seeded so it resulted in zero Bermuda grass biomass, followed by the biosolids compost and yard waste compost treatments, respectively. The poultry litter compost produced almost twice as much grass biomass as the biosolids compost; however, there were no significant differences between treatments. The high soluble salt content of the poultry litter compost did not appear to negatively affect the Bermuda grass relative to the other compost treatments.

Weed biomass was significantly higher in the hydroseeded treatments compared to the control and compost treatments. Among the compost treatments, the biosolids compost and poultry litter compost treatments had the highest weed biomass, although not statistically significant. Weed biomass was lowest in the yard waste compost and MSW compost followed by the control. There was a statistically significant difference between the biosolids compost and the yard waste compost treatments. It is interesting to note that the yard waste and MSW composts had a lower weed biomass than the bare soil, and the poultry litter compost treatment was nearly the same as the bare soil. This could be either that these composts have the ability to suppress weed growth or it could be the result of chance that either fewer weed seeds entered these plots from the surrounding fields, or that the weed seeds that did enter these plots were more representative of weeds with lower biomass characteristics.

While it is more desirable to have a high biomass from the intended erosion control grass that is seeded, a high biomass of weeds can serve to reduce erosion and sedimentation as well. Unfortunately, weeds are often undesirable either because of aesthetic reasons or because of their invasive potential. Weed proliferation can also be a signal that a compost has not been thoroughly composted. Both of the hydroseeded treatments had the highest standing vegetative biomass, followed by the poultry litter and biosolids compost treatments, respectively. Of course the bare soil had the lowest total biomass, followed by the yard waste and MSW composts, respectively. Low vegetative biomass can also indicate that the compost was not thoroughly composted or that it has a very low nutrient content. Either way the yard waste compost did the poorest job in supporting plant growth of any kind, according to these results. However, the only statistically significant difference was found between the hydroseeded treatments and the control. Table 3.3 also provides the ratio of Bermuda grass biomass to weed biomass for all treatments.

The yard waste compost and poultry litter compost have the highest ratios, respectively. The hydroseeded treatments had the lowest ratios, followed by the biosolids compost, all three had ratios below one.

Table 3.3: Average biomass of Bermuda grass, weed, and total vegetation in g/m^2 (10.8 ft^2) and ratio of average Bermuda grass biomass to average weed biomass by treatment at 12 months, n=3.

Treatment	**Bermuda**	**SD**	**Weed**	**SD**	**Total**	**SD**	**Bermuda:weed**
PLC/Mulch/Gypsum	244a	230.2	80.6bc	25.0	324.6ab	206.3	3.03:1
Biosolids Compost	128.5a	111.4	168.9b	74	297.4ab	173.1	0.76:1
MSW Compost/Mulch	191.5a	256.9	65.1bc	10.7	256.6ab	247.1	2.94:1
Yardwaste Compost	148a	139.0	43.2c	13.1	191.2ab	149.5	3.43:1
Hydroseed/Mulch Berm	199.5a	69.8	286a	71.4	485.5a	32.2	0.70:1
Hydroseed/Silt Fence	158.8a	105.7	287a	78.7	445.7a	27.4	0.55:1
Bare Soil (not seeded)	0a	0	76.7bc	63	76.7b	63	0

Treatments with same letter are not significantly different at α = 0.05 using Duncan's Multiple Range test.

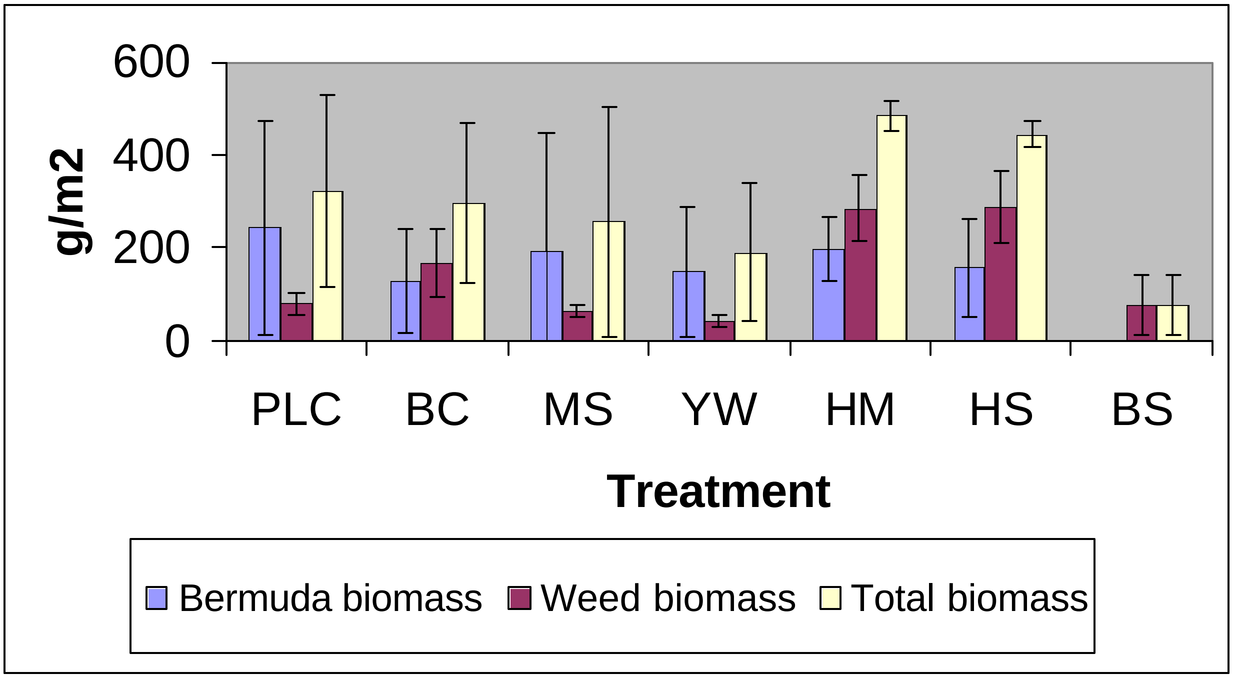


Figure 2.4: Comparison of average weed biomass, average Bermuda grass biomass, and average total biomass (g/m^2) between treatments at twelve months, n = 3.

Correlation Analysis

Results from correlation analysis (Table 3.4) were used to evaluate which of the treatment physical, chemical and biological characteristics, and rainfall and vegetation growth results were correlated with the parameters from vegetative growth and weed analysis. Only those that were highly correlated (r>0.70) are reported. Percent vegetative cover at three months was correlated to germination rate, total rainfall from the first storm event, and the initial N, P and K content of the treatments. Both the number of weed species and number of weed plants for each treatment at three months were correlated to ammonium nitrogen and nitrate nitrogen. The biosolids compost had the highest ammonium and nitrate nitrogen concentrations at the time of sampling and subsequently had the most number of weeds and weed species. In addition, treatment C:N ratio was a good indicator of weed biomass, as the biosolids compost had the lowest (narrowest) C:N ratio and the highest weed biomass of the compost treatments. Weed biomass and total biomass at twelve months were good indicators of weed cover at twelve months, as the hydroseeded treatments led in all three categories. Consequently, weed cover and total biomass at twelve months were good indicators of weed biomass.

Table 3.4: Results from correlation analysis. This table lists all variables with significant correlation ($r>0.70$, $\alpha = 0.05$, $n = 21$).

Response Variable	**Independent Variable (treatment) with Correlation Coefficient**
Vegetative cover at 3 months	Germination rate (0.71), K (0.71), rainfall amount from 1st storm (0.70), N (0.69), compost - P (0.68)
# of weed species at 3 months	NH_4 (0.81), NO_3 (0.82), # of weed plants (0.92)
# of weed plants at 3 months	NH_4 (0.84), NO_3 (0.85), # of weed species (0.94)
Weed cover at 12 months	Weed biomass at 12 months (0.81), total biomass at 12 months (0.72)
Weed biomass at 12 months	C:N ratio (0.78), weed cover at 12 months (0.87), total biomass at 12 months (0.76)

Summary and Conclusion

Based on this study and under these environmental conditions, compost did better than hydroseeding and bare soil at providing a quick vegetative cover. However, in the long term hydroseeding may be a better option. The caveat was that the better long term performance of the hydroseeding was due to the invasion of weeds, not the intended vegetation. From a practical standpoint, to control erosion this is a good result, but from an industry or commercial standpoint this may be undesirable. Additionally, this may provide evidence that some composts can suppress the growth of weeds when compared to hydroseeding. It should also be noted that wherever vegetation has not been established by hydroseeding, soil erosion will continue to occur and potentially get worse over time; unlike compost which still covers the soil surface in areas where vegetation may not have established. For erosion control professionals deciding on which measure to use for vegetation establishment, compost provides a quicker vegetative cover with less weed growth – particularly under conditions of heavy rainfall followed by drought (as experienced in this study), while hydroseeding (utilizing Bermuda grass seed) may require additional applications to provide sufficient and permanent vegetative cover without weed proliferation.

Composts with high germination rates, total nitrogen, total phosphorus, and potassium concentrations lead to a quicker vegetative cover. Additionally, plenty of rainfall or moisture is required. Thus, high nutrient, stable, and mature composts that get plenty of rainfall will provide the best and quickest cover. However, composts with high ammonium nitrogen, high nitrate nitrogen, and low C:N ratios appear to create greater weed growth, in number of species, number of plants, and biomass.

Photo Assay

Digital photos were taken of each test plot at three months (a) and twelve months (b).

1a.

1b.

2a.

2b.


3a.

3b.

4a.

4b.

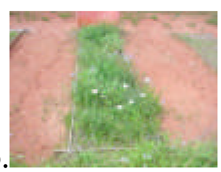

5a.  5b.  6a.  6b. 

7a.  7b.  8a.  8b. 

9a.  9b.  10a.  10b. 

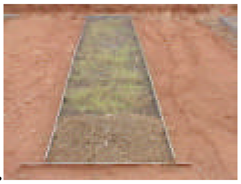
11a.  11b.  12a.  12b. 

13a.  13b.  14a.  14b. 

15a.  15b.  16a.  16b. 

17a.  17b.  18a.  18b. 

19a.  19b.  20a.  20b. 

21a.  21b. 

Test Plot Number	Treatment
1	Bare soil (control)
2	Biosolids compost blanket and filter berm
3	Poultry litter compost/mulch/gypsum blanket w/ mulch filter berm
4	Yardwaste compost blanket and filter berm
5	Hydroseed and silt fence
6	Bare soil (control)
7	Hydroseed and mulch filter berm
8	MSW compost/mulch blanket w/ mulch filter berm
9	Poultry litter compost/mulch/gypsum blanket w/ mulch filter berm
10	Biosolids compost blanket and filter berm
11	Hydroseed and silt fence
12	MSW compost/mulch blanket w/ mulch filter berm
13	Bare soil (control)
14	Hydroseed and mulch filter berm
15	MSW compost/mulch blanket w/ mulch filter berm

16	Hydroseed and silt fence
17	Yardwaste compost blanket and filter berm
18	Poultry litter compost/mulch/gypsum blanket w/ mulch filter berm
19	Biosolids compost blanket and filter berm
20	Hydroseed and mulch filter berm
21	Yardwaste compost blanket and filter berm

APPENDIX C

RESULTS AND DISCUSSION: STORM WATER RUNOFF AND SOLIDS LOSS

Storm Water Runoff

Few erosion and sediment control measures employed by the industry today work to decrease storm water runoff. If storm water runoff can be reduced or even eliminated through infiltration and/or increased water holding capacity of soils or soil covers, then erosion and sedimentation may be reduced and/or eliminated.

Three simulated storm events were conducted for each plot; at the time materials were applied (no vegetation), three months (vegetation established), and twelve months (vegetation matured). Each test plot was exposed to a simulated storm event, for one-hour duration, at a rate approximate to the 50-year/1 hour storm event for Athens, Georgia. Municipal tap water was used in the study. The water was monitored and tested for NO_3-N (0.673 mg L^{-1}) and $P0_4$-P (0.093 mg L^{-1}) contents prior to use in the study. Runoff was collected at the base of each plot as soon as runoff began to trickle from the installed flume. Parameters measured included: rainfall amount, antecedent soil water, time until start of runoff, time until steady state of runoff, runoff volume, and runoff rate. Rainfall infiltration and rainfall infiltration to runoff ratio were calculated from the results. See Materials and Methods for more information.

Average Rainfall and Soil Water

Actual rainfall amounts for each simulated storm event and the antecedent water content of the soil (Table 4.1) can have a profound effect on storm water runoff and varied considerably in this study. These differences can have significant effects on total runoff, runoff rate, time until start and steady state of runoff, infiltration rate, and sediment and nutrient concentrations and loads in the runoff.

Due to variability from the rainfall simulator, average rainfall totals from the first storm event ranged from a high of 97 mm (3.87 in) applied to the yardwaste compost treatments to a low of 73 mm (2.93 in) applied to the control (bare soil). The second storm event had an average total rainfall high of 89 mm (3.57 in) applied to the hydroseed with mulch berm treatment and a low of 77 mm (3.09 in) applied to the yard waste compost treatment. The final storm event had the lowest overall average totals for the three storm events. The yardwaste compost had the highest average total of 76 mm (3.03 in) and the control had the lowest at 58 mm (2.32 in). The yard waste compost did receive significantly greater rainfall than the control, poultry litter compost and hydroseed with silt fence treatments. There was an overall 39 mm (1.55 in) difference between the lowest and the highest average total rainfall amounts among treatments and between storm events. Variability from the rainfall simulator was caused by minor pump (from the tanker truck) and control box wiring malfunctions. No attempt was made to correct for differences in rainfall.

Average antecedent soil water content during the first storm event ranged from a high of 0.148 g g^{-1} underneath the yardwaste compost to a low of 0.109 g g^{-1} under the biosolids compost treatment. No data were collected on soil water for the hydroseeded treatments. No antecedent soil water contents were analyzed during the second storm event. Nearly all experimental plots were at saturated conditions during the final storm event due to natural rain events (102.4 mm one week prior to rain simulations, and 35.8 mm during the week of rain simulations). Variation during the final storm event ranged from a high of 0.411 g g^{-1} under the yardwaste compost treatment to a low of 0.296 g g^{-1} under the hydroseed with silt fence treatment. This may indicate that composts have a greater ability to hold water than hydroseed, even after one year. The poultry litter compost, biosolids compost and MSW compost had significantly greater antecedent soil water content than that of the control. There was a 0.302 g g^{-1} difference in antecedent water content between the lowest and the highest treatments between the first and final storm event. Figure 3.1 compares rainfall totals and antecedent soil water for each treatment and storm event.

Table 4.1: Total rainfall amount (mm) and antecedent soil water content (g g^{-1}) measured by treatment at day one, three months and twelve months, n=3.

	DAY ONE			THREE MONTHS		TWELVE MONTHS		
Treatment	AVG rainfall	SD	AVG soil water content	AVG rainfall	SD	AVG rainfall	SD	AVG soil water content
PLC/Mulch/Gypsum	87a	16.1	0.123a	79a	4.6	64b	4.9	.367a
Biosolids Compost	83a	17.0	0.109a	78a	3.8	66ab	4.3	.354a
MSW Compost/Mulch	83a	17.3	0.132a	81a	2.1	67ab	2.0	.346a
Yardwaste Compost	97a	12.8	0.148a	77a	3.1	76a	10.6	.411ab

Hydroseed/Mulch Berm	76a	3.8	Nd	89a	9.7	65ab	5.4	.376ab
Hydroseed/Silt Fence	74a	5.2	Nd	84a	6.1	61b	5.7	.296ab
Bare Soil (not seeded)	73a	5.2	0.122a	84a	9.7	58b	7.7	.328b

Treatments with same letter are not significantly different at α = 0.05 using Duncan's Multiple Range test.

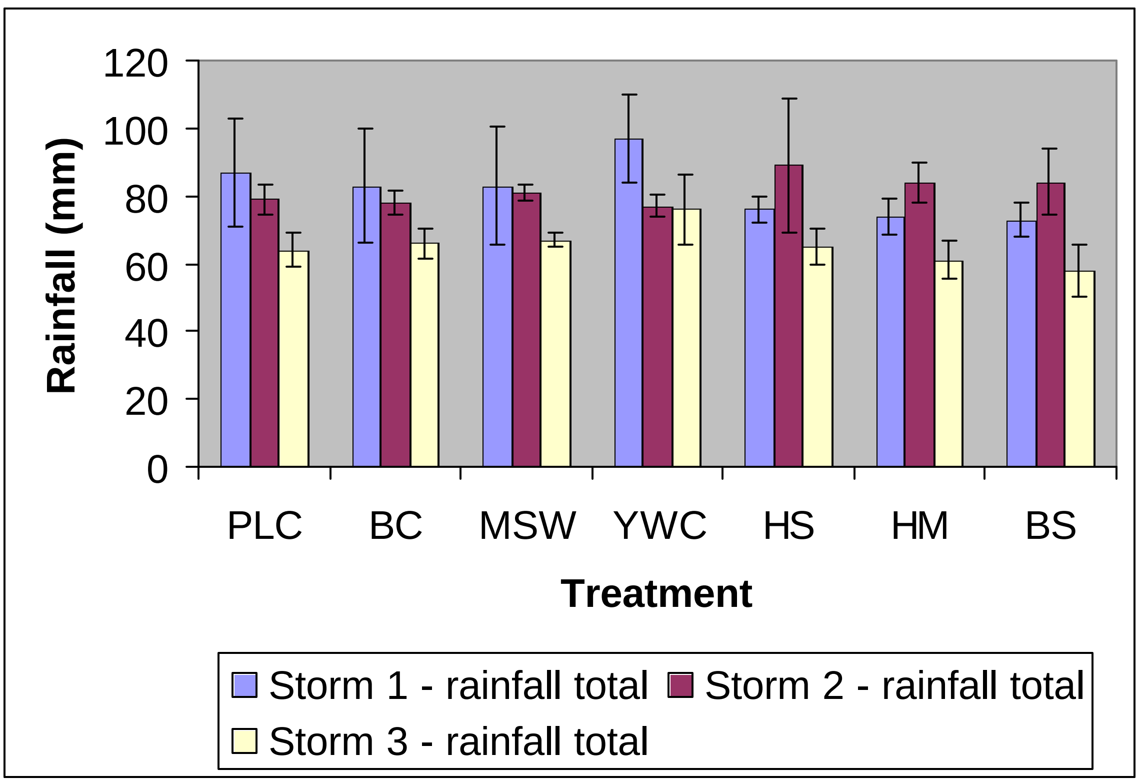


Figure 3.1: Average total rainfall (mm) for all storm events by treatment, n = 3.

Rainfall Distribution Pattern

Rainfall distribution can have an effect on runoff patterns and erosion potential. The rainfall distribution produced by the rainfall simulator was extremely variable. Results from distribution pattern analysis show that much of the rainfall was concentrated in the middle column of the test plots, while the left side of the plots received slightly more than the right side (Figure 3.2, 3.3, 3.4). This may have created a concentrated flow in the middle column of the plot, creating a greater likelihood for erosion in this area. The rainfall distribution pattern was calculated by averaging the difference from each rain gage from the average rainfall for the entire test plot, for all 21 test plots for each storm event.

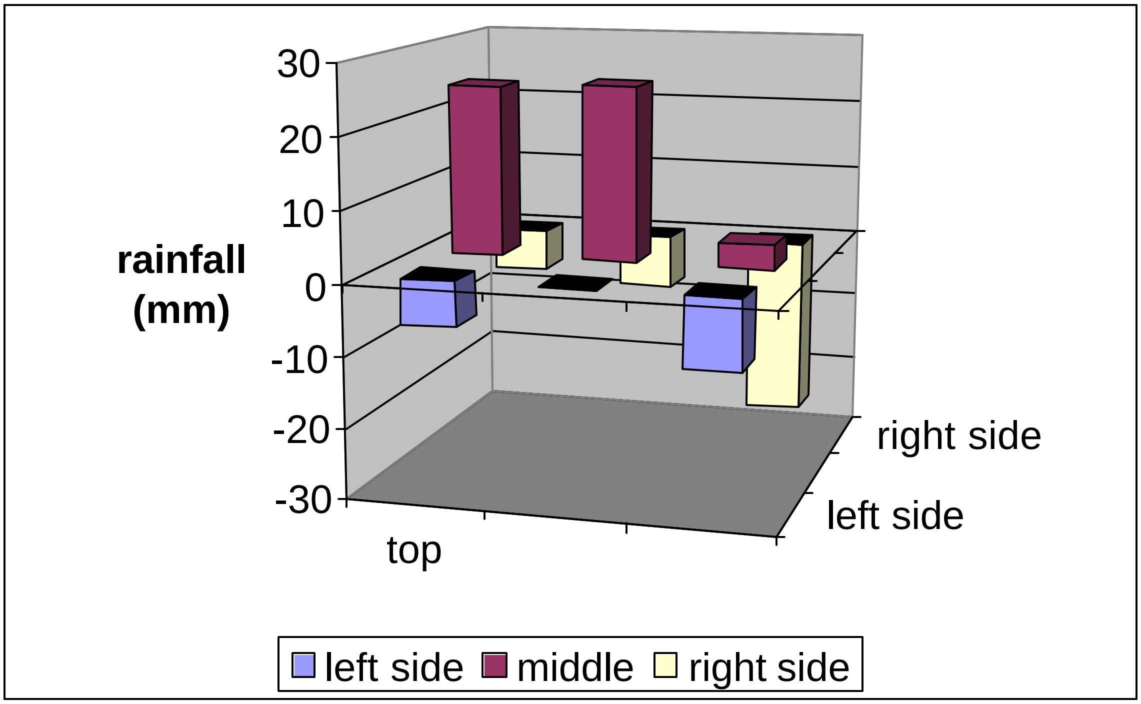


Figure 3.2: Rainfall distribution, average recorded difference of plot location from total plot average for first storm event, n = 21.

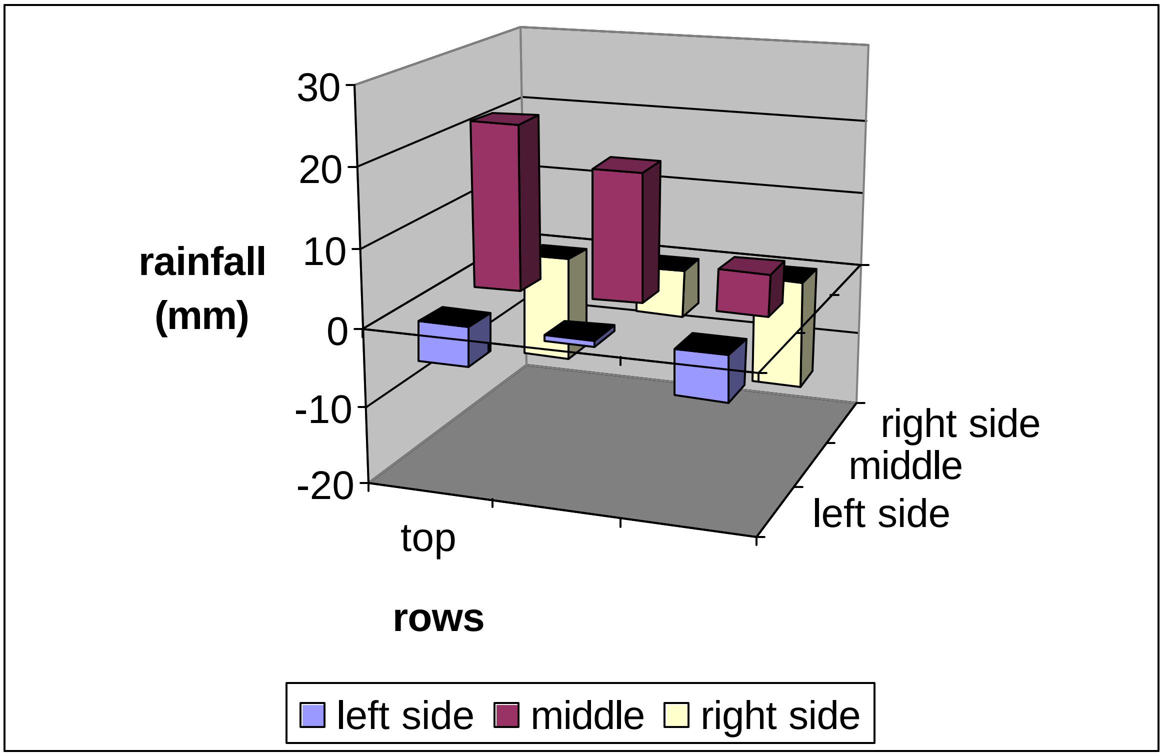


Figure 3.2: Rainfall distribution, average recorded difference of plot location from total plot average for second storm event, n = 21.

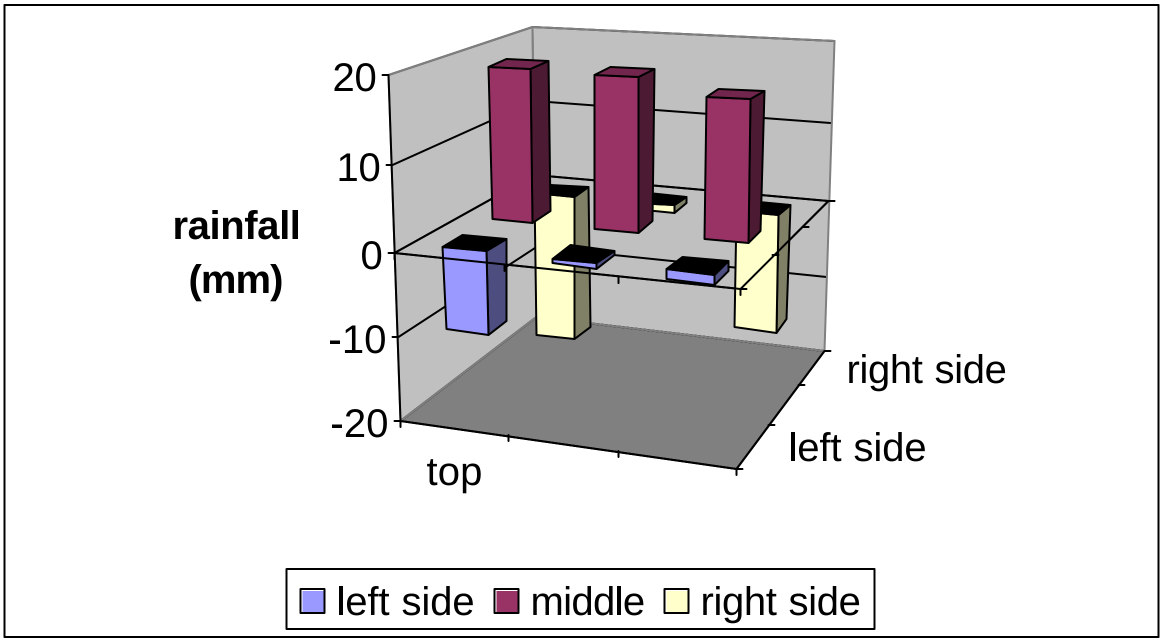


Figure 3.4: Rainfall distribution, average recorded difference of plot location from total plot average for third storm event, n = 21.

Time to Runoff Start and Steady State Conditions

According to the literature materials high in organic matter, like compost, have the ability to hold higher volumes of moisture compared to materials low in organic matter, like a bare soil (control) or hydroseed treated soils. In addition, it was expected that treatments with more vegetative cover would have longer time periods before the start of runoff and steady state runoff rate conditions. One way to measure how well a material holds water and reduces runoff is by quantifying how much time it takes before a treatment experiences runoff and reaches a steady state runoff rate based on a determined rainfall rate and intensity.

During the first storm event the yardwaste compost and poultry litter compost followed the MSW compost for length of time before the start of runoff, respectively (Table 4.2). The poultry litter compost was nearly the same as the MSW compost followed by the yardwaste compost, for length of time until steady state was achieved, and treatments were significantly different than the control. Statistically, the MSW compost differed from all other treatments in length of time until the start of runoff, while the yard waste compost was just significantly different than the hydroseeded treatments and the control. All four of the compost treatments were significantly different than the control, while the hydroseeded treatments were not.

During the second storm event, the MSW compost had the longest time until the start of runoff and was statistically different from all treatments except the poultry litter compost. There was no significant difference among the remaining treatments and the control, although the composts did appear to perform better than the hydroseeded treatments and the control. There was a significant difference in the time until steady state runoff was achieved between the compost treatments and the control and hydroseeded treatments. There was no significant difference between the hydroseeded treatments and the control.

During the final storm event the time periods before the start of runoff and steady state conditions were shorter, probably due to the higher antecedent soil moisture contents during that time. The biosolids compost had the longest period of time before the start of runoff followed by the poultry litter compost and yardwaste compost treatments, respectively; however, there was no significant difference in the time until the start of runoff between any treatment. The time period before steady state flow was reached was longest for the poultry litter compost followed by the biosolids compost and MSW composts, respectively.

In this analysis, all compost treatments increased the time until runoff began, compared to the hydroseed and control treatment. Notably, two replicates of the MSW compost and one replicate of the poultry litter compost produced NO runoff during the second storm event. Overall, during the three storm events the control had the shortest time until runoff began, as quick as 2.7 minutes, and the shortest times until the runoff reached a steady state, as quick as 9.3 minutes. The hydroseed treatments had the next shortest times after the control, as the hydroseed with mulch treatment performed slightly better than the hydroseed with silt fence treatment during the first and second storm events. This was probably due to the mulch filter berm's increased ability to hold water or slow down the flow of runoff. Of the four compost treatments the MSW compost had the longest time period before the start of runoff, as long as 51 min, and steady state for the first and second storm events. The longer an erosion control tool can prevent runoff from occurring and/or eventually reaching its maximum flow (steady state) the less likely there will be erosion and solids loss from that area. Figure 3.5 compares the time before the start of runoff and steady state flow between treatments and storm events.

Table 4.2: Average time (minutes) until start of runoff and steady state conditions by treatment at day one, three moths, and twelve months, n=3.

	DAY ONE		THREE MONTHS		TWELVE MONTHS	
Treatment	RO Start	RO Steady state	RO Start	RO Steady state	RO Start	RO Steady state
PLC/Mulch/Gypsum	12.0bc	40.3a	41.0ab	55.3a	21a	44.3ab
Biosolids Compost	8.3bcd	26.7ab	32.7b	56.0a	23.7a	40.3a
MSW Compost/Mulch	20.0a	40.0a	51.7a	>60.0a	14.3a	37.7ab
Yardwaste Compost	13.0b	31.3ab	33.3b	54.0a	14.7a	34.7ab

Hydroseed/Mulch Berm	7.3cde	25.7ab	14.3b	31.0b	9.0a	27.3ab
Hydroseed/Silt fence	6.0de	22.7ab	8.0b	19.7b	10.3a	33.7ab
Bare Soil (not seeded)	2.7e	9.3c	6.3b	19.7b	3.7a	18.7b

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

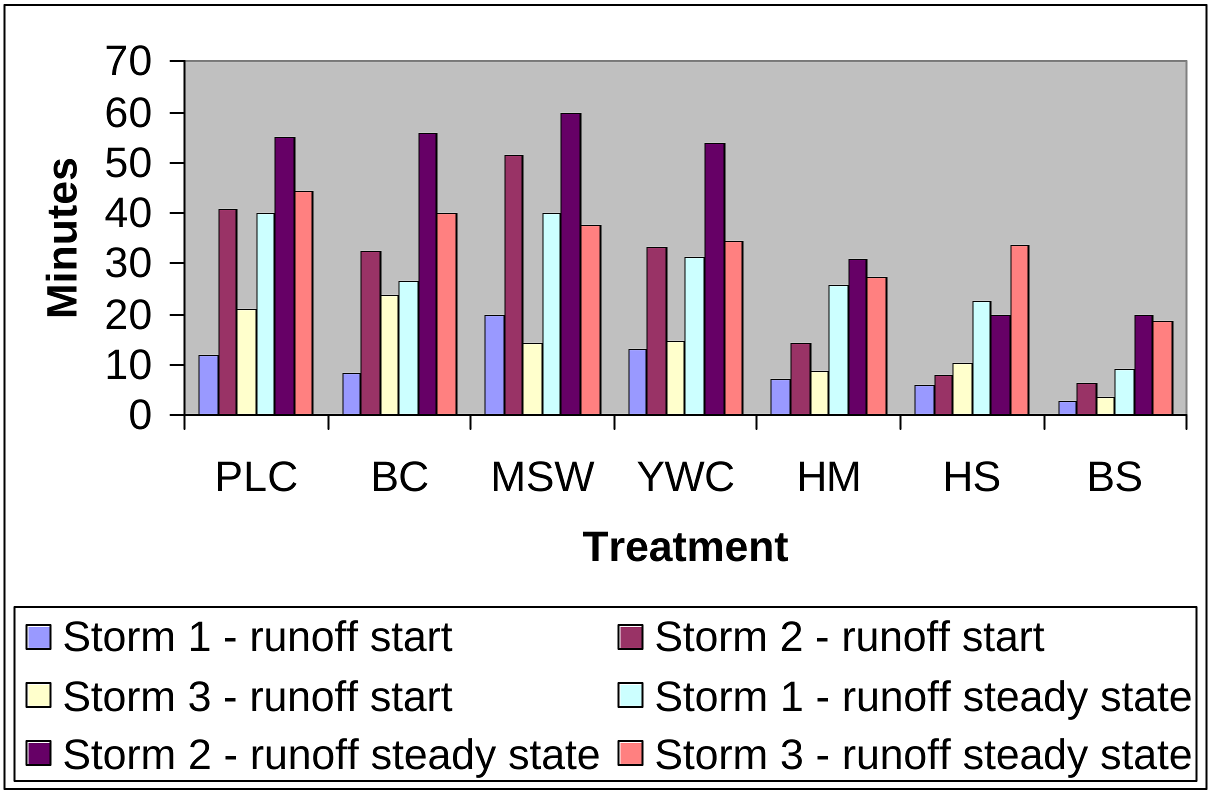


Figure 3.5: Average time until the start of runoff and steady state conditions (minutes) of runoff between treatments and storm events, n = 3.

Total Runoff Volume

The mechanisms that affect the rate at which runoff starts and how quick that runoff reaches steady state flow can also affect the quantity of runoff that a particular erosion control measure or experimental treatment may yield. During the first storm event, prior to vegetation establishment, although all of the treatments receiving erosion control measures generated less total runoff than the control, no statistical difference was measured among the six treatments (Table 4.3). The MSW compost had the lowest runoff volume of 22.5 mm followed by the hydroseed with silt fence, poultry litter compost and finally the yard waste compost. The biosolids compost generated the most runoff (excluding the control) followed by the hydroseed with mulch berm treatment (Figure 3.6). Compared to the control the MSW compost generated 47% less runoff, the hydroseed with silt fence generated 29% less runoff, the poultry litter compost produced 24% less, the yard waste compost produced 22% less, the hydroseed with mulch berm generated 13% less and the biosolids compost generated 10% less runoff. Statistically, the MSW compost was the only treatment that generated significantly less runoff than the control. All other treatments were statistically similar. It should be noted that difficulties were experienced collecting runoff during the first storm event with the silt fence treatment because it produced a damming effect, this may have reduced total runoff volumes in this treatment.

During the second storm event, as vegetation was beginning to establish, total runoff volumes plummeted in five of the treatments, while runoff volumes in the hydroseed with silt fence and control treatments showed small increases. It should be noted that during the three-month mid-summer period, between the first and second storm events, only 90.7 mm (3.57) of natural rainfall was recorded, with only 6.9 mm (0.27 in) recorded in the third month. This likely affected the water content of the treatments and soil. The unexpected increase in runoff from the hydroseed with silt fence treatment could be due to the sampling error from the first storm event, which may have produced artificially low runoff volumes. The increase could also be the result of soil surface crusting from the previous storm event. It should also be noted that two of the MSW compost treatments and one of the poultry litter compost treatments generated no runoff during the second storm. Statistically, the control generated more runoff than all treatments, except the hydroseed with silt fence, which also generated significantly more runoff than the compost treatments.

Again the MSW compost generated the least amount of runoff among all the treatments, and showed a 92% decrease from the first storm event. The poultry litter compost had the second least amount of total runoff followed by the yard waste and biosolids composts. Decreases in runoff yield percent from the first storm event to the second storm were; poultry litter compost 85%, yard waste compost 75%, biosolids compost 75%, and hydroseed with mulch berm 45%. The hydroseed with silt fence increased 7% and the control increased 8%. Compared to the control, the MSW compost produced 96% less runoff, the poultry litter compost produced 89% less runoff, the yard waste compost produced 82% less, the biosolids compost produced 79% less, followed by the hydroseed with mulch berm at 56% less and the hydroseed with silt fence at 30% less runoff.

By the final storm event, one year after the first storm, vegetation was well established on nearly all of the experimental treatments; however, total runoff volumes increased for all treatments with the exception of the control and hydroseed with silt fence treatments. This was probably due to the large increase in antecedent moisture content from the second to the third storm events, as all treatments were near field capacity during of the third storm. Overall, during the final storm, the poultry litter compost generated the least runoff, followed by the biosolids compost, MSW compost and yard waste compost, respectively. The hydroseed with silt fence generated less runoff than the hydroseed with mulch treatment, while the control produced the greatest runoff volume. Statistically, the poultry litter compost, MSW compost and biosolids compost generated less runoff than the rest of the treatments, including the yard waste compost (likely because it received more rain). It is interesting to note that the hydroseeded treatments and the control generated similar total runoff volumes during the third storm event and the first storm event, even though the hydroseeded treatments had a vegetative cover by the final storm.

Table 4.3: Total runoff volume (mm) by treatment at day one, three months, and twelve months, n=3.

	DAY ONE		THREE MONTHS		TWELVE MONTHS	
Treatment	AVG	SD	AVG	SD	AVG	SD
PLC/Mulch/Gypsum	32.0ab	12.7	5.0c	4.9	15.9c	7.0
Biosolids Compost	38.1ab	7.9	9.6c	6.9	21.6bc	17.0
MSW Compost/Mulch	22.5b	13.1	1.8c	Nd	21.9bc	2.2
Yardwaste Compost	33.0ab	5.6	8.1c	4.1	25.0abc	7.0
Hydroseed/Mulch Berm	36.7ab	5.8	20.2bc	2.4	34.2ab	9.9
Hydroseed/Silt Fence	30.0ab	11.6	32.3ab	28.3	27.6abc	5.1
Bare Soil (not seeded)	42.3a	5.6	45.9a	20.6	40.8a	8.9

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

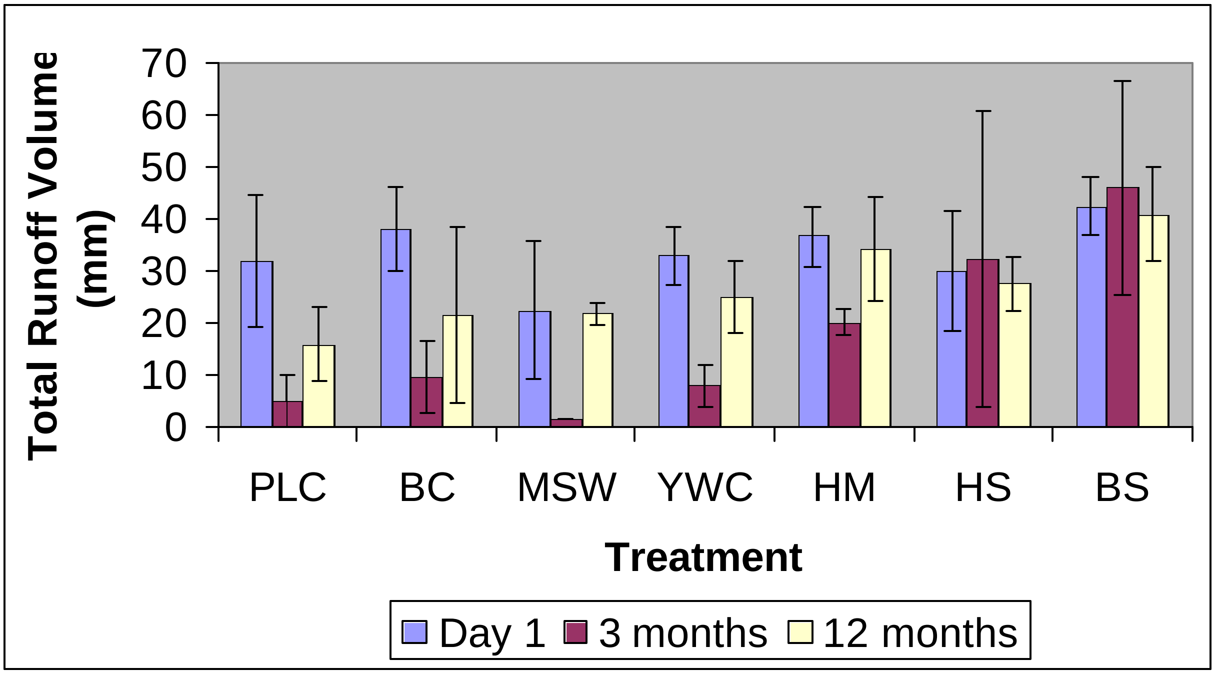


Figure 3.6: Average total runoff volume (mm) by treatment at day one, three months, and twelve months, n = 3.

Runoff Rate at Steady State

The steady state flow of runoff is reached when infiltration of rainfall no longer occurs because all pore spaces have been filled with water, thus reaching a given material's water holding capacity. The rate at which the runoff flows (mm/sec) once steady state occurs can tell us the infiltration capacity of the treatment and soil. In a bare soil, crusting may occur resulting in decreased infiltration and higher runoff rates, while compost treatments could improve soil structure resulting in increased infiltration and lower runoff rates. Additionally, higher runoff rates have higher erosive potential than lower rates; therefore reducing runoff rate can reduce the potential for soil loss. Consistent with runoff volume results, runoff rates were highest during the first storm event, followed by the third storm (Table 4.4). However, the control treatment reflected just the opposite, with runoff rates highest during the second storm and lowest during the first storm event (Figure 3.7), this was likely the result of soil crusting during the second storm event.

During the first storm event the hydroseed with silt fence had the lowest runoff rate (probably because of the damming effect created by the silt fence), followed by the MSW compost, the control, the hydroseed with mulch, the poultry litter compost, the yard waste compost and finally the biosolids compost. It should be noted that this may not be reflective of what is actually happening across the soil surface where the runoff is occurring, since samples were taken after passing through the silt fence and filter berms.

By the second storm the order had shifted dramatically, as all of the composts had lower runoff rates than the hydroseeded treatments, and all six treatments utilizing erosion control measures had lower rates than the control. The MSW compost had the lowest runoff rate, followed by the poultry litter compost, the biosolids compost, and yard waste compost, the hydroseed with silt fence, the hydroseed with mulch berm, and the control, respectively. Statistically, the MSW compost, poultry litter compost and biosolids compost had lower runoff rates than the control. This was partly influenced by the lack of two replicates of the MSW compost and one replicate of the poultry litter compost to reach a steady state runoff flow. This was likely due to the extremely dry conditions coupled with the ability of the compost treatment to continue to hold water or slow down overland runoff flow.

By the final storm event the poultry litter compost had the lowest runoff rate followed by the biosolids compost, the MSW compost, and the yard waste compost. Again, the composts had lower runoff rates than the hydroseeded treatments (the hydroseed with silt fence was lower of the two), and the control had the highest runoff rate. However, the only significant difference was between the control and the poultry litter compost. Over the one-year study, all four compost treatments showed a reduction in runoff rate, while the hydroseed with silt fence runoff rate remained unchanged and the bare soil runoff rate increased (Table 4.4). This may be the result of the compost blankets gradually increasing soil structure and water infiltration in the soil surface, while the control may have experienced soil crusting. Of the compost treatments the poultry litter and biosolids compost treatments reduced runoff rates the most over the one-year study period.

Table 4.4: Runoff rate (mm/sec) at steady state by treatment at day one, three months and twelve months, n=3.

	DAY ONE		THREE MONTHS		TWELVE MONTHS		ONE YR CHANGE
Treatment	AVG	SD	AVG	SD	AVG	SD	AVG
PLC/Mulch/Gypsum	0.014ab	0.003	0.006b	0.002	0.008b	0.003	-0.006
Biosolids Compost	0.015a	0.003	0.007b	0.005	0.01ab	0.005	-0.005
MSW Compost/Mulch	0.012ab	0.003	0.005b	Nd	0.01ab	0.001	-0.002
Yardwaste Compost	0.015a	0.002	0.007ab	0.005	0.011ab	0.002	-0.004
Hydroseed/Mulch Berm	0.014ab	0.001	0.01ab	0.001	0.013ab	0.002	-0.001
Hydroseed/Silt Fence	0.011b	0.005	0.009ab	0.006	0.011ab	0.002	0.000
Bare Soil (not seeded)	0.013ab	0.001	0.015a	0.004	0.014a	0.002	+0.001

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

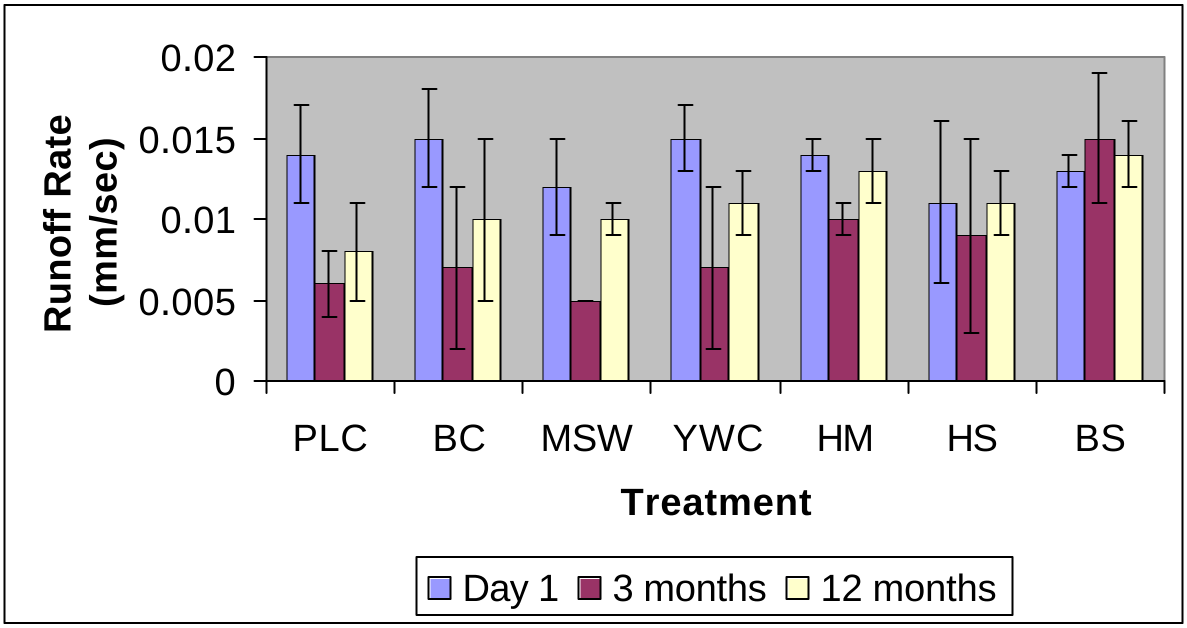


Figure 3.7: Average runoff rate (mm/sec) by treatment at day one, three months and twelve months, n = 3.

Rainfall Infiltration Volume

In a rainstorm, precipitation that makes contact with the soil surface has two potential fates, runoff or infiltration (and eventually a third, evapotranspiration). In this study, rain that did not infiltrate the soil surface is quantified as runoff. Soil surfaces that have a mulched cover, exhibit a variety of particle sizes, are high in organic matter, have low bulk densities or have a vegetative cover often allow more rainfall to infiltrate. By determining the total amount of rainfall applied to a treatment area and subtracting the total amount of runoff that left the treatment area we can determine how much rainwater actually penetrated the surface. High infiltration rates are desirable in storm water management applications (as evident from storm water utilities promoting pervious surfaces), as the higher the volume of infiltration the lower the volume of runoff, which usually equates to less erosion and sedimentation. Overall, the compost treatments allowed greater infiltration of storm water than the hydroseeded treatments, and all treatments allowed more than the control.

During the first storm event the MSW compost had the highest volume of rainwater to infiltrate the surface at 66.31 mm, followed closely by the yard waste compost (Table 4.5). The poultry litter compost and biosolids compost were followed by the hydroseed with silt fence and hydroseed with mulch berm treatments, respectively (Figure 3.8), while the control had the lowest infiltration volumes. Compared to the control the MSW compost and the yard waste compost treatments allowed 51% more water to infiltrate the surface, the poultry litter allowed 43% more, the biosolids 31%, the hydroseed with silt fence 24%, and the hydroseed with mulch berm 20%. Statistically, the poultry litter compost, MSW compost and yard waste compost had greater infiltration volumes than the control. Additionally, the MSW compost and yard waste compost was significantly different than the hydroseed with mulch berm.

The second storm event had the highest infiltration volumes of the three storm events, again probably due to the climate and soil moisture conditions. The MSW compost had the highest infiltration volumes at 80.27 mm followed by the poultry litter compost. The hydroseed with mulch berm, yard waste compost and biosolids compost treatments all had about the same volume of rainwater infiltration, while the hydroseed and silt fence treatment followed by the control had comparitively less. Statistically, the MSW compost had greater infiltration volumes than the control and the hydroseed with silt fence treatment. All treatments, except the hydroseed with silt fence, were significantly different than the control. Compared to the control the MSW compost allowed 51% more water to infiltrate the surface, the poultry litter allowed 48% more, the hydroseed with mulch berm allowed 45%, the yard waste compost allowed 45%, the biosolids compost allowed 44%, and the hydroseed with silt fence 25%.

The final storm event had the lowest infiltration volumes of the three storms. Once again, all treatments had infiltration volumes higher than the control, 18.0 mm, and all four composts had higher volumes of infiltration than the hydroseeded treatments, although all the treatments had a mature stand of vegetation. The yard waste compost infiltrated the most rainwater, followed by the poultry litter compost, the MSW compost and the biosolids compost, respectively. The hydroseed with silt fence treatment had slightly higher infiltration volumes than the hydroseed with mulch berm. Statistically, the composts were significantly different than the control but the yard waste compost was the only one statistically different than the hydroseeded treatments. Compared to the control the yard waste compost allowed 65% more water to infiltrate the surface, the poultry litter compost allowed 63% more, the MSW compost and the biosolids compost treatments allowed 61%, the hydroseed with silt fence allowed 47%, and the hydroseed with mulch berm 43%. The increased percentages (compared to the control) that resulted during this storm event were probably due to the increase in vegetation exhibited by all treatments. The decreased volume average (compared to the second storm) was likely due to the comparatively high antecedent water conditions.

Table 4.5: Infiltration volume of rainfall (mm) by treatment at day one, three months and twelve months, n=3.

	DAY ONE		THREE MONTHS		TWELVE MONTHS	
Treatment	AVG	SD	AVG	SD	AVG	SD
PLC/Mulch/Gypsum	56.0ab	6.1	75.4ab	5.4	48.7ab	7.1
Biosolids Compost	46.5abc	11.9	70.0ab	5.7	45.2ab	16.0
MSW	66.3a	12.2	80.3a	1.1	46.1ab	0.7

Compost/Mulch						
Yardwaste Compost	65.2a	8.3	71.2ab	4.9	51.9a	8.0
Hydroseed/Mulch Berm	40.3bc	3.9	70.9ab	21.3	31.5bc	8.6
Hydroseed/Silt Fence	42.4abc	16.8	52.3bc	25.5	34.2bc	10.8
Bare Soil (not seeded)	32.2c	6.3	39.1c	11.1	18.0c	1.6

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

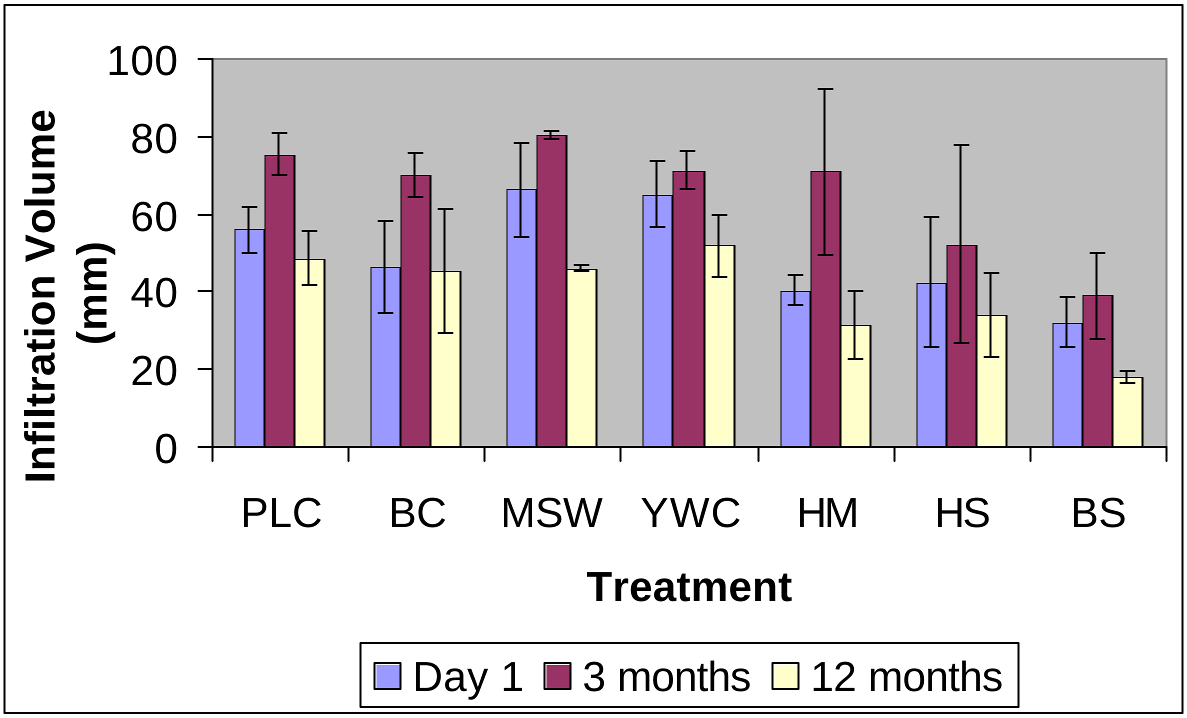


Figure 3.8: Average infiltration volume of rainfall (mm) by treatment at day one, three months and twelve months, n = 3.

Rainfall to Runoff Ratio

Comparing the amount of rainfall that is applied to the treatment area to the amount of rainfall that winds up as runoff is perhaps a better way to evaluate the effectiveness of each experimental erosion control measure, particularly since all rainfall rates were not exactly the same. The closer the ratio is to one the greater the volume of runoff relative to the total rainfall. In all but one case the compost treatments had higher rainfall to runoff ratios than the hydroseeded treatments, while all the treatments had higher ratios than the control during all three storm events (Table 4.6). Overall, rainfall to runoff ratios were highest during the second storm event, and were similar during the first and final storm events.

During the first event the MSW compost had the highest rainfall to runoff ratio at 3.09, followed by the yardwaste compost, the poulty litter compost, the hydroseed with silt fence (the one exception), the biosolids compost, the hydroseed with mulch berm, and the control, respectively. No significant differences were observed. The unexpectedly high ratio of the hydroseed with silt fence was probably due to either sampling difficulties or the damming effect (which were related) the silt fence had on the runoff – which would artificially decrease the amount of runoff on the treatment surface.

During the second storm event two MSW compost treatment plots and one poultry litter compost treatment plot experienced no runoff, which explains the comparatively high rainfall to runoff ratios for these treatments. Because of the ability to hold so much water, the MSW compost had the highest ratio again (245.11), followed by the poultry litter compost, the biosolids compost, the yard waste compost, the hydroseed with mulch berm, the hydroseed with silt fence, and the control, respectively. However, the only significant difference was between the MSW compost and all other treatments, with the exception of the poultry litter compost.

By the final storm event the biosolids compost had the highest rainfall to runoff ratio (6.1), followed by the poultry litter compost, the yard waste compost, the MSW compost, the hydroseed with silt fence, the hydroseed with mulch filter berm, and the control, respectively; however, these differences were not statistically significant.

Table 4.6: Rainfall to runoff volume ratios by treatment at day one, three months and twelve months, n=3.

	DAY ONE		THREE MONTHS		TWELVE MONTHS	
Treatment	AVG	SD	AVG	SD	AVG	SD
PLC/Mulch/Gypsum	1.90a	0.66	130.24ab	202.0	3.60a	1.6
Biosolids Compost	1.24a	0.33	16.08b	17.62	6.10a	8.2
MSW Compost/Mulch	3.09a	0.74	245.11a	199.94	2.10a	0.2
Yardwaste Compost	1.99a	0.21	14.13b	12.08	2.20a	0.8
Hydroseed/Mulch Berm	1.12a	0.29	3.66b	1.38	1.03a	0.6
Hydroseed/Silt Fence	1.46a	2.90	3.23b	3.73	1.33a	0.7
Bare Soil (not seeded)	0.78a	0.25	1.02b	0.57	0.43a	0.1

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Correlation Analysis

Results from correlation analysis (Table 4.7) were used to evaluate which of the treatment physical, chemical, and biological characteristics, and rainfall and vegetation growth results were correlated with the parameters from storm water runoff results. Only those that were highly correlated (r>0.70) are reported. During the first storm event, time until the start of runoff was correlated with total nitrogen, pH, stability, moisture content and various micronutrients. Among the compost treatments, the higher the pH, moisture content, stability index, and some micronutrients, the longer it took for runoff to begin. It is well known that high moisture content can affect early commencement of runoff; however, these compost treatments must have been under this range, as a general trend is not evident. Further research may be useful to determine at what moisture content runoff commencement is significantly reduced. Additionally, N, K and pH were good indicators of length of time before steady state was achieved. The volume of rainwater that infiltrated the surface during the first storm event was correlated to particle sizes passing 4mm, pH, germination rate, N, K, Al, and Mg. High germination rate and high pH were particularly good indicators of high volumes of rainwater infiltration. Based on the correlation analysis from the first storm event, characteristics of high quality composts, such as high stability and germination rates, neutral pH, and adequate total N, are the best indicator of increasing infiltration and decreasing runoff.

Total runoff volume in the second storm event was correlated to bulk density, N, P, K, and, Mg; however, the best indicator of low runoff volume was low phosphorus concentration in the compost treatment. Runoff rate was significantly correlated to the same parameters as total runoff volume with the exception of bulk density. Again, low phosphorus concentration in the compost was the best indicator of a low runoff rate. Rainwater infiltration volume was only correlated to N and pH during this storm. Time until the beginning of runoff and steady state conditions were correlated to particle sizes passing 25mm, 16mm, 9.5mm, 6.3mm, pH, germination rate, and percentage of vegetative cover. High germination rate, a greater percentage of particles passing through 9.5mm, and a greater percentage of vegetative cover (excluding MSW compost) were the best indicators of a longer period of time before the commencement of runoff. Based on this analysis, germination rate and the subsequent vegetative cover as well as a variety of particle sizes were the best means to reduce storm water runoff during the second storm event.

Infiltration volume from the final storm event was correlated to N, P, K, Mg, pH, and percent cover at three months. The best indicators of high rainwater infiltration volume were high K and Mg concentrations in the compost (excluding the poultry litter compost), and high percent cover at three months (excluding the poultry litter compost). After one year, it appeared that the parameters that most affect plant growth were the ones most correlated to increased infiltration volumes, which can lead to reduced storm runoff.

Table 4.7: Results from correlation analysis. This table lists all variables with significant correlation (r>0.70, $\alpha = 0.05$, n = 21).

Response Variable	**Independent Variable (treatment) with Correlation Coefficient**
Time to runoff start, Storm #1	N (0.83), pH (0.77), stability (0.72), moisture content (0.77), Na (0.76), Mg (0.70)
Time to runoff steady state, Storm #1	N (0.75), K (0.72), pH (0.74)
Rain infiltration volume, Storm #1	Particle size >4mm (7.0), pH (0.74), germination rate (0.70), Al (0.72), N (0.74), K (0.72), Mg (0.84)
Time to runoff start, Storm #2	Particle size >25mm (0.71), Particle size >16mm (0.82), Particle size >9.5mm (0.77), Particle size >6.3mm (0.72), pH (0.73), germination rate (0.80), percent vegetative cover (0.91)
Time to runoff steady state, Storm #2	Particle size >25mm (0.77), Particle size >16mm (0.89), Particle size >9.5mm (0.82), Particle size >6.3mm (0.74), pH (0.74), germination rate (0.84), percent vegetative cover (0.90)
Rain infiltration volume, Storm #2	N (0.74), pH (0.81)
Runoff rate, Storm #2	N (0.86), P (0.81), K (0.76), Mg (0.75)
Total Runoff, Storm #2	Bulk density (0.77), N (0.89), P (0.82), K (0.75), Mg (0.73)
Rain infiltration volume, Storm #3	N (0.73), P (0.70), K (0.75), Mg (0.77), pH (0.74), percent vegetative cover at 3 months (0.78)

Summary and Conclusion

Based on this study and under these environmental conditions, MSW compost is the best tool for reducing runoff volume in the short and long term. It also appears that hydroseeding is not very effective at reducing runoff compared to a bare soil, while compost is effective. Additionally, compost reduces runoff volume and runoff rate more over time than hydroseeding or a bare soil. Support for this is evident in the amount of rainfall that infiltrated each treatment, again the composts outperformed hydroseeding, and the MSW compost did particularly well. All of the treatments allowed for better infiltration than the control. Based on the time it takes for runoff to commence, compost may be a better tool to prevent runoff from occurring during small and medium intensity storm events. The MSW compost was particularly effective in this area.

Based on correlation analysis, general characteristics of high quality compost such as a high biological stability, high germination rate, and neutral pH are good indicators that there will be greater infiltration and less runoff. This is likely since these characteristics lead to good vegetation establishment, which in turn can lead to greater infiltration and less runoff. Additional parameters that provide good vegetative growth, such low bulk density, adequate N, P, and K and to some extent the particle size distribution of the compost, are important to increasing infiltration and reducing runoff. This provides compelling evidence that compost may be well suited for a variety of storm water management applications, particularly where it can eliminate runoff, thus preventing most erosion from ever occurring. For erosion control professionals deciding on which measure to use for managing storm water and reducing runoff, compost does a better job than hydroseeding at increasing infiltration and reducing storm runoff.

Solids Loss

While erosion prevention may be the best management for controlling sedimentation, the primary focus of the erosion and sediment control industry and regulators are to prevent sediment from leaving the designated site and/or reaching nearby surface waters. Establishing vegetation as quick as possible is one of the main goals to controlling soil erosion and sediment loss; however, establishing a *permanent* vegetative cover *and* providing a protective soil cover before vegetation is established can be just as important. Three simulated storm events were used to evaluate the performance of each treatment over time. Simulated storm events were conducted at the time materials were applied (no vegetation), three months (vegetation established), and twelve months (vegetation matured). Each test plot was exposed to a simulated storm event, for one-hour duration, at a rate approximate to the 50-year/1 hour storm event for Athens, Georgia. Runoff samples were collected at the base of each plot as soon as runoff began. Total solids loads and solid loss ratios were used as parameters to evaluate the erosion prevention and sediment control capabilities of each treatment during each storm event.

Total Solids Load

During the first storm event, before vegetation was established, all six treatments lost less total solids than the control (Table 4.8). In addition, each of the four compost treatments yielded less total solids than the two hydroseeded treatments (Figure 3.9). This is probably a result of the immediate and more stable soil surface cover the compost blankets provided relative to the hydroseed treatments. The hydroseed and mulch treatment produced less solids loss than the hydroseed and silt fence treatment, which may be the function of superior sediment filtration by the mulch berm over the silt fence. Of the composts, the yard waste and biosolids compost treatments yielded less solids than the poultry litter and MSW composts; interestingly the former had more runoff volume. The control was statistically greater than the rest of the treatments, and there was no significant difference between the six treatments during the first storm event. Visually, the control and hydroseeded plots had evidence of rilling, indicating erosion from flow stress. The composts had no evidence of rilling but did show some bridging of material, indicating potential erosion from flow stress.

During the second storm event, after three months of allowing vegetation to establish, all six treatments with erosion control measures generated significantly less solids than the control. In addition, all six treatments greatly reduced the loss of solids compared to the first storm event.

This was probably due to the establishment of vegetation coupled with the drought that ensued between the two storm events (only 90.7 mm of natural rain). The composts continued to perform better than either of the two hydroseed treatments, while the hydroseed with mulch berm treatment continued to perform better than the hydroseed with silt fence treatment. The difference in solids loss between the two hydroseed treatments was much greater during the second storm event. The MSW compost provided the best protection against soil loss, presumably because it produced very little runoff. The yard waste and poultry litter composts generated nearly the same solids yield, followed by the biosolids compost. It should be noted that two of the MSW compost treatments and one of the poultry litter compost treatments did not produce runoff during this storm event. Finally, the control and hydroseeded treatments continued to show some rilling from concentrated flow.

Table 4.8: Average total solids loads (g/m^2) and total solids loss ratio (treatment to control) by treatment at day one, three months, and twelve months, n=3.

	DAY ONE			THREE MONTHS			TWELVE MONTHS		
Treatment	AVG	SD	RATIO	AVG	SD	RATIO	AVG	SD	RATIO
PLC/Mulch/Gypsum	158.9b	91.3	0.025	14.6b	8.3	0.003	10.8b	4.5	0.010
Biosolids Compost	105.8b	13.0	0.016	18.9b	13.2	0.003	8.8b	6.4	0.008
MSW Compost/Mulch	191.9b	107.8	0.030	6.0b	nd	0.001	17.8b	6.8	0.016
Yardwaste Compost	88.5b	45.3	0.014	13.7b	6.6	0.002	17.1b	6.2	0.015
Hydroseed/Mulch Berm	265.1b	32.3	0.041	78.1b	21.7	0.014	10.9b	6.1	0.010
Hydroseed/Silt Fence	307.9b	127.8	0.048	219.6b	72.0	0.039	14.5b	6.7	0.013
Bare Soil (not seeded)	6428.1a	2182.7	1.0	5464.2a	3290.4	1.0	1109.7a	987.7	1.0

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

After twelve months of allowing vegetation to establish, all six treatments with erosion control measures provided superior soil protection compared to the control. By this time both hydroseed treatments experienced a "vegetation comeback" and the solids yield generated from these treatments was quite similar to the compost treatments. However, solids loss reduction among the compost treatments changed little from the second to the third storm event. The biosolids compost treatment improved the most of the four composts, and provided the best protection against solids loss during the final storm event, followed closely by the poultry litter compost and hydroseed and mulch treatments. The hydroseed and silt fence treatment generated less solids loss than the yard waste and MSW compost treatments, which produced similar results. However, consistent with previous storms, there was no significant difference between treatments, only between the control and the remaining six erosion control treatments. It should be noted that the water content of the soils during the final storm event were near field capacity, quite opposite conditions experienced during the second storm event. Finally, by this storm event rilling was only evident in the control treatments, likely due to the vegetative growth experienced by the hydroseeded treatments.

Treatment to Control Soil Loss Ratio

As predicted, all six treatments receiving grass seed improved over time as vegetation became more established and provided better soil cover compared to the control (Table 4.8). The biggest gains in solids loss reduction were made between the first and second storm events for the composts and between the second and third storm events for the hydroseeded treatments. Figure 3.10 depicts the solids loss ratios (treatment/control) of each treatment compared to the control for each of the three storm events. The closer the ratio is to one, the greater the similarity is to the performance of the control. Interestingly, the yard waste and MSW composts generated more solids loss during the final storm event compared to the previous storm event. Although some vegetative cover did establish on the non-seeded control plots, solids loss improved little between the first and second storm events, and increased nearly two-fold between the second and third storm events. These occurrences were probably due to the elevated antecedent soil water conditions experienced during the third storm event, which led to greater runoff. While all treatments produced runoff during the third storm event (unlike the second storm), the biggest surprise to the researchers was the late but vigorous improvement of the hydroseeded treatments between the second and final storm event.

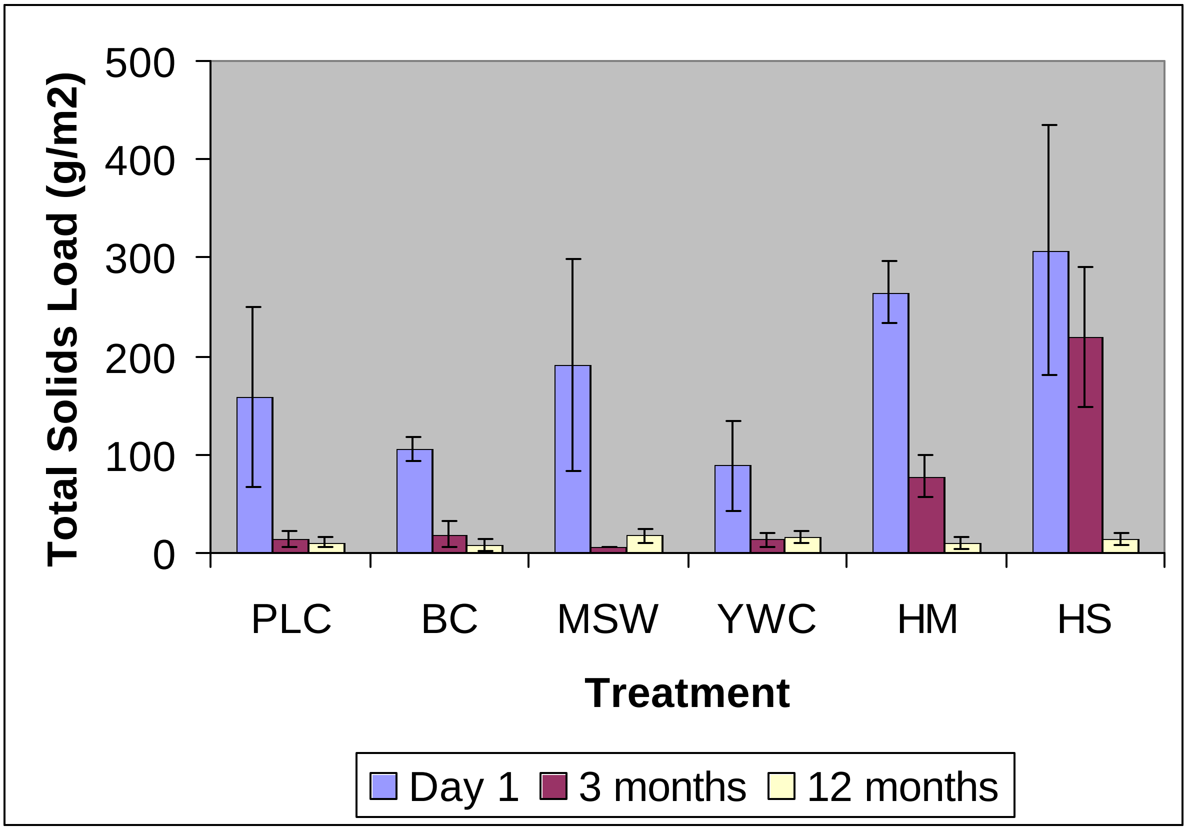


Figure 3.9: Average total solids loads (g/m^2) by treatment excluding bare soil control at day one, three months, and twelve months, n = 3.

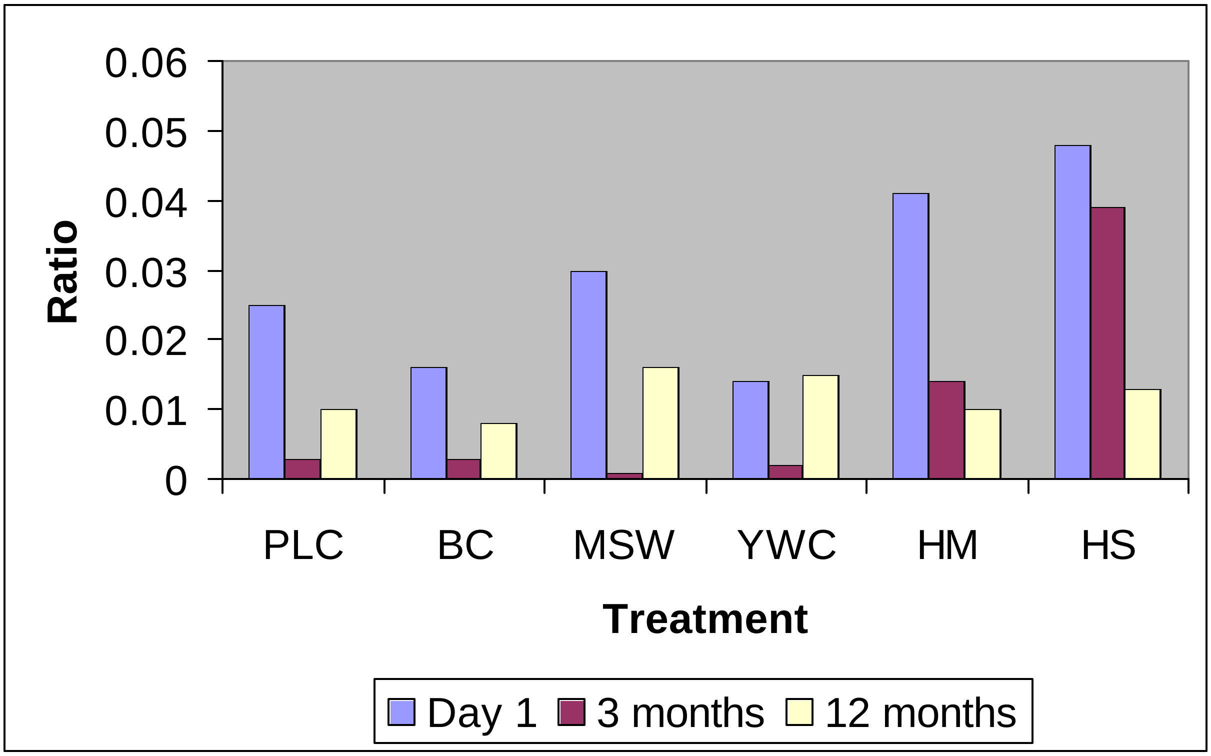


Figure 3.10: Average total solids loss ratio of treatment to control at day one, three months and twelve months, n = 3.

Correlation Analysis

Results from correlation analysis (Table 4.9) were used to evaluate which of the treatment physical, chemical, and biological characteristics, and rainfall and vegetation growth results (independent variables) were correlated with the parameters from total sediment concentrations and loads (response variables). Only those that were highly correlated (r>0.70) are reported. Bulk density of the compost treatments was well correlated to solids loss (concentration and load) for all three storm events. The MSW compost had the lowest bulk density and highest solids load for the first storm event; however, by the second storm event it had the lowest solids load of any treatment. Organic matter was correlated to solids load from the first and second storm event for the compost treatments. The MSW compost and poultry litter compost had the highest organic matter content and the highest solids loads for the first storm event, however, by the second storm event the MSW compost had the lowest solids loads.

Table 4.9: Results from correlation analysis. This table lists all variables with significant correlation (r>0.70, $\alpha = 0.05$, n = 21).

Response Variable	**Independent Variable (treatment) with Correlation Coefficient**
Total sediment concentration, Storm #1	Bulk density (0.93)
Total sediment load, Storm #1	Bulk density (0.90), organic matter (0.78)
Total sediment concentration, Storm #2	Bulk density (0.87), organic matter (0.71)
Total sediment load, Storm #2	Bulk density (0.73), organic matter (0.77)
Total sediment concentration, Storm #3	Bulk density (0.76)
Total sediment load, Storm #3	Bulk density (0.75)

Summary and Conclusion

Based on this study, all treatments were better than the control at reducing solids loss. While the differences were not significant, it appeared that the composts provided better erosion control than the industry standards, particularly in the short term, as solids loads were as much as 350% greater from the conventional methods during the first storm event. In addition, compost blankets continued to outperformed the industry standards three months after the initial application, although not statistically significant, solids loads were as much as 36 times greater from the industry standard treatments compared to compost. This study also lends some evidence that compost blankets may provide better protection from soil erosion than these industry standards during storms preceded by drought. After one year, however, the industry standards performed as well as the composts at reducing solids loss. The “vegetation comeback” of the hydroseeded plots, after obvious seed wash during the first storm event, can be partly attributed to the prolific growth that is characteristic of Bermuda grass (and weed growth).

While the compost treatments consistently showed a near 100% reduction (no less than 97%) in solids loss compared to the control, the industry standards maintained solids loss reductions no less than 95%. In addition, although differences were not statistically significant, the hydroseed with mulch filter berm consistently yielded less solids loss compared to silt fence throughout the entire study. Finally, it appears that the bulk density and organic matter content of compost is correlated to solids loading. For erosion control professionals deciding on which measure to use to provide the greatest protection against solids loss, compost generally outperforms hydroseeding and silt fence – particularly in short term applications, and mulch filter berms can provide better solids filtration than silt fence.

APPENDIX D

RESULTS AND DISCUSSION: NUTRIENT LOSS

Compost may be an effective tool in storm water management applications to control erosion and sedimentation; however, there may be a concern with nutrient losses from the composted materials. Composts that have not been well composted or are particularly high in N and P are of greatest concern because nutrients from these materials are less stable and/or more susceptible to losses in runoff. In addition, standard erosion control measures that utilize commercial fertilizers, such a hydroseeding, should also be scrutinized in the same manner.

It is well understood that although N and P are necessary to establish vegetation quickly and maintain vegetation permanently, it is important that applications do not exceed crop needs, when possible, they should not be applied before a storm event. To reduce potential nutrient losses in runoff, the poultry litter compost and MSW compost treatments were blended with wood mulch on a 3:1 volumetric basis (compost:mulch). This ratio was chosen because it was felt this was the most mulch that could be blended with these materials without adversely affecting plant growth from N immobilization. In addition, the poultry litter compost was blended with approximately 5% (volumetric basis) ground gypsum ($CaSO_4$). This was done to reduce potential P losses in the runoff from the reaction between P and $CaSO_4$ to form the more stable $Ca_3(PO_4)_2$.

It was hypothesized that treatments higher in N and P concentrations would have higher nutrient concentrations and loads in the storm water runoff. In addition, nutrient loading in the runoff would decrease with each subsequent storm event and those with better vegetative stands would be more likely to have lower nutrient loads in their runoff. Runoff samples were analyzed for total N, NO_3-N, NH_4-N, total P and DRP. See Materials and Methods section for complete treatment descriptions, sampling procedures, and analytical methods.

Total Nitrogen Concentrations and Loads

The total amount of nitrogen applied by each treatment was 132 g/m^2 from the poultry litter compost, 111 g/m^2 from the biosolids compost, 104 g/m^2 from the MSW compost, 94 g/m^2 from the yard waste compost, and 10 g/m^2 from the hydroseeded applications. The first simulated storm event was conducted immediately after treatment application, thus there was no vegetation and the potential for total N loss was greatest at this time period. Average total N (organic nitrogen + ammonium nitrogen + nitrate nitrogen) concentration of the runoff was highest from the biosolids compost treatment at 106.6 mg L^{-1}, followed by the MSW compost at 88.7 mg L^{-1} and then by both hydroseeded treatments at 38 mg L^{-1} (Table 5.1). The control had the lowest total N concentration (1.83 mg L^{-1}), while the poultry litter compost and yard waste compost represented the middle of the field at 28.6 and 14.4 mg L^{-1}, respectively. The total N concentration for the 25th percentile of reference streams is 0.03 mg L^{-1} (US EPA, 2000). Statistically, the biosolids compost, MSW compost, poultry litter compost, and both hydroseeded treatments were significantly different than the control, while the hydroseeded treatments were statistically similar to the poultry litter compost. With the exception of the biosolids compost and MSW compost the hydroseeded treatments had the highest total nitrogen concentrations in the runoff. This was probably due to the N fertilizer used in the initial hydroseed mixture. While the total N content of the biosolids compost was not appreciably higher than the other compost treatments, the addition of the wood mulch to the MSW compost and poultry litter compost treatments may be responsible for the lower total N concentrations in the runoff. However, more likely is the fact that 76% of the original total N content of the biosolids compost was inorganic N (ammonium-N and nitrate-N), which is more mobile and easily lost in storm water runoff relative to organic N. Comparatively, the yard waste compost had 2% of its total nitrogen as inorganic N, the MSW compost had 4%, and the poultry litter had 5%. Mature composts generally have high organic N and low inorganic N contents. Finally, the application of the mulch filter berm, when compared to the silt fence, did not appear to reduce total N concentration in the runoff of the hydroseeded treatments.

As predicted, by the second simulated storm event major reductions of total N concentration were observed in nearly all treatments. The control exhibited a slight increase between the two storm events. The biosolids compost continued to have the highest total N concentration overall at 25.8 mg L^{-1}, followed by the hydroseed with silt fence at 8.1 mg L^{-1}. The yard waste compost had a total N runoff concentration of 6.1 mg L^{-1}, followed by the hydroseed with mulch berm at 4.6 mg L^{-1}, the MSW compost at 4.1 mg L^{-1}, the poultry litter compost at 3.4 mg L^{-1} and finally the control at 2.1 mg L^{-1}. The biosolids compost was the only treatment significantly different from the control during the second storm event. While differences were observed between the hydroseeded treatments and some of the compost treatments during the first storm event, these differences in total N were not seen during the second storm event. The small difference between the hydroseed with mulch filter berm and hydroseed with silt fence treatment may be a result of the mulch berm filtering nutrients, but unlikely due to the similarity of total N concentrations during the first storm event.

By the final storm event, twelve months after the first storm, all treatments including the control had total N runoff concentrations between 1.25 mg L^{-1} and 2.44 mg L^{-1}. By this time period the vegetation probably assimilated most of the total N that was not already lost from previous storm events. However, the total N concentrations in the runoff from the yard waste compost and hydroseed with mulch berm were significantly less than the control.

Perhaps a more constructive tool for evaluating the pollution potential of these treatments is to compare total nitrogen loads (Figure 4.1). This is critical, for if a treatment exhibits comparatively high concentrations of nutrient loss but is comparatively more effective at reducing runoff, then it may be a more desirable method of erosion control, since in "real life" applications it is the *amount* of nutrients entering nearby surface water that we are most concerned.

During the first rainfall simulation the rank of treatments based on total N loads was the same as the total nitrogen concentrations. The biosolids compost released 4,033 mg/m^2 of total N followed by the MSW compost at 2014 mg/m^2, the hydroseed with mulch berm at 1391 mg/m^2, the hydroseed with silt fence at 1008 mg/m^2, the poultry litter compost at 842 mg/m^2, the yard waste compost at 451 mg/m^2, and the control at 77 mg/m^2 (Table 1). The biosolids compost, MSW compost, poultry litter compost, and both hydroseeded treatments were significantly different from the control. In addition, the biosolids compost was significantly greater than all other treatments. Based on the data, the mulch berm did not reduce total N load compared to silt fence among the hydroseeded treatments.

By the second storm event, three months later, total N loads were lower than the control (92 mg/m^2) in all treatments except the hydroseed with silt fence (188 mg/m^2) and the biosolids compost treatment (254 mg/m^2). The biosolids compost was still significantly different than the MSW compost and poultry litter compost. All treatments did exhibit major load reductions between the two storm events. The ability of the composts to have load values much lower than the control (although concentration was higher) is likely due to the infiltration and water holding capacity of the composts, as the runoff quantity was comparatively much higher with the control. Again, the lower load values exhibited by the mulch filter berm compared to the silt fence may be a result of the berm filtering this nutrient, but unlikely due to the load similarity from the first storm event.

By the final storm event, one year after the first storm, all total N loads were significantly less than the control. Again, this was probably due to assimilation by the vegetation, in addition to the losses from previous storm events. The dense vegetative stand and the water holding ability of the composts were certainly factors that reduced runoff and subsequent total N loads among these treatments, when compared to the control. While significant total nitrogen loading can occur during the first *large* storm event after application of these materials, in most cases by the second storm event there is little occurrence of total N loading unless you are working with high fertilizer value materials. Total N lost in the runoff, combined from all three storms, as a percent of the total applied by the treatments was 15.3% from the hydroseed with mulch, 12.2% from the hydroseed with silt fence, 3.9% for the biosolids compost, 2% for the MSW compost, and 0.7% for both the yard waste compost and poultry litter compost treatments.

Table 5.1: Average total N concentration (mg L^{-1}) and average total N load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n=3.

	DAY ONE			THREE MONTHS			TWELVE MONTHS		
Treatment	AVG	SD	LOAD	AVG	SD	LOAD	AVG	SD	LOAD
PLC/Mulch/Gypsum	28.64cd	10.36	841.9cde	3.38b	2.95	24.5b	2.15ab	1.16	39.9b
Biosolids Compost	106.63a	6.6	4060.9a	25.79a	6.36	254.3a	1.96ab	0.24	41.8b
MSW Compost/Mulch	88.7b	14.98	2014.1b	4.08b	7.07	22.7b	2.11ab	0.14	46.5b
Yardwaste Compost	14.42de	6.97	450.5de	6.11b	2.60	38.5ab	1.35b	0.09	34.2b
Hydroseed/Mulch Berm	38.49c	10.68	1391.2cb	4.57b	1.75	89.8ab	1.25b	0.07	43.3b
Hydroseed/Silt Fence	38.26c	7.83	1008.3cd	8.13b	2.61	188.2ab	1.45ab	0.12	40.1b
Bare Soil (not seeded)	1.83e	0.57	76.7e	2.06b	0.19	92.0ab	2.44a	0.66	102.9a

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

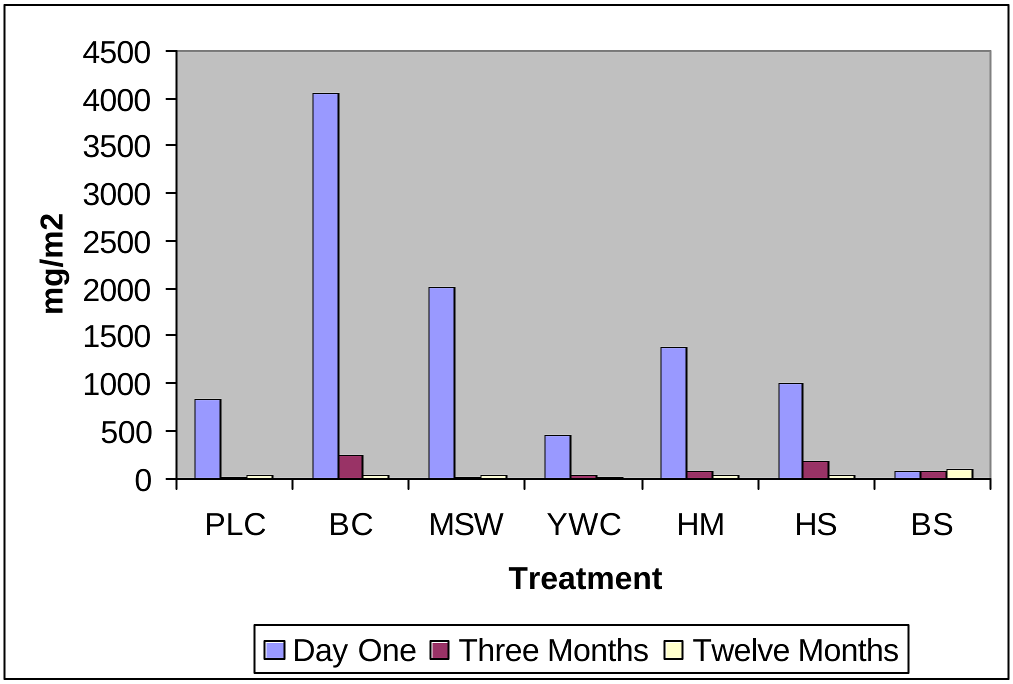


Figure 4.1: Average total N load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n = 3.

Nitrate Nitrogen Concentrations and Loads

Nitrate nitrogen is a highly mobile form of N and is most commonly cited as the form of nitrogen polluting ground water. High concentrations of NO_3-N in drinking water have been linked to negative health effects in humans as well as eutrophication in surface waters. The US EPA has set safe drinking water standards for NO_3-N at 10 mg L^{-1} (US EPA, 2004); however, it should be noted that runoff concentrations would likely be diluted, by moving over land surfaces, before reaching any water resource. During the first storm event nitrate nitrogen concentrations in the runoff were highest in the biosolids compost at 67 mg L^{-1}, followed by the hydroseed with mulch berm at 22 mg L^{-1}, the poultry litter compost at 17 mg L^{-1}, the hydroseed with silt fence at 15 mg L^{-1}, the yard waste compost at almost 3 mg L^{-1}, the control at 1 mg L^{-1} and finally the MSW compost at 0.10 mg L^{-1} (Table 5.2). The elevated concentrations of nitrate nitrogen from the hydroseeded treatments, relative to the control, were likely due to the mineral nitrogen fertilizer used in the initial hydroseed mixture. In addition, the higher levels of nitrate nitrogen concentrations in runoff from the poultry litter compost and particularly the biosolids compost was likely a result of the higher nitrate concentrations in these treatments. It should be noted that these levels of nitrate nitrogen were observed *from a large storm event as it came off the treatment*, once the runoff reaches (if it does) and subsequently assimilates with surface water, it would be significantly diluted. According to statistical analysis the biosolids compost was significantly greater than the rest of the treatments. The poultry litter compost and both hydroseeded treatments were statistically lower than the biosolids compost but greater than the remaining treatments. There was no significant difference between the MSW compost, the yard waste compost and the control.

By the second storm event, three months later, all treatments showed major reductions in nitrate nitrogen concentrations in the runoff. Only the biosolids compost (11.82 mg L^{-1}) and hydroseeded treatments (6.96 and 3.25 mg L^{-1}) had runoff nitrate nitrogen levels appreciably higher than the control (1.42 mg L^{-1}). However, only the biosolids compost and hydroseed with silt fence were significantly different than the control. Furthermore, the biosolids compost was significantly different from all other treatments, while the hydroseed with silt fence was statistically greater than all treatments excluding the biosolids compost and hydroseed with mulch berm treatments.

By the final storm event there was little difference between the treatments or the control, as all nitrate nitrogen levels were between 0.26 and 0.49 mg L^{-1}. Again, the mulch filter berm did not appear to reduce the nitrate nitrogen concentration in the runoff of the hydroseed treatments. Like the concentration of total nitrogen in the runoff, the hydroseeded treatments and the biosolids compost may pose concern after the first storm event, but not by the third storm. It is likely that most nitrate nitrogen was either taken up by plants or already lost in the runoff from the first storm for most treatments (and possibly minor amounts lost to denitrification – particularly because the treatments were saturated from the first storm event creating anaerobic conditions favorable to denitrification), and certainly for all treatments after the second storm. It should be noted that the yard waste compost and MSW compost treatments did not have appreciable concentrations of nitrate nitrogen in the runoff during any storm event. This may make these composts more desirable for erosion control measures near surface waters and environmentally sensitive areas.

Nitrate N loads were comparatively similar to nitrate nitrogen concentrations. The biosolids compost had the greatest nitrate nitrogen loss at 2,568 mg/m^2, followed by the hydroseed with mulch berm at 797 mg/m^2, the hydroseed with silt fence at 644 mg, the poultry litter compost at 527 mg/m^2, the yard waste compost at 88 mg/m^2, the control at 53 mg/m^2 and the MSW compost at 3 mg/m^2 (Table 5.2 and Figure 4.2). The biosolids compost and hydroseeded treatments were significantly different from the control. Again, the biosolids compost was significantly greater than all other treatments, and the hydroseeded treatments were significantly different from all but the poultry litter compost. The amount of nitrate nitrogen loss by each treatment was reflective of the amount of nitrate in the treatment at the time of application. In addition, these loads were calculated *as they came off the treatments*, these loads would be significantly reduced once the runoff traveled over land and entered into any surface water (if indeed it reaches surface water). Treatments with high nitrate N loads may not be desirable for use adjacent to, or potentially in, surface water.

By the second storm event, major nitrate N load reductions were observed in all treatments excluding the control and the MSW compost, which had comparatively low losses from the first storm. Only the hydroseed with silt fence (172 mg/m^2) and the biosolids compost (126 mg/m^2) had measurably higher nitrate N loads than the control (60 mg/m^2), although differences were not statistically significant. The other three compost treatments had extremely low loads of nitrate N, between 3 to 9 mg/m^2, partly because they generated relatively little runoff during this storm event, an attribute that makes them attractive for other storm water management applications.

During the final storm event, one year later, the control had the highest losses of nitrate N in the runoff, followed by both hydroseeded treatments. This was probably due to the higher volume of runoff produced by these treatments. All compost treatments lost less than half the amount of nitrate N as the control, ranging between 5 mg/m^2 and 10 mg/m^2. Parallel to previous discussion, the MSW compost and yard waste compost may be more desirable in applications near surface water, as the nitrate N loads from these treatments were similar to a bare soil throughout the study. After the first storm event, there would be reduced concern of nitrate N loading from the poultry litter compost and hydroseed with mulch berm applications as well. After the second storm event there is little concern for any of these treatments on nitrate N loading of lakes, rivers or streams.

Table 5.2: Average nitrate N concentration (mg L^{-1}) and average nitrate N load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n=3.

	DAY ONE	THREE MONTHS	TWELVE MONTHS

Treatment	AVG	SD	LOAD	AVG	SD	LOAD	AVG	SD	LOAD
PLC/Mulch/Gypsum	17.20b	3.57	526.8bc	0.68c	0.98	2.9a	0.32cd	0.09	4.7c
Biosolids Compost	67.37a	2.89	2568.3a	11.82a	5.78	126.1a	0.43abc	0.10	9.7bc
MSW Compost/Mulch	0.10c	0.08	3.4d	1.53c	2.65	8.5a	0.26d	0.09	5.7c
Yardwaste Compost	2.77c	0.93	88.2cd	1.45c	1.46	6.8a	0.34bcd	0.02	8.4bc
Hydroseed/Mulch Berm	21.79b	4.53	796.4b	3.25bc	2.74	64.3a	0.45ab	0.01	15.4ab
Hydroseed/Silt Fence	15.05b	12.22	644.3b	6.96b	1.56	171.6a	0.49a	0.09	13.8abc
Bare Soil (not seeded)	1.28c	0.47	53.4cd	1.42c	0.52	60.1a	0.49a	0.05	20.1a

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

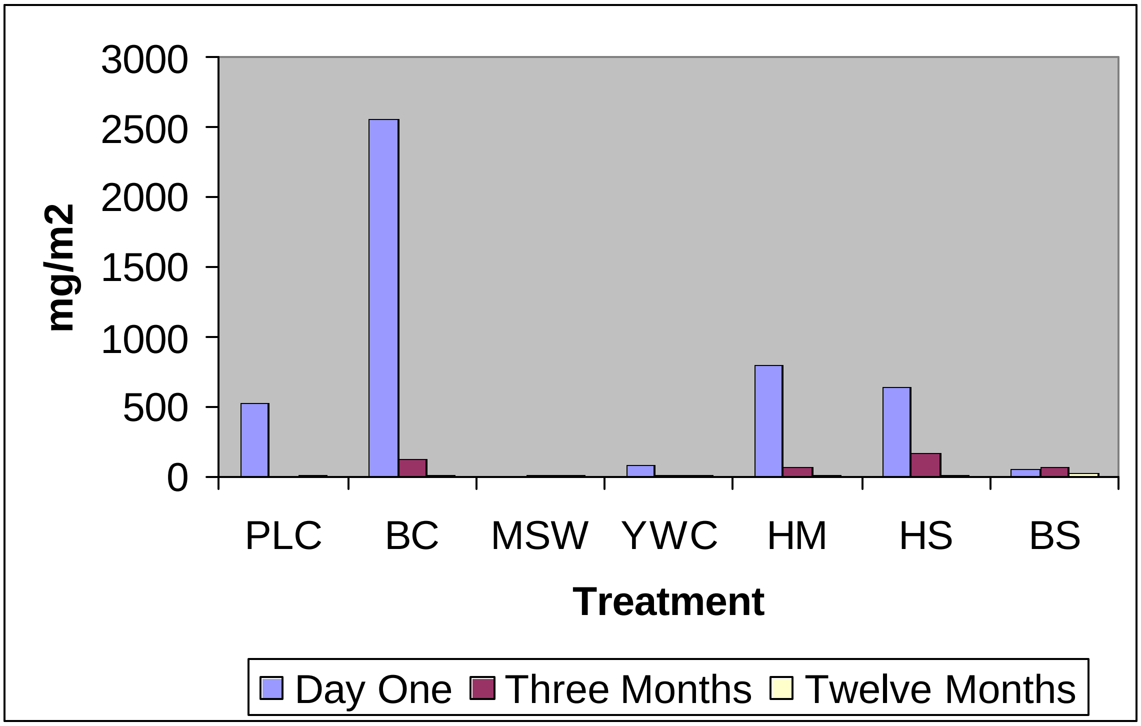


Figure 4.2: Average nitrate N load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n = 3.

Ammonium Nitrogen Concentrations and Loads

During the first storm event ammonium N concentrations in runoff were highest from the biosolids compost at 36.6 mg L^{-1}, followed by the hydroseed with silt fence at 29.1 mg L^{-1}, the MSW compost at 13.5 mg L^{-1}, the hydroseed with mulch berm at 10.2 mg L^{-1}, the poultry litter compost at 2 mg L^{-1}, the yard waste compost at 0.7 mg L^{-1} and finally the control at 0.4 mg L^{-1} (Table 5.3). The biosolids compost and hydroseed with silt fence treatments were found to be significantly different than the control. The high concentrations of ammonium N in the runoff from the biosolids compost and the hydroseeded treatments are likely a result of the relatively high levels of ammonium N in the treatments at the time of application. In addition, this data may indicate that a mulch filter berm can be effective in filtering ammonium N from storm runoff; however, further replication would be required to draw definitive conclusions. Also, the blending of wood mulch with the poultry litter compost may have been partly responsible for the comparatively low levels of ammonium N in the runoff. The moderate levels of ammonium loss by the MSW compost may be because of its high pH (8.1), which attracts base forming cations like ammonium N.

During the second storm event ammonium N concentrations in the runoff were appreciatively lower for the biosolids compost (9.8 mg L^{-1}) and hydroseeded treatments (0.8 and 0.4 mg L^{-1}); however, the biosolids compost remained significantly different from the control. All other treatments including the control ranged from 0.35 to 1.48 mg L^{-1}. Again, this was likely due to plant uptake and losses from the previous storm. By the final storm event, there appeared to be little difference in runoff ammonium N concentrations between treatments. The poultry litter compost had the highest concentrations at 0.71 mg L^{-1}, followed by the control at 0.36 mg L^{-1}, the biosolids compost at 0.20 mg L^{-1}, and the hydroseed with silt fence at 0.19 mg L^{-1}. The remaining treatments had concentrations under the detectable limit. Differences between treatments during the final storm event were not statistically significant.

Based on this study, using yard waste compost as an erosion control measure, would have about the same ammonium N concentration in the runoff as a bare soil, during the first *large* storm event after application; while the hydroseeded treatments, biosolids compost, and MSW compost may pose a risk if used directly adjacent to or potentially in surface water. After the first large storm, the hydroseed treatments would likely no longer pose a risk, and after the second storm none of these treatments would pose a risk from ammonium N concentrated runoff. It is interesting to note that ammonium N would still be elevated in the biosolids compost runoff three months after application (this may be an indication that the material was not well composted prior to the study). Often ammonium N transforms to nitrite and then to nitrate N through nitrification within several weeks (and during the curing phase of the composting process) unless pH levels are high (they were not), this may be why ammonium N concentrations were lower overall relative nitrate N concentrations during the second storm event. Another reason ammonium N concentrations can be lower is that ammonium N adsorbs to clay and humus colloids (both were in abundance – mature composts have high humus content), unlike nitrate N, making it less susceptible to loss in runoff. Additionally, plants and microorganisms would likely take up extra ammonium N.

Ammonium N loading may be a better indicator of the potential pollution of ammonium N released from these experimental treatments during a storm event. During the first storm the biosolids compost generated the highest ammonium N loads at 1400 mg/m^2, followed by the hydroseed with silt fence at 536 mg/m^2, the hydroseed with mulch berm at 406 mg/m^2, the MSW compost at 298 mg/m^2, the poultry litter compost at 52 mg/m^2, the yard waste compost at 26 mg/m^2 and finally the control at 18 mg/m^2 (Table 5.3). Again, the biosolids compost and hydroseed with silt fence treatments were significantly different than the control. Additionally, the biosolids compost was significantly different than all other treatments, while hydroseed with silt fence was significantly different from each of the compost treatments.

By the second storm event ammonium N loads decreased to levels below the control for all treatments except the biosolids compost, which remained the only treatment significantly different from the control (Figure 4.3). This was likely due to the comparatively high volumes of runoff produced by the control, as well as the relatively high content of ammonium N in the biosolids compost treatment. By the final storm event, only the poultry litter compost (17 mg/m^2) had slightly greater ammonium N losses than the control (15 mg/m^2), although the difference was not statistically significant.

Under field application, all but the biosolids compost treatment would have a negligible effect on ammonium N loading of surface water after the first *large* storm event. In fact, because of reductions in runoff volumes of these treatments, relative to the control, there may be less ammonium N loading from these erosion control measures than a bare soil.

Table 5.3: Average ammonium N concentration (mg L^{-1}) and average ammonium N load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n=3.

	DAY ONE			THREE MONTHS			TWELVE MONTHS		
Treatment	AVG	SD	LOAD	AVG	SD	LOAD	AVG	SD	LOAD
PLC/Mulch/Gypsum	2.02b	1.56	51.9c	0.66b	0.59	5.0b	0.71a	0.80	16.5a
Biosolids Compost	36.62a	2.17	1400.6a	9.79a	1.05	89.3a	0.20a	0.11	5.5a
MSW Compost/Mulch	13.51b	1.48	298.2bc	0.95b	1.65	5.3b	UDL	UDL	UDL
Yardwaste Compost	0.72b	0.63	26.0c	1.48b	0.76	8.9b	UDL	UDL	UDL
Hydroseed/Mulch Berm	10.17b	___	406.2bc	0.79b	1.35	14.6b	UDL	UDL	UDL
Hydroseed/Silt Fence	29.13a	18.58	535.8b	0.37b	0.52	2.8b	0.19a	___	5.2a
Bare Soil (not seeded)	0.42b	0.12	18.4c	0.35b	0.49	22.6b	0.36a	0.15	14.9a

UDL = under detectable limit; treatments with same letter are not significantly different at α = 0.05 using Duncan's Multiple Range test.

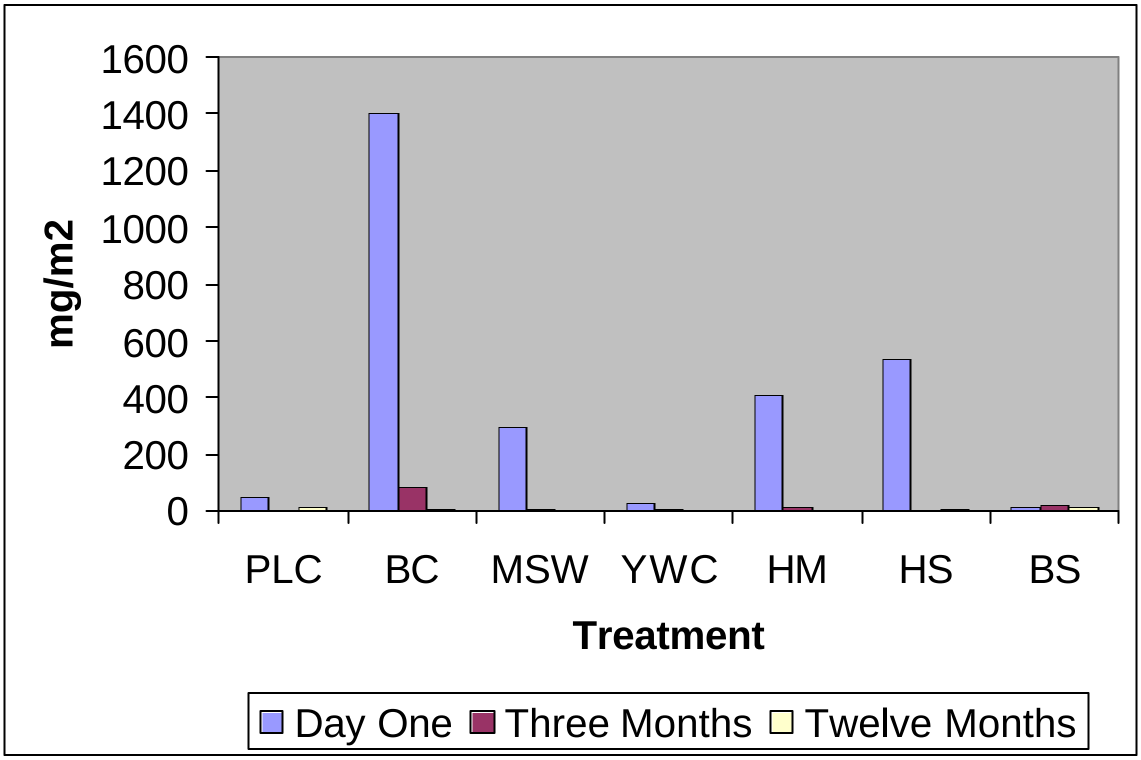


Figure 4.3: Average ammonium N load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n = 3.

Total Phosphorus Concentrations and Loads

While phosphorus is not toxic to animals and humans it is one of the main causes of eutrophication in surface water, which can lead to impaired water quality. Total phosphorus concentrations generally used for wastewater treatment plant discharges is 5 mg L^{-1}, while the critical concentration of total P (particulate P + dissolved P) in streams at which eutrophication is triggered is 0.10 mg L^{-1}, and 0.03 mg L^{-1} for dissolved P (Brady and Weil, 1996). The total amount of phosphorus applied by each treatment was 95 g/m^2 from the poultry litter compost, 85 g/m^2 from the biosolids compost, 23 g/m^2 from the MSW compost, 61 g/m^2 from the yard waste compost, and 10 g/m^2 from the hydroseeding.

During the first storm event, immediately after treatment application, total phosphorus concentration in the runoff was highest in the hydroseeded treatments, 25.87 mg L^{-1} from the hydroseed with mulch berm and 22.4 mg L^{-1} from the hydroseed with silt fence (Table 5.4). This was probably due to the high degree of soluble P fertilizer in the initial hydroseed mixture. All treatments, including the four compost treatments, had higher concentrations of total P in the runoff than the control, although only the hydroseeded treatments were statistically different than the control. The biosolids compost treatment had the highest total P runoff concentration among the composts with 4.13 mg L^{-1}, followed by the poultry litter compost at 3.07 mg L^{-1}. The MSW compost and yard waste composts had the lowest total P concentrations among the composts, with 2.19 and 2.15 mg L^{-1}, respectively. It appeared that the mulch filter berm did not reduce total P concentrations compared to silt fence among the hydroseeded treatments.

During the second storm event, three months after treatment application, all treatments had reductions in total P concentration in runoff with the exception of a slight increase from the control and the biosolids compost treatment. Only the biosolids compost was significantly different than the control by this storm event. The hydroseeded treatments showed the greatest decrease in total P concentrations in the runoff, probably because most if it was already lost after the first storm event while the vegetation took up lesser amounts and/or it moved into the soil profile. The biosolids compost had the highest concentrations of total P at 6.3 mg L^{-1} (up from 4.13 mg L^{-1}), followed by the hydroseed with silt fence at 1.64 mg L^{-1}, the yard waste compost at 1.61 mg L^{-1}, the poultry litter compost at 1.58 mg L^{-1}, and the hydroseed with mulch berm at 1.42 mg L^{-1}. The MSW compost treatment had lower total P concentrations in the runoff during the second storm event than the control.

During the third storm event, one year after the first storm, all treatments had reduced concentrations of total P in the runoff from the first and second storm events, with the exception of the control and MSW compost, which showed very slight increases. The biosolids compost continued to have the highest total P concentration at 1.96 mg L^{-1} followed by the poultry litter compost at 1.039 mg L^{-1}. The biosolids compost remained the only treatment significantly different than the control, while the poultry litter compost was significantly different than the yard waste compost and hydroseed with mulch berm treatments. The yard waste compost had the lowest concentrations during the final storm event at 0.479 mg L^{-1}, followed closely by the hydroseed with mulch berm at 0.485 mg L^{-1}, the MSW compost at 0.532 mg L^{-1}, the control at 0.642 mg L^{-1} and finally the hydroseed the silt fence at 0.704 mg L^{-1}.

Table 5.4: Average total P concentration (mg L^{-1}) and average total P load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n=3.

	DAY ONE			THREE MONTHS			TWELVE MONTHS		
Treatment	AVG	SD	LOAD	AVG	SD	LOAD	AVG	SD	LOAD
PLC/Mulch/Gypsum	3.073b	1.403	86.7c	1.582b	1.374	16.2a	1.039b	0.029	16.5ab
Biosolids Compost	4.125b	0.265	156.7bc	6.298a	0.592	53.9a	1.962a	0.498	46.2a
MSW Compost/Mulch	2.192b	0.251	33.2c	0.450b	0.779	7.5a	0.532bc	0.278	11.9b
Yardwaste Compost	2.152b	0.279	70.1c	1.610b	0.567	10.3a	0.479c	0.112	12.5b
Hydroseed/Mulch Berm	25.867a	13.241	924.7a	1.420b	0.309	27.7a	0.485c	0.145	17.5ab
Hydroseed/Silt	22.398a	6.077	483.0b	1.635b	0.563	41.0a	0.704bc	0.364	20.5ab

Fence									
Bare Soil (not seeded)	0.015b	0.003	0.6c	0.490b	0.046	22.0a	0.642bc	0.257	26.9ab

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Total phosphorus runoff loads were similar to total P concentrations with the exception of the third storm event when runoff totals where comparatively high due to saturated soils created from preceding natural rainfall. During the first storm event the hydroseeded treatments had the highest total P runoff loads, 925 mg/m^2 from the hydroseed with mulch berm and 483 mg/m^2 from the hydroseed with silt fence treatment, both were significantly different from the control and the four composts (Table 5.4). Among the compost treatments the biosolids compost had the highest P loads in the runoff at 156 mg/m^2, followed by the poultry litter compost at 87 mg/m^2, the yard waste compost at 70 mg/m^2, and the MSW compost at 33 mg/m^2. The control had the lowest total P loads at 0.6 mg/m^2. It appeared that the mulch filter berm did not reduce total P loss compared to silt fence among the hydroseeded treatments. Finally, while differences were not significant, the poultry litter compost with gypsum had less P loss than the biosolids compost although treatment concentrations of P were similar. This may give some evidence that calcium sulfate (gypsum) can reduce P losses from compost blankets; however, more testing is needed to draw any conclusions.

During the second storm event, three months later, all treatments, with the exception of the control, had major reductions in total P loads in the runoff. Again the hydroseeded treatments had the greatest reductions between the first and second storm events. The biosolids compost had the highest total P loads during the second storm event at 54 mg/m^2, followed by the hydroseed with silt fence at 41 mg/m^2, the hydroseed with mulch berm at 28 mg/m^2, the control at 22 mg/m^2, and the poultry litter compost at 16 mg/m^2. The MSW compost had the lowest total P loads followed by the yard waste compost at 7 mg/m^2 and 10 mg/m^2, respectively; however, there were no significant differences between treatments during this storm event.

By the final storm event, the biosolids compost continued to have the highest total P loads in the storm runoff at 46 mg/m^2 followed by the control at 27 mg/m^2. The MSW compost and yard waste compost continued to have the lowest total P loads at 12 mg/m^2 and 13 mg/m^2, respectively. Although not significantly different from the control, the biosolids compost was significantly different from these two composts. Both hydroseeded treatments continued to have higher total P loads than the poultry litter compost in the storm runoff. Total P lost in the runoff as a percent of the total P applied from the treatments for all three storms combined was 9.7% from the hydroseed with mulch berm, 5.4% from the hydroseed with silt fence, 0.4% from the biosolids compost, 0.2% from the MSW compost, and 0.1% for both the yard waste compost and poultry litter compost. See Figure 4.4 for total P loads in the storm runoff for all treatments and storm events.

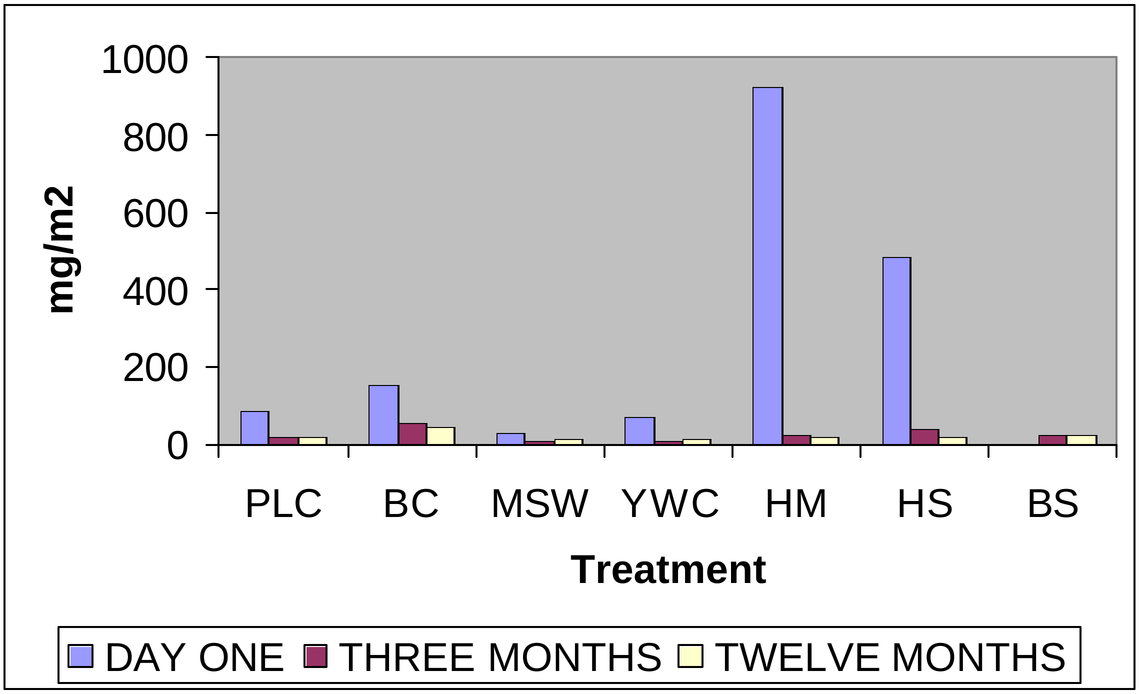


Figure 4.4: Average total P load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n = 3.

Dissolved Reactive Phosphorus Concentrations and Loads

During the first storm event, just after treatment application, the runoff concentrations of dissolved reactive phosphorus (DRP) were highest among the hydroseeded treatments, 24.19 mg L^{-1} from the hydroseed with mulch berm and 19.24 mg L^{-1} from the hydroseed with silt fence treatment (Table 5.5). These were the only treatments significantly different than the control for this storm event. As with total P concentrations, the biosolids compost had the highest DRP concentrations among the compost treatments at 3.72 mg L^{-1}, followed by the poultry litter compost at 2.68 mg L^{-1}. Again the MSW compost had the lowest DRP concentrations after the control, 0.20 and 0.01 mg L^{-1} respectively. These results were interesting for several reasons. First, it is well documented that highly weathered clay soils (like Fe/Al oxides represented in this study) have a relatively high capacity to fix dissolved P (as PO_4^-), and it is likely that most of the dissolved P in hydroseed comes in contact with the soil which should create a higher propensity for the soluble P from hydroseeding to adsorb to clay colloids and become insoluble and unavailable. Second, organic matter (much higher in the compost treatments) can inhibit the adsorption of dissolved P to soil colloids by physically blocking exchange sites, chelating Fe and Al - thus preventing reaction with P ions, and organic acids can displace P ions by filling up potential exchange sites on clay particle surfaces. These conditions are more favorable for P loss from compost than hydroseed; however, the results indicate just the opposite. Finally, it appeared that the mulch filter berm did not reduce DRP concentrations compared to silt fence among the hydroseeded treatments.

By the second storm event, three months later, the biosolids compost and the poultry litter compost had the highest DRP concentrations due to major reductions from the hydroseeded treatments relative to the first storm event. The biosolids compost had the highest concentration at 5.94 mg L^{-1}, while the poultry litter compost was 1.29 mg L^{-1}. The yard waste compost and two hydroseeded treatments ranged from 1.02 to 1.18 mg L^{-1}. The MSW compost and control were virtually unchanged at 0.235 and 0.009 mg L^{-1}, respectively. Statistically, all composts, except the MSW compost, were significantly different from the control. The biosolids compost was significantly different from the rest of the composts as well. The statistical difference between the biosolids compost and the poultry litter compost may be the result soluble P in the poultry litter compost reacting with the gypsum (calcium sulfate), but further evaluation would be required to draw conclusions. In addition, the low DRP concentrations from the MSW compost may be the result of the high pH (8.1) of this compost, which would reduce its solubility because of adsorption to Ca and Mg. Finally, the minor increase in DRP concentration of the biosolids compost from the first to the second storm event could be from minor acidification caused by the rainfall, which could lead to an increase in the solubility of P.

By the final storm event, one year after the first event, all treatments showed reductions in DRP concentrations with the exception of the MSW compost and control, which showed slight increases. The biosolids compost again had the highest concentrations at 1.65 mg L^{-1}, followed by the poultry litter compost treatment at 0.86 mg L^{-1}, the control at 0.47 mg L^{-1}, the hydroseed with silt fence at 0.44 mg L^{-1}, the hydroseed with mulch berm at 0.38 mg L^{-1}, the yard waste compost at 0.37 mg L^{-1}, and finally the MSW compost at 0.33 mg L^{-1}. Both the biosolids compost and poultry litter compost were significantly different from the control, and from each other. The major reduction in DRP concentrations in the runoff of the hydroseeded treatments between the first and second storm events was probably due to the same factors that led to the reductions in the concentration of total P.

Table 5.5: Average DRP concentration (mg L^{-1}) and average DRP load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n=3.

	DAY ONE			THREE MONTHS			TWELVE MONTHS		
Treatment	AVG	SD	LOAD	AVG	SD	LOAD	AVG	SD	LOAD
PLC/Mulch/Gypsum	2.68b	1.261	75.3c	1.293b	1.121	13.4a	0.863b	0.022	13.7b
Biosolids Compost	3.722b	0.406	141.2bc	5.935a	0.480	51.4a	1.652a	0.348	37.8a
MSW Compost/Mulch	0.204b	0.079	2.7c	0.235bc	0.407	3.9a	0.332c	0.068	7.4b
Yardwaste Compost	1.738b	0.246	56.5c	1.176b	0.355	7.7a	0.366c	0.117	9.7b
Hydroseed/Mulch	24.194a	12.753	865.6a	1.059bc	0.434	20.3a	0.382c	0.140	13.8b

Berm									
Hydroseed/Silt Fence	19.240a	5.461	412.0b	1.015bc	0.452	26.7a	0.444c	0.162	12.8b
Bare Soil (not seeded)	0.013b	0.001	0.54c	0.009c	0.015	0.33a	0.466c	0.056	19.4ab

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Dissolved reactive phosphorus runoff loads were similar to DRP concentrations with the exception of the third storm event when runoff totals where comparatively high due to saturated soils created from natural rainfall just prior to the simulated storm. During the first storm event DRP loads were highest among the hydroseeded treatments, 866 mg/m^2 lost from the hydroseed with mulch berm treatment and 412 mg/m^2 lost from the hydroseed with silt fence treatment (Table 5.5). Both were significantly different from the control. Again, the biosolids compost had the highest DRP losses among the compost treatments with 141 mg/m^2, followed by the poultry litter compost at 75 mg/m^2 and the yard waste compost at 57 mg/m^2. The control had the least DRP loss at 0.5 mg/m^2 followed closely by the MSW compost at 3 mg/m^2. It appeared that the mulch filter berm did not reduce DRP loads compared to silt fence in the hydroseeded treatments.

During the second storm event, all treatments, with the exception of the MSW compost, had major reductions in DRP loss, particularly among the hydroseeded treatments. The biosolids compost showed the greatest DRP loss with 51 mg/m^2, followed by the hydroseed with silt fence at 27 mg/m^2, the hydroseed with mulch berm at 20 mg/m^2, the poultry litter compost at 13 mg/m^2, and finally the yard waste compost with 8 mg/m^2. Again the control had the lowest DRP load with 0.3 mg/m^2 followed by the MSW compost at 4 mg/m^2 (up from 2.7 mg/m^2). None of these differences were statistically significant.

During the final storm event, DRP loads had decreased relative to the first storm event but were similar to the second storm event, probably due to the increased runoff volumes experienced during this storm. Only the hydroseeded and biosolids compost treatments showed DRP load reductions between the second and final storm event. The biosolids compost had the highest DRP loads at 38 mg/m^2, followed by the control with 19 mg/m^2, the hydroseed with mulch berm at 13.8 mg/m^2, the poultry litter compost at 13.7 mg/m^2, the hydroseed with silt fence at 12.8 mg/m^2, the yard waste at 10 mg/m^2, and finally the MSW compost at 7 mg/m^2. Interestingly, the biosolids compost was significantly different from all other treatments except the control – likely due to the high runoff volumes generated by the control. See Figure 4.5 for DRP loads among treatments and between storm events.

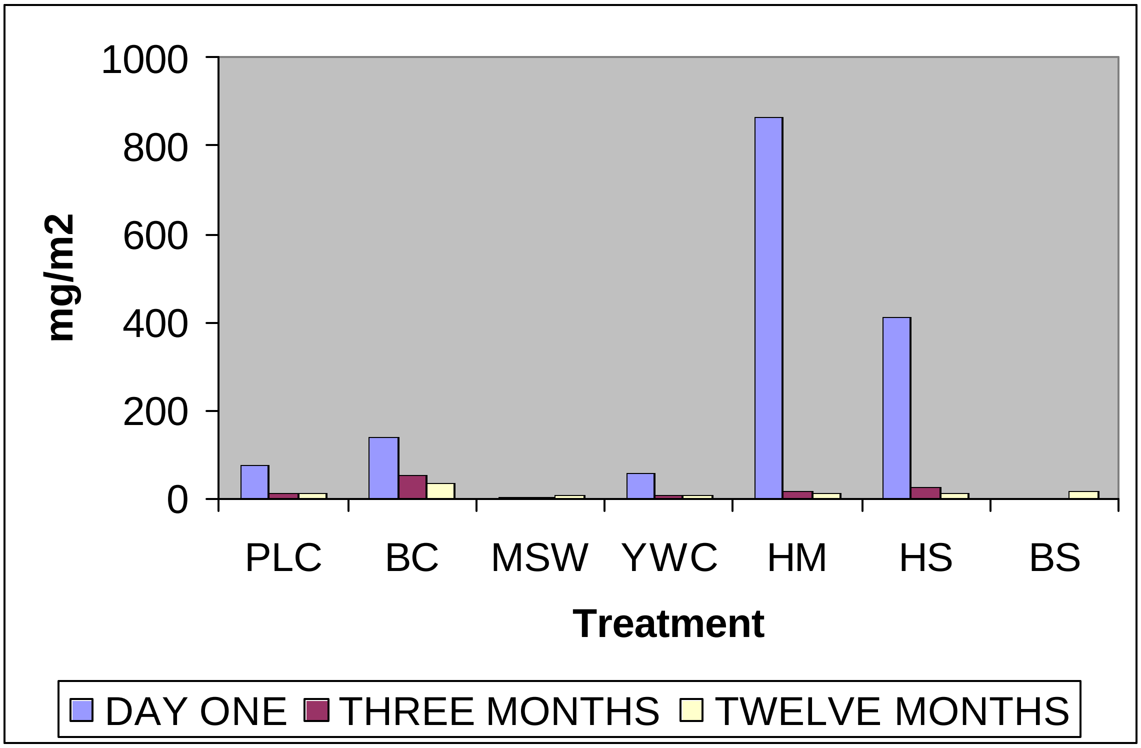


Figure 4.5: Average DRP load (mg/m^2) in runoff by treatment at day one, three months and twelve months, n = 3.

Dissolved Reactive Phosphorus to Total Phosphorus Load Ratio

Another way to look at P loss is to calculate the DRP to total P load ratio, particularly because DRP is bioavailable while not all total P is bioavailable. It is DRP that reacts immediately with plants causing eutrophication while the remaining P (that attached to sediment) is not immediately bioavailable. A ratio of 1.0 signifies 100% of the total P lost was in the form of DRP. During the first storm event the DRP:total P of the control was 0.9 (Table 5.6). The biosolids compost, poultry litter compost, and both hydroseeded treatments had similar ratios. The hydroseed with mulch berm treatment had the highest ratio of 0.94 while the MSW compost had the lowest ratio at 0.08, signifying that most of the P lost from the hydroseed was bioavailable while most lost from the MSW compost was not.

By the second storm event, all DRP to total P ratios declined, with the exception of the MSW compost and biosolids compost treatments. The control and hydroseeded treatments showed the greatest decline between the first and second storm events. The biosolids compost had the highest DRP:total P loss, while MSW compost had the lowest (except for the control). During the final storm event, the poultry litter compost, biosolids compost, yard waste compost and hydroseed with mulch all had similar DRP:total P loss ratios, while the MSW compost and hydroseed with silt fence continued to have lower ratios relative to the other treatments.

Table 5.6: Average DRP to total P load ratio in runoff by treatment at day one, three months and twelve months, n=3.

Treatment	DAY ONE	THREE MONTHS	TWELVE MONTHS
PLC/Mulch/Gypsum	0.87	0.83	0.83
Biosolids Compost	0.90	0.95	0.82
MSW Compost/Mulch	0.08	0.52	0.62
Yardwaste Compost	0.81	0.75	0.78
Hydroseed/Mulch Berm	0.94	0.73	0.79
Hydroseed/Silt Fence	0.85	0.65	0.62
Bare Soil (not seeded)	0.90	0.02	0.72

Correlation Analysis

Results from correlation analysis (Table 5.7) were used to evaluate which of the treatment physical, chemical, and biological characteristics, and rainfall and vegetation growth results (independent variables) were correlated with the parameters from nutrient loss results (response variables). Only those that were highly correlated (r>0.70) are reported. Results from the first storm event show that total N, nitrate N, and ammonium N concentrations and loads were all highly correlated to the ammonium N and nitrate N content of the compost treatment. Generally, the higher the nitrate and/or ammonium N content of the compost the greater the loss of that nutrient in the runoff.

Total P and DRP concentrations and loads from the first storm event were correlated to organic matter content, C content and C:N of the compost treatments. Generally, the higher the organic matter content, C content, and C:N of the compost the lower the P concentration and load in the resulting storm runoff; however, the yard waste compost did have comparatively low organic matter, C and C:N along with relatively low losses of P. This may indicate that some dissolved inorganic P in the runoff reacted with humus colloids in the compost treatments or that microorganisms immobilized some dissolved inorganic P because of insufficient P relative to C. This may also be an indication that composts with a higher percentage of organic P relative to soluble P (although not directly tested) in compost can lead to less P loss. Also interesting to note (although not well correlated in this analysis), is that the compost treatments that lost the most P had near neutral pH, while the MSW compost and yard waste compost pH levels were near 8.0, potentially meaning that the P was not as mobile in the latter composts because it was bound to Ca and Mg. Additionally, the higher the total P concentration in the compost, the greater the concentration and load in the runoff.

Analysis from the second storm event still show a high correlation with total N concentrations, nitrate N concentrations, ammonium N concentrations, and ammonium N loads with nitrate and ammonium content of the compost treatment. Additionally, the nitrate N concentration, ammonium N concentration, and ammonium N load was correlated to the number of weed species and weed plants at this time period. Generally, the greater the ammonium N loss in the runoff, the greater the number of weed species and weed plants in the treatment. A similar trend was found with nitrate N loss as well. This may signal that composts higher in ammonium N and nitrate N are more susceptible to weed growth; additionally, ammonium N in compost is often a signal that it has not been composted sufficiently which can also lead to inadequate elimination of weed seeds during the composting process.

Interestingly, the parameters correlated to total P losses and DRP losses during the second storm were not the same as the first storm. Total P concentration, DRP concentration and DRP loads were correlated to nitrate N and ammonium N contents of the compost as well as the number of weed species and weed plants present (excluding DRP loads). The greater the number of weed plants and weed species, the higher the total P concentration, DRP concentration, and DRP load in the runoff. These correlations may signify that composts high in P are more susceptible to weed growth and that generally if compost is high in P it is more likely to have a relatively high ammonium N and nitrate N content as well (at least among these four composts).

During the final storm event total P and DRP concentrations were correlated to nitrate N and ammonium N content of the compost and to the number of weed species and percent cover of weeds during the storm event. Generally, the higher the total P and DRP concentration in the runoff, the higher the ammonium N and nitrate N content in the compost, and the fewer the number of weed species growing the compost treatment.

Table 5.7: Results from correlation analysis. This table lists all response variables with significant correlation (r>0.70, α = 0.05, n = 21).

Response Variable	**Independent Variable (treatments) with Correlation Coefficient**
Total N concentration, Storm #1	NH_4(0.92), NO_3(0.92)
Total N load, Storm #1	NH_4(0.93), NO_3(0.92)
Nitrate-N concentration, Storm #1	NH_4(0.94), NO_3(0.94)
Nitrate-N load, Storm #1	NH_4(0.94), NO_3(0.93)
Ammonium-N concentration, Storm #1	NH_4(0.99), NO_3(0.98),
Ammonium-N load, Storm #1	NH_4(0.97), NO_3(0.96)
Total P concentration, Storm #1	OM(0.74), C(0.73), C:N ratio (0.88)
Total P load, Storm #1	OM(0.72), C(0.72), C:N ratio (0.89)
DRP concentration, Storm #1	OM(0.70), C(0.69), C:N ratio (0.88)
DRP load, Storm #1	OM(0.71), C(0.769), C:N ratio (0.88)
Total N concentration, Storm #2	NH_4(0.91), NO_3(0.91)
Nitrate-N concentration, Storm #2	NH_4(0.84), NO_3(0.82), # of weed species(0.76), # of weed plants (0.76)
Ammonium-N concentration, Storm #2	NH_4(0.96), NO_3(0.96), # of weed species(0.88), # of weed plants (0.88)
Ammonium-N load, Storm #2	NH_4(0.71), NO_3(0.70), # of weed species(0.69), # of weed plants (0.70)
Total P concentration, Storm #2	NH_4(0.93), NO_3(0.93), # of weed species(0.82), # of weed plants (0.82)
DRP concentration, Storm #2	NH_4(0.95), NO_3(0.95), # of weed species(0.84), # of weed plants (0.84)
DRP load, Storm #2	NH_4(0.73), NO_3(0.72)
Total P concentration, Storm #3	NH_4(0.85), NO_3(0.88), # of weed species(0.79), # of weed plants (0.83)
DRP concentration, Storm #3	NH_4(0.88), NO_3(0.91), # of weed species(0.85), # of weed plants (0.89)

Summary and Conclusion

Based on this study, materials high in ammonium N and nitrate N will release greater amounts of each form of nitrogen in storm runoff, in both concentration and load. These materials showed reduced N loss over time, particularly after the first storm event; however, high N content composts and hydroseeding applications may still have elevated levels of N in the runoff during the next large storm event. Over time, N losses from composts and hydroseed treated soils returned to background levels. Total N lost in the runoff as a percent of the total applied by the composts after three large storms ranged between 0.7 and 3.9% compared to 12.2 to 15.3% for the hydroseeded treatments. Additionally, composts high in ammonium N and Nitrate N may be more susceptible to weed growth. It does not appear that mulch filter berms substantially reduce total N or nitrate N in runoff from hydroseeded applications; however, there may be evidence that mulch berms can filter ammonium N from storm water runoff. For professionals utilizing compost blankets it is recommended that composts have a high percentage of organic N content relative to inorganic N to avoid pollution from runoff.

Based on this study, soil application of hydroseeding can lead to high P concentrations and loads in storm runoff. However, this may only be a concern for the first storm event after application. Generally, composts pose a much lower risk than hydroseeding, particularly just after application. However, it appears that composts with high P concentrations can have elevated P losses in runoff, even after the first storm event, but unlikely after a second large storm. Additionally, it appears that blending ground gypsum wallboard (calcium sulfate) may reduce P losses from compost blankets, although more testing is needed to draw conclusions. Composts with low P concentrations are the best insurance for reducing P losses and preventing P from entering surface waters. In addition, composts high in organic matter and C may reduce P loading. This may provide evidence that composts with a higher relative content of organic P, compared to plant available P, may have lower total P losses in runoff. Additionally, no more than 0.4% of the total P applied by compost was lost in storm runoff from three large storm events. It does not appear from this study that mulch filter berms substantially reduce P losses from hydroseeding applications. Finally, compost high in ammonium N, nitrate N and/or exhibit relatively prolific weed growth may indicate that runoff P concentrations may be elevated but not P loads.

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APPENDIX E

RESULTS AND DISCUSSION: SOIL QUALITY

According to a review of the literature, applications of compost can benefit overall soil quality. Although the principal objective of the experimental treatments is to evaluate their effect on erosion and sediment control, the quality of the soil underneath these treatments may have an effect on their ability to provide effective storm water management. Soil characteristics such as increased water infiltration rates, reduced bulk density, increased organic matter content, neutralized pH levels, increased nutrient contents, and increased microbiological populations all can benefit the long term health of vegetation, which is essential to preventing soil erosion and subsequent sedimentation. The sustained growth of healthy vegetation, in this type of application, will serve to increase soil quality characteristics over time, creating a sustainable cycle of perpetually increasing soil quality and plant growth with a net effect of reducing runoff and steadily reducing soil loss. Unfortunately, little attention is given to soil quality in storm water management applications and/or the erosion and sediment control industry. A paradigm shift toward a focus on sustainable soil quality would have monumental affects on the improvement of our water quality and our approach to managing storm water and other water resources. See Materials and Methods (Appendix A) for complete sampling procedures and analytical methods.

Bulk Density

Soil bulk density from 0-7.5 cm (0-3 in) was measured at the beginning of the study and after a year and a half. The first measurement was taken before treatment application, while the second measurement was sampled underneath the compost blanket (e.g. at the compost and soil interface). At first sampling, all soils prior to treatment application classified as “restrictive for root growth” (USDA, 1998). Soil bulk densities were consistent among the compost treatments and the hydroseed with mulch berm treatment, ranging from 1.99 to 2.1 g/cm^3. The hydroseed with silt fence and control treatments had slightly denser soils of 2.24 and 2.23 g/cm^3, respectively, although there were no differences statistically between any treatments.

Eighteen months after treatment application, soil bulk densities decreased in all but the poultry litter compost, which was unchanged, and the MSW compost, which increased slightly (Table 6.1, Figure 5.1). The hydroseed with silt fence followed by the control showed the greatest reduction in soil bulk density, 1.92 and 1.99 g/cm^3, respectively. Of the compost treatments, the biosolids compost showed the greatest reduction in soil bulk density over the eighteen-month period, from 2.1 to 1.94 g/cm^3. All bulk density levels were still classified as such that would “restrict root growth” (USDA, 1998). Soils underneath the MSW compost and yard waste composts were the densest, while soils under both hydroseeded treatments had the lowest bulk densities. No statistically significant differences were observed.

Although reductions in soil density were observed, they appeared to be slight. This was probably due to the unusually high density of the soils, as less dense soils would allow more organic matter and compost to infiltrate the soil surface and subsequent soil horizons over time, thus reducing overall bulk density. In addition, less dense soils would allow for better root penetration, as there is evidence that although root growth was substantial in the compost blankets, roots did not penetrate the soil surface, presumably because of soil density characteristics. A longer period of time may show a gradual reduction in soil bulk densities in all treatments due to prolonged root growth and with the compost treatments, organic matter infiltration into the soil surface. Soil bulk densities may have decreased to a greater degree in the hydroseeded treatments because there was no other growing medium where plant roots could establish. Perhaps the compost blankets were thick enough and provided adequate nutrients and moisture so plant roots did not need to exploit the hardened soil for additional resources.

Table 6.1: Average soil bulk density (g/cm^3) and average water infiltration rate of soil (minutes/cm) by treatment at six months and eighteen months by treatment at day one and eighteen months, n=3.

	DAY ONE		EIGHTEEN MONTHS		SIX MONTHS			EIGHTEEN MONTHS		
Treatment	AVG	SD	AVG	SD	AVG	SD	Class	AVG	SD	Class
PLC/Mulch/Gypsum	1.99a	0.301	1.99a	0.244	8.73a	4.45	Moderately Rapid	125.78a	85.24	Slow
Biosolids Compost	2.1a	0.41	1.94a	0.06	6.59a	9.66	Moderately Rapid	86.22a	54.58	Moderately Slow
MSW Compost/Mulch	2.08a	0.104	2.11a	0.193	17.24a	15.26	Moderate	139.33a	63.32	Slow
Yardwaste Compost	2.1a	0.25	2.0a	0.075	16.26a	9.87	Moderate	128.67a	23.10	Slow
Hydroseed/Mulch Berm	2.01a	0.251	1.93a	0.131	31.11a	27.44	Moderate	102.44a	68.83	Moderately Slow
Hydroseed/Silt Fence	2.24a	0.243	1.92a	0.165	25.16a	19.14	Moderate	82.0a	45.11	Moderately Slow
Bare Soil (not seeded)	2.23a	0.165	1.99a	0.165	3.96a	2.7	Rapid	38.44a	5.0	Moderate

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

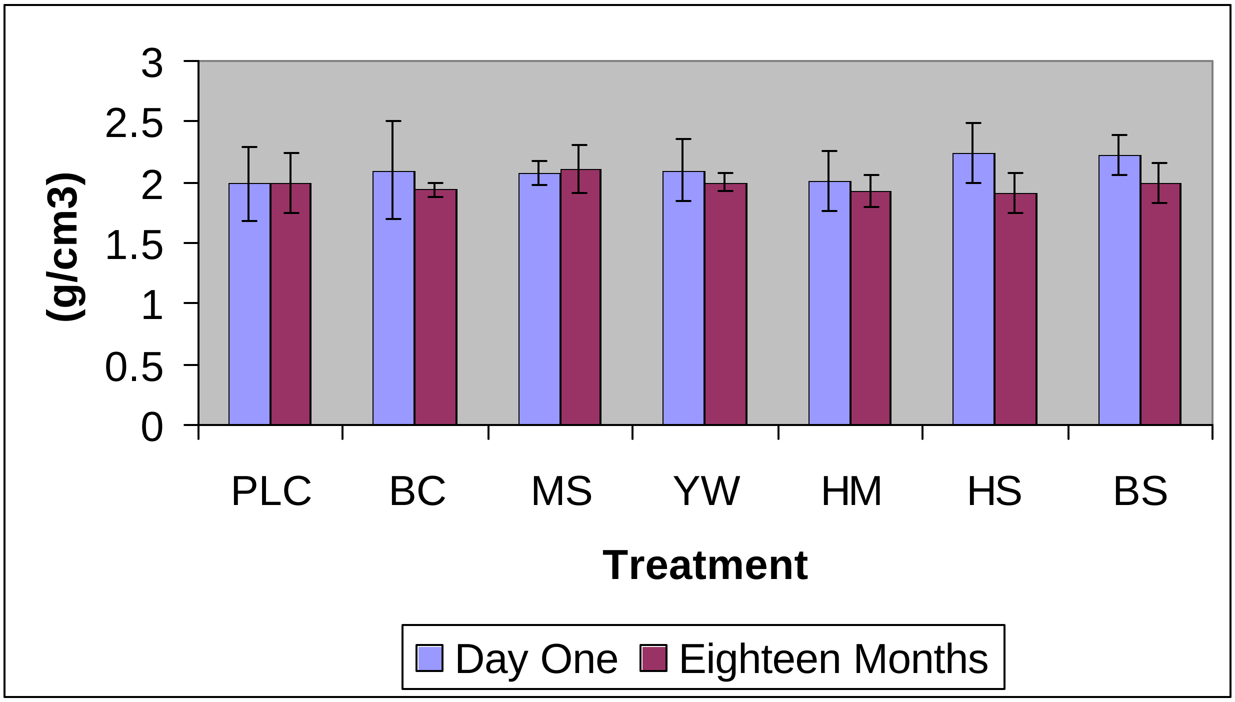

Figure 5.1: Average soil bulk density (g/cm^3) by treatment at day one and eighteen months, n = 3.

Water Infiltration Rate

Soil water infiltration rates were taken at six months and eighteen months after the beginning of the study. It was decided after the first set of soil samples that infiltration rate would supplant aggregate stability, because it would provide a more accurate analysis of the soil's ability to "handle" storm water. In addition, soil aggregate stability was no longer evaluated after the initial sampling due to suspect results - likely due to the extremely dense nature of the subsoil tested. Water infiltration rate of the soil after six months was faster under all compost blanket treatments compared to hydroseeded treatments (Table 6.1). The biosolids compost had the fastest infiltration rate, followed by the poultry litter compost, yard waste compost and MSW compost, respectively. Although, the bare soil control showed the fastest infiltration rates it is believed this was due to water leakage underneath the infiltration ring, as it was not possible to insert the ring to its proper soil depth because the soil surface was so hard, this did not occur for any other treatment. The same was true during the eighteen-month water infiltration test.

Water infiltration rates at eighteen months were much slower overall than after six months (Figure 5.2). This was probably due to the extreme dry nature of the soil at six months (The test plots had no natural rainfall for nearly four months, and it was the middle of the summer) compared to the eighteen-month sampling period. The hydroseed with silt fence plots had the highest infiltration rate, followed by the biosolids compost, hydroseed with mulch berm, poultry litter compost, yard waste compost and MSW compost, respectively; although differences were not significant. The biosolids compost and hydroseeded treatments were classified as "moderately slow"; the remaining treatments were all classified as "slow" according to a USDA infiltration rate classification system (1998).

Better performance by the hydroseeded treatments during the eighteen-month testing period, compared to the compost treatments, may be due to increased soil penetration by the grass roots, even though, differences were not significant. Based on visual inspection, grass roots established very well within the compost blankets but did not penetrate the underlying soil well, probably because the compost provided a better or sufficient growing medium for the grass roots. The hydroseeded plots had no soil amendment; therefore grass roots were forced to penetrate through the dense soil to survive. This root penetration may have led to increased water infiltration rates at the soil surface for the hydroseeded treatments. This would not be true if water infiltration rate tests had included the composts blankets.

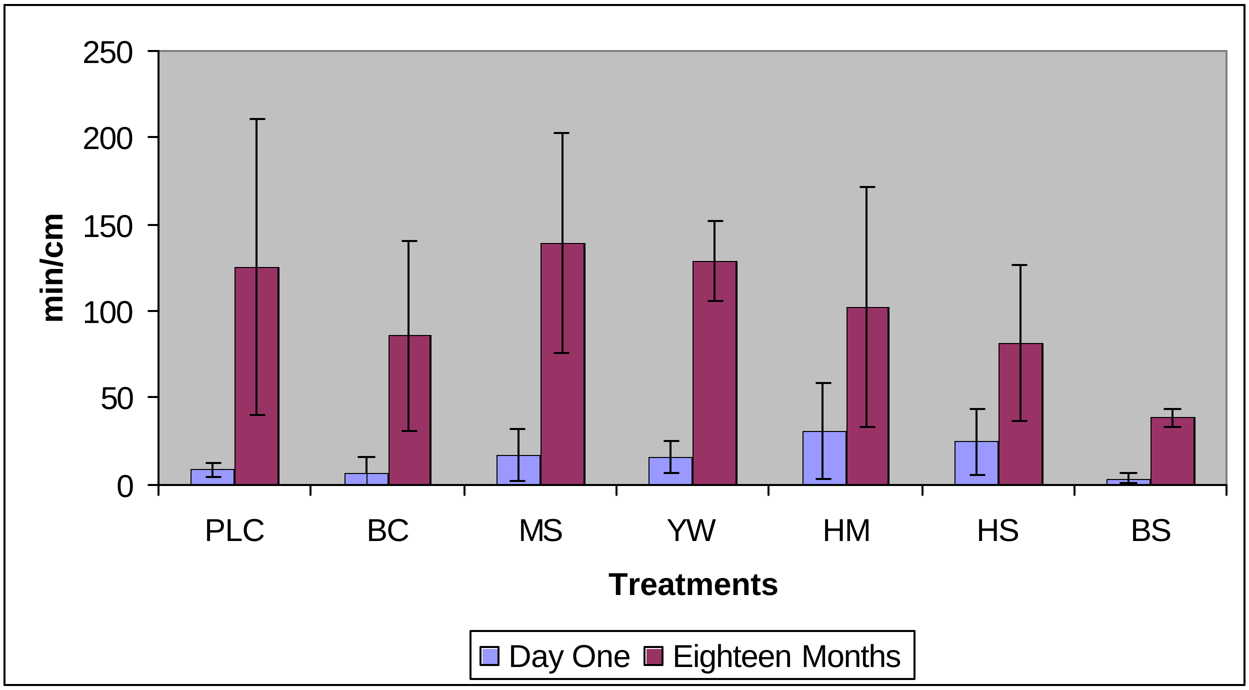

Figure 5.2: Average water infiltration rate of soil (minutes/cm) by treatment at six months and eighteen months, n = 3.

Extractable Organic Carbon

Extractable organic soil carbon was evaluated at the 0-5 cm (0-2 in) horizon as an estimate of the soil microbial biomass of the soil. Six months after treatment application soil organic carbon levels were highest in the control at 33.74 mg kg^{-1}, followed closely by MSW compost treatment at 32.71 mg kg^{-1} and the hydroseed with mulch treatment at 30.74 mg kg^{-1} (Table 6.2). The biosolids compost treatment had the lowest total organic carbon levels at 18.46 mg kg^{-1}, followed by the poultry litter compost at 19.09 mg kg^{-1}. Differences were not statistically significant.

Eighteen months after treatment application (one year after the previous soil analysis) soil extractable organic carbon levels had increased in all treatments including the control. The MSW compost had the highest soil organic carbon levels at 93.95 mg kg^{-1}, followed by the biosolids compost at 58.88 mg kg^{-1} and the hydroseed with mulch berm treatment at 58.74 mg kg^{-1}. The yard waste compost had the lowest levels at 41.2 mg kg^{-1}, followed by the hydroseed with silt fence at 48.34 mg kg^{-1}. The control was 50.78 mg kg^{-1}. The MSW compost was significantly greater than the rest of the treatments during this sample period.

Between sample periods (one year duration) the MSW compost showed the greatest increase in total soil organic carbon levels followed by biosolids compost and the poultry litter compost treatments. The yard waste compost showed the lowest increas followed by the control. With the exception of the yard waste compost, the compost treatments showed a greater increase than the hydroseeded treatments and the control; however, only the MSW compost was significantly greater than the hydroseeded treatments (Figure 5.3). The biosolids treatment was significantly greater than the control. Based on extractable organic carbon analyis, MSW compost and biosolids compost increase soil microbial biomass under these soil conditions.

Table 6.2: Average soil extractable organic carbon (mg kg^{-1}) from by treatment at six months and eighteen months, n=3.

	SIX MONTHS		EIGHTEEN MONTHS		ONE YR CHANGE
Treatment	AVG	SD	AVG	SD	AVG
PLC/Mulch/Gypsum	19.09a	17.08	57.4b	16.96	38.31bc
Biosolids Compost	18.46a	12.32	58.88b	0.37	40.42ab
MSW	32.71a	8.09	93.95a	13.46	61.24a

Compost/Mulch					
Yardwaste Compost	27.02a	12.33	41.2b	9.4	14.18d
Hydroseed/Mulch Berm	30.74a	15.99	58.74b	24.63	28.0bcd
Hydroseed/Silt Fence	28.36a	14.69	48.34b	11.44	19.98bcd
Bare Soil (not seeded)	33.74a	22.38	50.78b	12.8	17.04cd

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

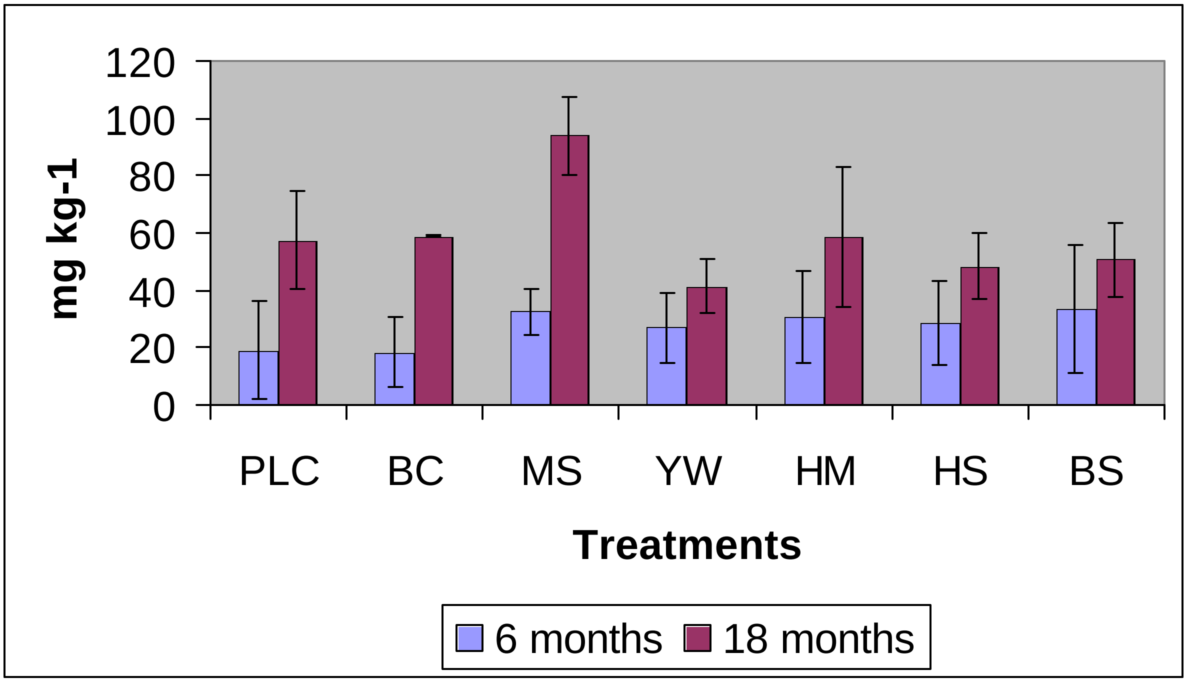

Figure 5.3: Average soil extractable organic carbon (mg kg^{-1}) by treatment at six months and eighteen months, n = 3.

Surface Chemical, pH and Organic Matter Characteristics

Soil core samples taken from the soil surface to a depth of 5 cm (2 in) were analyzed for total carbon, total nitrogen, C:N ratio, total phosphorus, plant available phosphorus, potassium, calcium, pH, and organic matter at the beginning of the study, six months, and after eighteen months (Table 6.3).

Total Carbon

Initial total carbon analysis of soils prior to application of treatments showed the control had the highest soil carbon content at 7350 mg kg^{-1}, followed closely by the hydroseed with silt fence and MSW compost treatments, respectively. The yardwaste compost plots had the lowest soil carbon content at 3503 mg kg^{-1}, followed by the hydroseed with mulch and biosolids compost treatments, respectively. Six months after treatment application the MSW compost treatment had the highest soil carbon content at 9367 mg kg^{-1} followed by the poultry litter compost at 8250 and the biosolids compost at 7667 mg kg^{-1}. The hydroseeded treatments had the lowest soil carbon content followed by the control. Over the six month time period all compost treatments had increased soil carbon contents, notably the yard waste compost treatment more than doubled. During the same time period there was a slight reduction in soil carbon for both hydroseeded treatments and the control. Eighteen months after treatment application the poultry litter compost had the highest soil carbon levels at 14,270 mg kg^{-1} followed by the MSW compost and hydroseed with silt fence treatments, respectively. Again the control experienced a slight reduction in soil carbon levels, as well as the biosolids compost, from the previous soil sampling. The greatest increases in soil carbon were found in the poultry litter compost followed by both hydroseeded treatments. After eighteen months all treatments had higher levels of soil carbon compared to the control.

The greatest increase in soil carbon over the eighteen-month study period was shown in the poultry litter compost treatment, increasing from 5833 to 14270 mg kg^{-1}, followed by the yard waste compost, 3503 to 7480 mg kg^{-1}, and the hydroseed with mulch berm treatment, 5023 to 8050 mg kg^{-1}. The control was the only treatment that experienced a decrease in soil carbon content over the entire study period. Differences between treatments were not statistically significant at any time period; however, the increase in soil C from the poultry litter compost over the eighteen-month study period was significantly different.

Total Nitrogen

Initial soil analysis for total nitrogen from the 0-5 cm (2 in) soil samples showed little variation in soil N levels prior to treatment application (Table 6.3). The plots to be treated with MSW compost had the highest levels at 627 mg kg^{-1}, while the plots to be treated with yard waste compost had 353 mg kg^{-1}. Six months after treatment application little change was noticed in soil N levels. The poultry litter compost, MSW compost, both hydroseeded treatments, and the control all showed slight decreases in soil N levels. The yard waste compost and biosolids compost treatments showed slight increases. Overall, the poultry litter compost and MSW compost had the highest soil N levels after six months, followed closely by the biosolids compost. Three of the four highest soil N levels after six months were from compost treatments while the control had the lowest levels.

After eighteen months the control still had the lowest soil N levels, followed by the yard waste compost and hydroseed with mulch berm treatments, respectively. The poultry litter compost continued to have the highest levels of soil N followed by the MSW compost and hydroseed with silt fence treatments, respectively. Between the last two sample periods the poultry litter compost was the only treatment that showed an increase in soil nitrogen. The same is true from the beginning to the end of the eighteen-month study period. However, no differences observed were statistically significant for any sampling period.

Carbon to Nitrogen Ratio

Soil carbon to nitrogen ratios prior to treatment application ranged from a high of 14.04 in the control to a low of 8.22 with the yard waste treatment (Table 6.3). No significant differences were observed. Six months after treatment application C:N ratios increased for all treatments, including the control, with the exception of the hydroseed with silt fence treatment. The yard waste compost treatment showed the greatest increase followed by the poultry litter compost and MSW compost treatments, respectively. All four compost treatments showed greater increases than the hydroseeded treatments and the control. Overall, the bare soil treatment had the highest C:N ratio followed closely by the MSW compost and yard waste compost treatments. The hydroseeded treatments had the lowest soil C:N ratios followed by the poultry litter compost after six months. Statistically, the control and the MSW compost were significantly different than the hydroseed with silt fence treatment.

By eighteen months the yard waste compost had the highest C:N ratio followed by the hydroseed with mulch and poultry litter compost treatments. The biosolids compost had the lowest C:N ratios followed by the MSW compost and hydroseed with silt fence treatments. From the six month sampling period to the end of the study the yard waste compost showed the highest increase in soil C:N ratio followed closely by the hydroseed with mulch berm and then the poultry litter compost treatment. The MSW compost and biosolids compost showed less increase in C:N ratio than the control.

Over the entire study period all treatments including the control showed increased soil C:N ratios. The yard waste compost exhibited the greatest increase in soil C:N ratio followed by the poultry litter compost and the hydroseed with mulch treatment, respectively. The lowest increases were found in the biosolids compost and MSW compost treatments. Although significant differences were observed from the six-month sample period, none were observed from the eighteen month sample period.

Total Phosphorus

Total phosphorus levels of the soil sampled at the 0-5 cm (2 in) horizon, prior to treatment application, ranged from a high of 449 mg kg^{-1}, where the yard waste composts were to be applied, to a low of 348 mg kg^{-1} in the control (Table 6.3). No significant differences were found. Six months after treatment application total soil P levels increased under all treatments. The hydroseeded treatments had the highest levels of total P as well as the greatest increase over the six-month period. The hydroseed with mulch berm had a total soil P level of 590 mg kg^{-1} and the hydroseed with silt fence had an average of 568 mg kg^{-1}, both significantly different than the control. All four compost treatments were similar in range, from 475 mg kg^{-1} under the yard waste compost to 433 mg kg^{-1} under the biosolids compost. Among the compost treatments, the MSW compost increased soil total P the most, while the yard waste compost had the smallest increase, over the six-month period. The control had the lowest soil total P during this sample period at 358 mg kg^{-1}.

After eighteen months total soil P levels, from the 0 to 5 cm (2 in) horizon, increased for all treatments compared to the previous sample period, with the exception of the control. The hydroseeded treatments had the highest total P levels, which were significantly greater than the control. The hydroseeded treatments had the greatest increase in surface soil total P from the previous sample period and were the only treatments that showed a significant increase in P over the eighteen month study period. Among the compost treatments, the MSW compost had the highest total soil P at 534 mg kg^{-1} as well as the greatest increase, while the poultry litter compost had the lowest soil total P at 479 mg kg^{-1}, and the least increase. The control decreased to 325 mg kg^{-1}. The high level of soil total P in the hydroseeded treatments was probably due to the high level of P fertilizer in the initial hydroseed mixture. It is interesting to note that it continued to increase after six months from an initial one-time application at the beginning of the experiment. This relatively high level of soil total P near the soil surface by the hydroseeded treatments over the eighteen-month period may contribute to prolonged P loss in runoff.

Plant Available Phosphorus

Plant available phosphorus from the 0 to 5 cm (2 in) soil horizon, prior to treatment application, was quite low, ranging from 36 mg kg^{-1} under the future hydroseed with silt fence application to 17 mg kg^{-1} where the yard waste compost treatments would soon be applied (Table 6.3). No significant differences were found. Six months after treatment application the hydroseeded treatments showed the greatest increase and highest levels of plant available P, additionally, they were the only treatments significantly different than the control. Among the compost treatments, the biosolids compost showed the greatest increase and highest level of plant available P. The yard waste compost had the lowest level of plant available P; however, the poultry litter compost showed the least increase between the sample periods. The control was the only treatment that showed a slight decrease in plant available P at this time.

After eighteen months, all treatments showed appreciable declines in plant available P from the previous sample period; however, the hydroseeded treatments showed a net gain in surface plant available P from the beginning of the study. These gains were significantly different from the control, poultry litter compost and MSW compost treatments. The hydroseeded treatments maintained the highest levels of plant available P, followed by the biosolids compost. The yard waste compost had the lowest plant available P levels, followed closely by the MSW compost and the control at the end of the eighteen-month study period. The only treatments that were significantly different were the yard waste compost and the hydroseed with silt fence treatment. As with soil total P levels, plant available P in the soil was high in the hydroseeded treatments probably because of the plant available P fertilizer included in the initial hydroseed mixture. The increasing level of soil plant available P near the soil surface by the hydroseeded treatments over the eighteen-month period may contribute to prolonged P loss in runoff, particularly if it does not adsorb to soil colloids. All four compost treatments exhibited decreased soil plant available P over the eighteen-month period. This may be because the P in mature compost is typically in organic form and less available until it is mineralized.

Potassium

Soil potassium at the 0 to 5 cm horizon was very similar among treatments prior to treatment application (Table 6.3). No significant differences were observed. Levels ranged from a low of 130 mg kg^{-1} in the control, to a high of 157 mg kg^{-1} in the hydroseed with mulch berm treatment. Six months after treatment application soil K was virtually unchanged, with no more than 2 mg kg^{-1} difference in any treatment between the two sampling periods. As expected, no significant differences were found.

Eighteen months after treatment application soil K levels declined in the control and biosolids compost treatments, while the remaining three compost treatments showed slight increases in soil K. The poultry litter compost treatment increased soil K the most among the compost treatments, but only by 18 mg kg^{-1}. Overall, the greatest increases in soil K were found by the hydroseeded treatments, likely due to the potassium fertilizer included in the initial hydroseed mixture. The hydroseed with silt fence treatment had the highest soil K level at 236 mg kg^{-1}, an increase of 86 mg kg^{-1} from the previous sampling period (one year prior). Statistically, this was the only treatment that was significantly different from the control.

Calcium

Soil calcium levels at the 0 to 5 cm horizon were quite similar prior to treatment application, with a low of 173 mg kg^{-1} from the control to high of 217 mg kg^{-1} from the hydroseed with silt fence treatment (Table 6.3). No significant differences were found. Six months after treatment applications soil Ca levels were virtually unchanged, with no more than 3 mg kg^{-1} variation from the initial soil analysis. The control continued to have the lowest soil Ca at 170 mg kg^{-1} and the hydroseed with silt fence treatment had the highest soil Ca at 218 mg kg^{-1}. Still no statistically significant differences were found.

Eighteen months after treatment application, all treatments showed increases in soil Ca content with the exception of the control and biosolids compost, which showed minor decreases. The hydroseeded treatments showed the highest levels of soil Ca and the greatest increase from the previous soil analyses. Of the compost treatments, the MSW compost and poultry litter compost had the highest soil Ca, 573 mg kg^{-1} and 464 mg kg^{-1}, respectively. The MSW compost and the hydroseeded treatments were significantly different than the control. The biosolids compost had the lowest soil Ca of the compost treatments at 158 mg kg^{-1}, while the control was 64 mg kg^{-1}. The increased levels of soil Ca in the hydroseeded treatments could be a result of the lime in the application mixture. Likewise, the increase in soil Ca from the poultry litter compost treatment may be from the gypsum addition.

pH

Soil pH levels at the 0 to 5 cm horizon were very similar among treatments prior to treatment application (Table 6.3). Levels ranged from a low of 5.54 in the yard waste compost and biosolids compost treatments to a high of 5.67 in the MSW compost treatments. Differences were not statistically significant. After six months, all treatments including the control, showed an increase. The MSW compost treatment had the highest soil pH at 6.52, followed by the poultry litter compost and hydroseed with mulch berm, respectively. Each of these treatments was significantly different from the control, and the two compost treatments were significantly different from the biosolids compost. The control had the lowest soil pH followed by the biosolids compost treatment. The poultry litter compost and MSW compost treatments showed the greatest increase after six months, while the control followed by the biosolids compost showed the lowest increases.

After eighteen months, the MSW compost treatment had the highest soil pH at 7.03, followed by the hydroseeded treatments at 6.77 and 6.65. The biosolids compost had the lowest pH at 6.16, followed by the poultry litter compost at 6.4. The pH of the control was 6.42. Statistically, the MSW compost was the only treatment significantly different from the control, additionally, it was significantly different from the other three compost treatments. This is likely due to the higher initial pH of the MSW compost relative to the others. As well, the hydroseeded treatments were significantly different from the biosolids and poultry litter compost treatments, likely due to the lime included in the hydroseed application.

All treatments increased soil pH throughout the study period. The greatest increase in soil pH over the entire study period was found with the MSW compost followed by both hydroseeded treatments. The lowest increase was found with the biosolids compost, followed by the control and poultry litter compost treatment. The reason for the lower increase from the biosolids compost was probably due to the relatively low pH of the treatment itself; the converse was true for the MSW compost. Increases in soil pH at this depth, over the length of the experiment, may have increased the amount of soluble P near the soil surface, increasing both vegetative growth and/or P losses in the runoff. Both were characteristic to the hydroseeded treatments.

Organic Matter

Soil organic matter levels analyzed from 0 to 5 cm into the soil, prior to treatment application, ranged from a low of 3.91 g kg^{-1} in the control to a high of 4.95 g kg^{-1} in the poultry litter compost treatment (Table 6.3). Differences were not statistically significant. Six months after treatment application, soils treated with yard waste compost had the highest organic matter levels at 5.23 g kg^{-1}, followed by the MSW compost at 4.77 g kg^{-1}, and the poultry litter compost at 4.63 g kg^{-1}. The control had the lowest soil organic matter at 4.01 g kg^{-1}, followed closely by the hydroseed with silt fence at 4.03 g kg^{-1}. The MSW compost and yard waste compost were the only treatments to show an increase over the six-month period. Eighteen months after treatment application the MSW compost had the highest soil organic matter, followed by the poultry litter compost and hydroseed with silt fence, respectively. The control remained lowest in soil organic matter followed by the hydroseed with mulch berm and the biosolids compost treatment, respectively.

Over the entire study period the MSW compost, followed by the yard waste compost showed the greatest increase in soil organic matter. The poultry litter compost and hydroseed with silt fence also showed some increase in soil organic matter, while the control virtually stayed the same. Interestingly, the hydroseed with mulch berm and biosolids compost showed slight declines in soil organic matter at the 0 to 5 cm level. Although it appeared that most treatments did increase soil organic matter levels, particularly among the compost treatments, these differences were not statistically significant from the control.

Table 6.3: Selected soil chemical characteristics from 0-5 cm (0-2 in) by treatment at day one, six months and eighteen months, n=3.

	DAY ONE						SIX MONTHS						EIGHTEEN MONTHS						1.5 YR CHANGE
Characteristic	Total C (mg kg^{-1})		Total N (mg kg^{-1})		C:N Ratio		Total C (mg kg^{-1})		Total N (mg kg^{-1})		C:N Ratio		Total C (mg kg^{-1})		Total N (mg kg^{-1})		C:N Ratio		Total C (mg kg^{-1})
Treatment	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg
PLC/Mulch/Gypsum	5833	3900	593	331	9.34	3.16	8250	3748	585	177	13.77ab	2.2	14270	12830	670	680	25.89	10.1	8437a
Biosolids Compost	5543	3711	476	205	10.31	4.37	7667	4219	553	298	13.83ab	0.56	7380	4490	370	180	18.84	3.82	1837ab
MSW Compost/Mulch	7143	2467	627	319	11.99	2.38	9367	1762	583	127	16.1a	0.68	9580	1210	480	130	20.58	2.92	2437ab
Yardwaste Compost	3503	3679	353	181	8.22	4.96	7033	3350	470	286	15.7ab	1.9	7480	2206	290	180	30.58	12.0	3977ab
Hydroseed/Mulch Berm	5023	3705	400	175	11.2	4.87	4800	400	367	116	12.59ab	2.36	8050	2110	310	130	27.44	5.81	3027ab
Hydroseed/Silt Fence	7347	3709	560	275	12.84	0.90	6033	560	490	150	11.79b	3.26	8500	3170	400	220	22.99	4.91	1153ab
Bare Soil (not seeded)	7350	1247	526	101	14.04	0.64	6367	526	393	140	16.2a	2.52	5950	1160	260	28	24.95	0.88	-1400b

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 6.3 (cont.): Selected soil chemical characteristics from 0-5 cm (0-2 in) by treatment at day one, six months and eighteen months, n=3.

	DAY ONE				SIX MONTHS				EIGHTEEN MONTHS				1.5 YR CHANGE	
Characteristic	Total P (mg kg^{-1})		Plant available P (mg kg^{-1})		Total P (mg kg^{-1})		Plant available P (mg kg^{-1})		Total P (mg kg^{-1})		Plant available P (mg kg^{-1})		Total P (mg kg^{-1})	Plant available P (mg kg^{-1})
Treatment	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	Avg
PLC/Mulch/ Gypsum	415.33	69.86	29.67	25.11	463ab	165	44ab	15	479ab	100	12ab	10	63.67b	-17.67
Biosolids Compost	389.67	71.74	32.67	24.83	433ab	34	76ab	35	486ab	84	16ab	12	96.33b	-16.67
MSW Compost/ Mulch	398.33	58.35	29.0	8.89	463ab	120	48ab	24	534ab	222	7ab	3	135.67ab	-22.0
Yardwaste Compost	449.33	83.05	16.67	13.28	475ab	80	41ab	20	501ab	92	4b	2	51.67b	-12.67
Hydroseed/ Mulch Berm	441.67	75.22	20.67	15.31	590a	46	141a	108	728a	141	32ab	28	286.33a	11.33
Hydroseed/ Silt Fence	402.33	33.5	35.67	26.31	568a	121	139a	56	691a	166	47a	47	288.67a	11.33
Bare Soil (not seeded)	347.67	30.09	32.67	8.5	358b	83	25b	17	325b	56	7ab	2	-22.67b	-25.67

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 6.3 (cont.): Selected soil chemical characteristics from 0-5 cm (0-2 in) by treatment at day one, six months and eighteen months, n=3.

	DAY ONE				SIX MONTHS				EIGHTEEN MONTHS			
Characteristic	K (mg kg^{-1})		Ca (mg kg^{-1})		K (mg kg^{-1})		Ca (mg kg^{-1})		K (mg kg^{-1})		Ca (mg kg^{-1})	
Treatment	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
PLC/Mulch/Gypsum	143.33	25.17	210	40	142.0	25.24	211.33	38.5	160ab	86.2	464.3abc	254.3
Biosolids Compost	133.33	25.17	206.67	25.17	132.33	25.77	204.0	25.94	81b	43.3	158bc	62.2
MSW Compost/Mulch	133.33	5.77	213.33	65.06	132.33	4.16	212.0	65.51	135.7ab	50.0	573.3ab	96
Yardwaste Compost	140.0	26.46	190	60.83	137.67	28.54	189.67	60.96	152.7ab	14.0	420.3abc	86.2
Hydroseed/Mulch Berm	156.67	25.17	186.67	20.82	157.67	26.76	186.0	18.68	206ab	99.2	629.7ab	471.3
Hydroseed/Silt Fence	150.0	40.0	216.67	32.15	150.0	44.0	217.67	29.87	235.7a	111.8	868.7a	358.6
Bare Soil (not seeded)	130.0	17.32	173.33	30.55	131.67	15.37	170.33	32.19	90.3b	52.4	64.3c	39.7

	DAY ONE				SIX MONTHS				EIGHTEEN MONTHS			
Characteristic	pH		OM (g kg^{-1})		pH		OM (g kg^{-1})		pH		OM (g kg^{-1})	
Treatment	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
PLC/Mulch/Gypsum	5.58	0.27	4.95	1.05	6.44a	0.3	4.63	2.91	6.4bc	0.16	5.37	0.88
Biosolids Compost	5.54	0.22	4.69	0.44	5.86bc	0.14	4.3	1.83	6.16c	0.23	4.56	0.24
MSW Compost/Mulch	5.67	0.17	4.35	1.09	6.52a	0.33	4.77	2.06	7.03a	0.23	5.69	2.43
Yardwaste Compost	5.54	0.11	4.36	0.36	6.17abc	0.14	5.23	1.43	6.46bc	0.08	4.99	0.57
Hydroseed/Mulch Berm	5.6	0.11	4.67	0.26	6.31ab	0.46	4.4	1.46	6.65ab	0.27	4.28	0.62
Hydroseed/Silt Fence	5.66	0.26	4.59	0.51	6.17abc	0.16	4.03	1.2	6.77ab	0.10	5.03	1.44
Bare Soil (not seeded)	5.6	0.37	3.91	0.76	5.68c	0.16	4.01	1.18	6.42bc	0.39	3.95	1.04

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Chemical, pH and Organic Matter Characteristics from 0 to 15 cm

Soil core samples taken from the soil surface to a depth of 15 cm (6 in) were analyzed for pH, organic matter, phosphorus, potassium, calcium, magnesium, manganese, and zinc at the beginning of the study and after eighteen months (end of study) (Table 6.4).

pH

Initial soil pH levels, prior to treatment application, had little variability, ranging from a low of 4.6 (yard waste compost) to a high of 4.8 (MSW compost). After eighteen months pH levels increased in the soils under all treatments, including the control. The poultry litter compost and MSW compost treatments increased the most over the study period from 4.67 to 5.43 and 4.8 to 5.47, respectively. The least amount of change was observed under the hydroseed with mulch berm treatment, 4.73 to 5.07, followed by the control, 4.7 to 5.13. The difference between the poultry litter compost and the hydroseed with mulch berm treatment was statistically significant. Overall, soil pH levels at this soil depth did not increase as much as soil pH levels from the 0 to 5 cm horizon. In addition, soil pH levels remained low enough to keep soil P insoluble and therefore unavailable to plants or subject to losses in runoff.

Organic Matter

The soil organic matter levels for all treatments were similar at the beginning of the study, ranging from 2.4 (biosolids compost) to 2.65 g kg^{-1} (yard waste compost). These differences were not statistically significant. The percentage of soil organic matter was relatively unchanged in all but the poultry litter compost and biosolids compost treatments, the latter was significantly different than the control. The soil organic matter under the biosolids compost plots increased the most from 2.4 to 3.5 g kg^{-1}, and with the exception of the poultry litter compost, was significantly greater than all other treatments. The hydroseeded treatments and the control showed minor decreases in soil organic matter after the year and half, while the hydroseed with silt fence was also significantly different than the biosolids compost. This may give evidence that compost can increase soil organic matter through the soil profile, while hydroseed applications do not - and may exhibit reductions in soil organic matter until sufficient litter from the vegetation and roots contribute to building soil organic matter.

Total Phosphorus

Soil phosphorus levels were also very similar prior to the application of the treatments, ranging from 2.49 to 4.3 mg kg^{-1}. The treatments did appear to have an affect on the soil P over the eighteen-month study period. The biosolids compost increased the most from 3.56 to 34.04 mg kg^{-1}, followed by the poultry litter compost from 4.3 mg/kg^{-1} to 21.55 mg/kg^{-1}, the hydroseed with mulch berm from 2.96 mg kg^{-1} to 20.88 mg kg^{-1}, and the hydroseed with silt fence from 3.81 mg kg^{-1} to 15.78 mg kg^{-1}. The yard waste compost and the MSW compost increased slightly, while the control showed a slight decrease in soil P. Increased levels of soil P were probably the result of P in the treatment applied to the soil surface. Differences observed in soil P at this depth were not statistically significant. It is interesting to note that soil P levels under the hydroseeded treatments were similar to compost treatments at this soil depth, while at the 0 to 5 cm soil depths soil P under the hydroseeded treatments was appreciably higher. Leaching of fertilizer P from the hydroseeded treatments did not appear to reach this soil depth. This means that some of the leached fertilizer P may have been “captured” through plant roots or was adsorbed to iron and/or aluminum oxides (high P fixing capacity is characteristic of most clay soils), since it appears to stop between 5 cm and 15 cm.

Potassium

Soil potassium levels were also very similar prior to treatment application, ranging from 45.56 mg kg^{-1} to 58.1 mg kg^{-1}. Differences were not statistically significant. All but two treatments, including the control, showed minor decreases in soil K after eighteen months, ranging from 38.73 mg kg^{-1} in the yard waste compost to 50.69 mg kg^{-1} in the hydroseed with silt fence. The two exceptions that showed slight increases in soil K included the poultry litter compost, 55.73 mg kg^{-1} to 74.57 mg kg^{-1}, and the hydroseed with mulch berm, 50.77 mg kg^{-1} to 57.98 mg kg^{-1}. Both were significantly different from the control, and each other at eighteen months.

Calcium

Soil calcium levels were fairly uniform across the soil plots prior to treatment application, ranging from a low of 150.47 mg kg^{-1} under the biosolids compost to a high of 184.43 mg kg^{-1} under the MSW compost. No significant difference was observed. After eighteen months, all the compost treatments increased soil Ca; the poultry litter compost had the highest level at 398 mg kg^{-1}, followed by the MSW compost at 274 mg kg^{-1}. The control and hydroseed with silt fence treatments showed minor decreases in soil Ca levels, while the hydroseed with mulch berm treatment remained relatively unchanged. The poultry litter compost was the only treatment significantly different from the control; it was also the only compost treatment significantly different from the hydroseeded treatments. This may be a result of the gypsum that was originally blended with the poultry litter compost.

Magnesium

Soil magnesium levels were relatively similar at the beginning of the study, ranging from 23.23 mg kg^{-1} (control) to 36.9 mg kg^{-1} (yard waste compost). No significant differences were found during the initial soil sampling. The poultry litter compost showed the greatest increase in soil Mg levels over the study period, 28.67 mg kg^{-1} to 49.35 mg kg^{-1}, while the MSW compost and yard waste compost showed minor decreases. The yard waste compost, poultry litter compost, and hydroseed with mulch berm were all significantly different from the control. In addition, the poultry litter compost was significantly different from the biosolids compost, MSW compost, and the hydroseed with silt fence treatments.

Zinc

Finally, all soil zinc levels increased, including the control, over the study period. The biosolids compost had the greatest increase, from 0.12 mg kg^{-1} to 4.13 mg kg^{-1}, followed by the MSW compost, from 0.19 mg kg^{-1} to 2.6 mg kg^{-1}; while the smallest increase was found with the control, from 0.17 to 0.94 mg kg^{-1}. No significant differences were found between treatments during either sampling period.

Table 6.4: Selected average soil chemical characteristics from 0-15 cm (0-6 in) by treatment at day one and eighteen months, n=3.

	DAY ONE								EIGHTEEN MONTHS								1.5 YR CHANGE		
Characteristic	pH		OM (g kg^{-1})		P (mg kg^{-1})		K (mg kg^{-1})		pH		OM (g kg^{-1})		P (mg kg^{-1})		K (mg kg^{-1})		pH	OM (g kg^{-1})	P (mg kg^{-1})
Treatment	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	Avg	Avg
PLC/Mulch/Gypsum	4.67	0.12	2.51	0.35	4.3	3.3	55.73	9.02	5.43	0.31	3.13ab	0.68	21.55	23.32	74.57a	8.31	0.76a	0.62ab	17.25
Biosolids Compost	4.67	0.15	2.4	0.17	3.56	3.32	54.0	10.67	5.13	0.06	3.5a	0.91	34.04	42.07	43.53bc	12.42	0.46ab	1.10a	30.48
MSW Compost/Mulch	4.8	0.0	2.6	0.67	3.18	2.17	55.03	17.04	5.47	0.15	2.77ab	0.58	8.44	7.42	48.01bc	9.72	0.67ab	0.17b	5.26
Yardwaste Compost	4.6	0.2	2.65	0.55	2.49	2.39	45.56	7.74	5.27	0.21	2.67ab	0.25	6.11	8.11	38.73c	5.84	0.67ab	0.02b	3.62
Hydroseed/Mulch Berm	4.73	0.15	2.6	0.45	2.96	2.91	50.77	12.42	5.07	0.25	2.56ab	0.43	20.88	22.55	57.98b	9.54	0.34b	-0.04b	17.92
Hydroseed/Silt Fence	4.73	0.06	2.45	0.33	3.81	2.55	58.1	2.55	5.23	0.21	2.35b	0.45	15.78	14.33	50.69bc	8.13	0.50ab	-0.10b	11.97
Bare Soil (not seeded)	4.7	0.1	2.5	0.16	3.23	1.18	56.73	14.63	5.13	0.15	2.39b	0.15	2.67	1.2	40.6c	6.85	0.43ab	-0.11b	-0.56

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Table 6.4 (cont.): Selected average soil chemical characteristics from 0-15 cm (0-6 in) by treatment at day one and eighteen months, n=3.

	DAY ONE						EIGHTEEN MONTHS					
Characteristic	Ca (mg kg^{-1})		Mg (mg kg^{-1})		Zn (mg kg^{-1})		Ca (mg kg^{-1})		Mg (mg kg^{-1})		Zn (mg kg^{-1})	
Treatment	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
PLC/Mulch/Gypsum	176.43	21.99	28.67	4.75	0.26	0.0	398.68a	228.94	49.35a	18.66	2.54	1.91
Biosolids Compost	150.47	17.21	28.77	9.1	0.12	0.0	199.23ab	75.09	31.65bc	6.5	4.13	4.27
MSW Compost/Mulch	184.43	69.38	24.0	10.37	0.19	0.1	274.37ab	46.18	23.65bc	6.26	2.6	1.48
Yardwaste Compost	171.33	38.94	36.9	12.61	0.21	0.08	269.97ab	155.04	35ab	3.06	1.51	0.99
Hydroseed/Mulch Berm	168.93	55.37	28.77	7.34	0.30	0.16	172.03b	11.62	36.27ab	9.25	1.24	0.35
Hydroseed/Silt Fence	166.07	32.51	23.93	3.52	0.30	0.21	145.68b	29.49	30.22bc	7.24	1.03	0.22
Bare Soil (not seeded)	173.57	19.27	23.23	8.25	0.17	0.08	140.48b	29.98	15.99c	5.39	0.94	0.03

Treatments with same letter are not significantly different at $\alpha = 0.05$ using Duncan's Multiple Range test.

Correlation Analysis

Results from correlation analysis (Table 6.5) were used to evaluate which of the treatment physical, chemical, and biological characteristics, and rainfall and vegetation growth results (independent variables) were correlated with the results from soil analysis (response variables). Only those that were highly correlated (r>0.70) are reported. Surface (0-5 cm) soil carbon to nitrogen ratio at six months was correlated with Al content of the treatment. Surface soil available P at six months was correlated to the percent cover of weed species at twelve months and with weed biomass at eighteen months. Both hydroseeded treatments had the highest soil available P at six months; subsequently they had the highest percent cover of weed species and weed biomass by the end of the study. Total P (0-5 cm) at eighteen months was correlated with total carbon content of the treatment and total biomass at the end of the study. The hydroseeded treatments and biosolids compost had the highest soil total P at eighteen months, and the highest total biomass. Soil pH (0-5 cm) and soil extractable organic carbon (0-5 cm) at eighteen months were good indicators of sodium content in the treatment; additionally, the extractable organic carbon was a positive indicator of Cu in the treatment. Finally, soil K (0-15 cm) at eighteen months was correlated with treatment sulfur content.

Table 6.5: Results from correlation analysis. This table lists all variables with significant correlation ($r>0.70$, $\alpha = 0.05$, $n = 21$).

Response Variable	Independent Variable (treatments) with Correlation Coefficient
Soil C:N ratio at 6 months (0-5cm)	Al (0.70)
Soil labile P at 6 months (0-5cm)	% cover of weed plants at 12 months (0.72), weed biomass (0.72)
Soil total P at 18 months (0-5cm)	C (0.73), total biomass (0.70)
Soil pH at 18 months (0-5)	Na (0.73),
Soil TOC at 18 months (0-5cm)	Na (0.75), Cu (0.75)
Soil K at 18 months (0-15cm)	S (0.70)

Summary and Conclusion

Based on this study, under these environmental conditions compost blankets can increase soil extractable organic carbon (used to estimate soil microbial biomass) compared to hydroseed treated soils, and increase surface soil total C, compared to bare soils, which can be in indicator of improved soil quality. Soils treated with hydroseed may experience elevated levels of soil phosphorus near the surface for a short and long term period. This may be beneficial to plant growth (including weeds) but it may contribute to increased phosphorus in storm water runoff and any nearby surface waters contributing to eutrophication. It also appears that some composts, and the application of hydroseed can increase soil potassium, calcium and pH near the soil surface which can be beneficial to plant growth; while some composts may increase pH, organic matter, calcium and magnesium at deeper soil horizons, particularly over a longer period of time. Erosion control professionals that are deciding which measure to use should be aware that hydroseed applications can cause P losses in runoff well after application because it tends to increase surface soil P, including plant available P which is more mobile and available to algae. Both hydroseed and compost have properties that can enhance plant growth; however, compost has a better ability to increase soil quality at a variety of soil depths and can increase soil microbial biomass – which can be beneficial to nutrient cycling and availability to plants over a prolonged period of time.

References Cited

USDA. 1998. Soil Quality Test Kit Guide. US Department of Agriculture. Washington, DC, p.7-10, 55-58.

APPENDIX F

OUTREACH AND TECHNOLOGY TRANSFER

It is often stated that researchers often conduct research for the sake of research with little to no attempt at transferring the results to the "real world". This chapter will focus on demonstration sites that have been created in Georgia to educate professionals, legislators, activists and the general public; it will report results of an economic survey that was designed to assess the state's market infrastructure on compost use for erosion and sediment control; it will review the US EPA's National Pollution Discharge Elimination System Storm Water Program for construction activities – as these regulations above all others will govern the future use of compost in this application; and finally, it will give recommendations to further develop and sustain the growing momentum behind this new compost market.

Demonstration Sites

Establishing new markets and creating a fresh demand for an old product can be a considerable challenge. The relatively new use of compost in erosion and sediment control applications has generated widespread interest and attention in both the private and public sector. Perhaps its greatest attribute is the fact that a recycled product can be used for another environmental application, one of rapidly increasing concern and regulatory pressure. And while the adoption of this new technology may seem a slow and laborious process for those at the forefront, much progress has been made in a relatively short time.

Several universities and private organizations are conducting applied research; product and application specifications are being developed at state and federal levels, new technologies for application methods are being developed, government agencies responsible for approval and enforcement of erosion and sediment control measures have supported and approved the use of compost, engineers and architects responsible for erosion and sediment control plans have begun to include compost in their designs, and related small businesses have sprung up all over the country.

While all of this is evidence of a snowballing interest to create a new and sustainable large market for compost and to alleviate growing concerns around water quality and storm water management issues, perhaps the greatest contributing factor to propelling compost into the largess market of erosion and sediment control products is the establishment of working demonstration sites. After all, seeing is believing.

Support Network

The University of Georgia's Engineering Outreach Service and the Georgia Composting Association have worked extensively over the past year and a half to establish a variety of sites demonstrating the use of compost in erosion and sediment control applications. The number of private and public organizations that have supported and participated in these projects dictates the widespread interest and potential impact that compost may have in reducing erosion and improving water quality. Supporters/participators in Georgia include: Georgia Department of Transportation, Pollution Prevention Assistance Division of the Georgia Department of Natural Resources, Georgia Soil and Water Conservation Commission, Cobb County Solid Waste, Rockdale County, Gwinnett County, Erth Products LLC, Filtrexx International, Gromor

Organics, Georgia Natural Compost, Poultry Gold Compost, Beers/Skanska USA Building, Bobo Grinding, WoodTech Mulch, Metro Mulch Blowing Services, Rayonier Paper Products, US Poultry and Egg Association and the Animal and Poultry Waste Management Center at North Carolina State University. While demonstration sites rarely produce quantitative data and are most often used to exhibit publicly what has been learned through research, they often provide direction for future research projects, as many of the following demonstration sites have contributed to the research that was conducted at the University of Georgia.

Kenworth Truck Dealership

Located in Cobb County, Georgia adjacent to Atlanta's perimeter/belt-way, I-285, this demo site was featured at the BioCycle: Southeast Conference in August, 2001. Demonstrations provided during the conference tour included compost blanket applications of poultry litter compost (Georgia Natural) and MSW compost (Cobb County Bio-Blend); and equipment demonstration and applications included blower trucks (Rexius and Metro Mulch) and filter berm builders (Mill Creek Manufacturing Co.).

A long-term demonstration site was established at the Kenworth Dealership, prior to the conference tour, to educate attendees and local erosion and sediment control professionals on how compost blankets and filter berms perform over time. Biosolids compost (Erth Food) blankets were established in three test plots, 2.5 cm seeded, 5 cm unseeded, and 5 cm seeded. A Filtrexx Filter Sock filled with Erth Food was placed at the base of each plot. Additionally, a mixed particle size mulch blanket and mulch filter berm plot, a hydroseeded plot, a bare soil plot with a silt fence, and a bare soil plot with a Filtrexx Filter Sock were installed. A storm water collection bucket and sampler were placed at the base of the silt fence plot and at the base of the 5 cm seeded compost blanket and filter sock plot.

Results from the first storm event (7.5 cm) showed much of the hydroseed, and sediment from that plot, had washed away leaving the upper quarter of the plot with no cover. The storm water collection device showed that no runoff left the 5 cm compost blanket/filter sock plot while the 18.9 liter (5 gal) collection device at the base of the silt fence plot was nearly full of sediment. No rilling was evident in the compost or mulch blanket plots, while significant rilling was apparent in the bare soil and hydroseeded plots. Six months after application the vegetation establishment on the compost plots was near 100%, while the hydroseeded plots had no cover on the top half of the plot.

Georgia Department of Transportation

Three demonstration sites were established on Highway 53 extension near Interstate 85 and Pendergrass north of Atlanta. The first two sites used poultry litter compost blankets exclusively (Poultry Gold, Georgia Natural and Gromor Organics) on a 3:1 slope and a 2:1 slope. All plots were seeded with a rye and bermuda grass mix. Finn and Metro Mulch pneumatic blower trucks were used for application. The third demo site featured Poultry Gold compost filter berms using a Mill Creek Berm Builder. All products performed well and were approved by the Georgia DOT.

Beers/Skanska USA

Beers/Skanska USA is a commercial construction company owned by Swedish parent company Skanska. Beers/Skanska USA was building a new wastewater treatment facility north of Atlanta adjacent to the very popular Mall of Georgia. After trying nearly everything to stabilize the slopes of a large sediment retention pond on the site, biosolids seeded compost (Erth Products) was applied to the slopes and over the shoulders of the pond. Filtrexx Filter Socks were installed around the storm runoff intake drains feeding the sediment pond. Mulch from ground land clearing debris was applied above the sediment pond culverts. Six months later, vegetation was well established and the retention pond slopes well stabilized. The mulch blankets and filter socks were effective in reducing sediment from building up in the retention pond.

Rayonier Paper Products

Rayonier Paper Products produces specialty paper products for clients like NASA and the US military. As part of a comprehensive waste management plan they compost their paper fiber, a byproduct of their manufacturing process. While waste reduction and the subsequent cost avoidance is the goal of Rayonier's composting efforts they have put some energy into marketing their finished product. Two demonstration sites were set up at their facility to show how their compost could be used for erosion and sediment control on sandy soils. Both were street embankments, one pitched at a 2:1 slope the other a 1.5: 1 slope. While much of the compost did hold to the 1.5:1 slope this was probably its steepness threshold. The compost applied to the 2:1 slope performed quite well.

Habitat for Humanity International Global Village & Museum

Located in downtown Americus, this six-acre site is a future model village for "smart development". It will feature environmental landscape designs, a village market, a cultural museum, a winding watercourse, and pedestrian friendly pathways, all within the design of the residential neighborhood.

Stormwater management and erosion control were key issues at the inception of this project, as alternative measures, such as compost, were included in the erosion and sediment control designs. As Wayne King of Erth Products stated, "This particular construction site had a history of problems with erosion caused by surrounding impervious surfaces and downhill drainage. The blankets were used to control erosion and to improve the soil structure. This is part of a program designed to use engineered soils and landscape systems to offset impervious surfaces and retain stormwater on site."

Compost filter berms were constructed using ERTH Food compost screened to 1.25 cm (½ in) minus. The berm dimensions were 30 cm (2 ft) wide x 60 cm (1 ft) high. Eight and twelve inch Filtrexx filter socks were filled with the compost and used as ditch checks. The socks were also used in lieu of silt fences and in a stream bank retaining wall. Compost blankets were installed with filter berms and filter socks throughout the project site. The blankets were seeded and application rates varied from 1.25 to 2.5 cm depths.

Gromor Organics

In the fall of 2002 Gromor Organics Inc. and the Georgia Composting Association sponsored a Compost Field Day to coincide with the annual Sunbelt Agricultural Expo in Moultrie, Georgia. There were two main objectives of the field day; to demonstrate the production and utilization of compost blankets and filter berms to a group of visiting Russian farmers, and to demonstrate and promote the use of compost as an erosion and sediment control best management practice (BMP) to state legislators. Speakers from the University of Georgia addressed the farmers on the use of compost in the production of vegetable seedlings and on compost blankets and filter berms.

For demonstration purposes compost blankets were established on a 2:1 slope and compost filter berms were established around the contour of the slope's base. Compost blankets were seeded with rye grass and applied at a depth of 2.5 – 3.75 cm. The filter berms were approximately 60 cm high by 90 cm wide at the base.

Glenwood Green

Located in Grant Park, a neighborhood of Atlanta, Glenwood Green is an apartment complex with approximately 100 new apartments that were in various stages of construction in May of 2002. Although erosion and sediment control BMPs were employed, the construction site had high rates of storm runoff due to surrounding impervious surfaces as well as excessive amounts of sediment discharge from the site's retention/detention pond. Area storm drains had to be cleaned out and alternative measures adopted to manage the storm water more effectively, as mandated by City of Atlanta officials.

Polyacrylamide (PAM) was initially suggested to stabilize the disturbed soil, however compost was ultimately the new measure adopted to reduce the runoff and sediment leaving the construction site. A 2.5 cm thick compost blanket was pneumatically applied to the exposed soil surfaces to reduce runoff and prevent soil erosion. Filtrexx filter socks were placed around storm drains to filter any moving sediment and prevent it from reaching the drains. Compost blankets and filter berms were also used in lieu of silt fences to prevent sediment from entering streets and parking areas.

Erthfood compost was used to provide the temporary soil stabilization necessary for this project and was the same material later used for permanent vegetation and final landscaping projects at the apartment site.

Oakview Detention Pond

Integrated Science and Engineering firm contracted with Erth Products through an EPA 319 grant to demonstrate how innovative and performance based BMPs can be used in conjunction to increase biodiversity and soil stabilization around retention/detention ponds in the city of Griffin. The retention/detention pond had 30.3 m (100 ft) long slopes slightly greater than 2:1. Compost blankets were applied with a pneumatic blower at one-inch depths and seeded with a rye, wheat, and bermuda grass mix. For comparative purposes a standard geotextile mat with hydroseed was applied next to the seeded compost blankets. After three months, significant rilling was evident underneath the geotextile mat and none was evident in the compost. Additionally, the compost blanket produced a near 100% vegetative cover while the hydroseeded mat had nearly 50%, according to visual inspection by project managers. The site continues to be used for educational and demonstrative purposes on the effectiveness of compost as a temporary and permanent vegetative erosion and sediment control measure.

City of Griffin

The City of Griffin has recently set up a 12 ha (30 acre) demonstration site to evaluate the use of new and innovative measures in storm water management. Five field plots, 15 m (50 ft) by 30 m (100 ft), with modest slopes ranging from 3.5 to 10% have been established to evaluate these techniques. Seeded compost blankets and filter berms are being evaluated as well filter socks filled with compost. The compost filter sock is being compared to sediment fences and straw bales as an alternative sediment-trapping device.

Infrastructure Behind the Market

Currently, five composting operations in Georgia have used their products in erosion and sediment control applications at nearly 15 demonstration sites. Four companies have established themselves as compost applicators for erosion and sediment control. Three county government agencies in Metro Atlanta have requested demonstration sites to be set-up in their county. The Georgia Department of Transportation has approved the use of compost for erosion and sediment control and is currently developing appropriate specifications. The Georgia Soil and Water Conservation Commission (the state agency charged with approving and publishing best management practices for erosion and sediment control) is considering including compost in its next edition of *Erosion and Sediment Control in Georgia.* While the widespread adoption of compost in this new application may seem laggard the interest and support network it has generated in a relatively short time period is not only impressive but vital to its forward movement in being an approved equal or better.

Survey of Georgia Composts and Market Prices

Of the 38 composting operations in Georgia, 11 operations have or could enter the erosion and sediment control market based on the ability to meet the recommended specifications and the ability to produce a large enough quantity to fulfill potential demand. The following information was gathered through phone interviews and site visits to each of Georgia's composting operations. Through field demonstrations it has become increasingly clear that cost may be the limiting factor to the growth of this new market.

Below is a price survey of compost manufacturers (Table 7.1) that can or have produced a compost product for erosion and sediment control compared with approved industry standard measures of erosion and sediment control. All prices are “installed” (material and cost of installation) in 2003 US dollars. Costs are based on application with a pneumatic blower truck, which is the recommended application method for this technology. Three-fourths of a cubic meter (1 yd^3) of compost or mulch will provide 19.5 m^2 (210 ft^2) of blanket cover (3.75 cm inches deep) or 7.3 linear meters (24 ft) of filter berm (30 cm high by 60 cm wide).

Compost blankets ranged from $0.69/$m^2$ to $3.63/$m^2$ ($0.83/$yd^2$ to $4.32/$yd^2$). Filter berms ranged from $0.23 to $0.61/linear meter ($0.74 to $2.00/linear ft). Hydroseed is the least expensive erosion control method costing $0.38/$m^2$ ($0.45/$yd^2$) while rip-rap is the most expensive at $9.61/$m^2$ ($31.50/$yd^2$). The most comparative methods, straw mats and geotextile blankets, cost slightly more than compost blankets. The filter berms were cost competitive with class A silt fences and less expensive than class C silt fences, which are specified more often. In addition, silt fences have an associated maintenance, removal, and disposal cost, creating a life cycle cost that could be *more than double* a compost filter berm. While compost blankets are more expensive than hydroseed, hydroseeding often *requires more than one application* to achieve the minimum 70% cover required by the G DOT. In addition, because compost blankets fill uneven areas and surface holes during application, unlike conventional erosion control mats or hydroseeding, no final grading is required (along with its associated cost).

Table 7.1: Economic survey of composts and conventional erosion & sediment control measures as reported by industry (units in US Customary)

Compost	Cost per yd^2 @ 1.5 inch depth (seeded)	Cost per linear ft. of filter berm (1'x2')
Sargent Nutrients	$4.32	$2.00 (1:2)/2.69
Poultry Gold	$1.62	$1.25
Gromor Organics	$1.65	$1.40
Erth Products	$1.34/$0.67 (3/4")	ND
Wood Tech	$0.96	$0.85
Cobb Co.	$0.96	$0.85
City of Brunswick	$1.04	$0.93
Hutchins Farm	$1.20	$1.07
Bricko Farms	$1.87	$1.67
Shealy Farms	$1.43	$1.40
Free material	$0.83	$0.74

Erosion Control Method	Cost per yd^2	Cost per linear foot
Hydroseed	$0.45	
Silt fence (Class A)		$1.25 – 3.00
Silt fence w/ wire reinforcement (Class C)		$4.00
Rip Rap	$31.50	
Coconut hull mat	$2.50 - 3.00	
Straw mat	$1.50 - 2.00	
Straw mat w/ hydroseed	$1.75 - 2.50	
Geotextile blanket (wood fiber mat)	$1.25 - 2.00	
Geotextile blanket w/ hydroseed	$1.50 - $2.50	
Mulch	$0.83 - $0.95	$0.74 - $0.85

One inch = 2.5cm; One foot = 30cm or 0.305 m, One square yard = 0.84 square meters

Background and History of the National Pollution Discharge Elimination System

Polluted storm water runoff is the leading cause of impairment to the nearly 40 percent of surveyed U.S. water bodies which do not meet water quality standards (US EPA, 2003). Over land or via storm sewer systems, polluted runoff is discharged, often untreated, directly into local water bodies (US EPA, 2003). This water pollution can result in the destruction of fish, wildlife, and aquatic life habitats; a loss in aesthetic value; and threats to public health due to contaminated food, drinking water supplies, and recreational waterways (US EPA, 2003).

Mandated by Congress under the Clean Water Act (CWA), the National Pollution Discharge Elimination System (NPDES) Storm Water Program is a comprehensive two-phased national program for addressing the non-agricultural sources of storm water discharges that adversely affect the quality of our nation's surface waters (US EPA, 2003). The Program uses the NPDES permitting mechanism to require the implementation of controls designed to prevent harmful pollutants from being washed by storm water runoff into local water bodies (US EPA, 2003). For a copy of the federal Clean Water Act of 1977 go to the internet at www.epa.gov/npdes/pubs/cwatxt.txt. The ultimate goal of the NPDES program is to clean up over 20,000 rivers, lakes, and estuaries so they are safe for swimming and fishing (US EPA, 2000).

The Federal Water Pollution Control Act of 1956 was amended in 1972 to combine The Water Quality Act of 1965, The Clean Water Restoration Act of 1966, and The Water Quality Improvement Act of 1970 (US EPA, 2003). The 1977 amendments to the Federal Water Pollution Control Act (known as the Clean Water Act) provides the statutory basis for the NPDES permit program and the basic structure for regulating the discharge of pollutants from point sources to waters of the United States (US EPA, 2003). Section 402 of the CWA specifically required EPA to develop and implement the NPDES program (US EPA, 2003).

The CWA gives EPA the authority to set effluent limits on an industry-wide (technology-based) basis and on a water-quality basis that ensure protection of receiving waters. The CWA requires anyone who wants to discharge pollutants to first obtain an NPDES permit, or else that discharge will be considered illegal.

The CWA allowed EPA to authorize the NPDES Permit Program to state governments, enabling states to perform many of the permitting, administrative, and enforcement aspects of the NPDES Program. In states that have not been authorized to implement CWA programs, EPA still retains oversight responsibilities (US EPA, 2003).

The NPDES program areas include animal feeding operations, combined sewer overflows, pretreatment, sanitary sewer overflows, and storm water. Activities covered under the NPDES storm water area include municipal separate storm sewer systems (MS4s), discharges from industrial facilities, and discharges from construction activities. This analysis will focus specifically on storm water discharges from construction activities.

In response to the 1987 Amendments to the Clean Water Act, which mandated construction sites to control storm water, erosion, and sediment originating from their site, the U.S. EPA developed Phase I of the NPDES Storm Water Program in 1990 (US EPA, 2000). The Phase I program addressed sources of storm water runoff that had the greatest potential to negatively impact water quality. Under Phase I, EPA required NPDES permit coverage for storm water discharges from eleven categories of industrial activity, which includes construction activities that disturb five or more acres (2.03 ha) of land (US EPA, 2003).

The Phase II Final Rule, published in the Federal Register on December 8, 1999, requires NPDES permit coverage for storm water discharges from construction activities (including other land-disturbing activities) that disturb one acre (0.4 ha) or more to be regulated under the NPDES storm water program (US EPA, 2003). On March 10, 2003, NPDES Phase II became effective, thus extending coverage to construction sites that disturb one to five acres (0.4 – 2.03 ha) in size, including smaller sites that are part of a larger common plan of development (US EPA, 2003).

Operators of regulated construction sites are required to develop and implement storm water pollution prevention plans and to obtain permit coverage from an authorized state or from EPA, if the state is not authorized by EPA to issue NPDES permits (US EPA, 2003). Currently, most states are authorized to implement the NPDES permit program.

The Water Permits Division (WPD) within the U.S. Environmental Protection Agency's Office of Wastewater Management leads and manages the National Pollutant Discharge Elimination System permit program in partnership with EPA Regional Offices, states, tribes, and other stakeholders. To ensure the NPDES permit program is effective, the WPD performs a wide variety of activities, including: shaping the direction of the national NPDES permit program; producing policies and regulations; developing technical and administrative tools to support permit issuance; tracking and managing critical information related to permit issuance, permit quality, and point source pollution abatement; overseeing the programs managed by the States and Regional Offices; and providing access to information on NPDES permitting to promote increased awareness and involvement in the NPDES permitting process (US EPA, 2003). The Water Permits Division of the US EPA has twelve staff members (US EPA, 2003). The EPA’s budget for Clean and Safe Water under which the NPDES program is funded in 2002 was $3,738,990 (US EPA, 2003).

Program Objective, Process, Monitoring and Evaluation

The overall objective of the NPDES storm water program for construction activities is to increase the nation’s surface water quality by increasing controls on erosion and sedimentation. Specifically, the program is designed to decrease sediment loading in surface water, maintain stream turbidity levels of surface water entering and leaving a construction site, and increase numbers of sensitive aquatic organisms in local water bodies (US EPA, 2003). The EPA judges the effectiveness of NPDES storm water program based on these parameters (US EPA, 2003).

The NPDES storm water program seeks to accomplish this objective by requiring all construction sites and land disturbing activities greater than one acre (0.4 ha) to: submit a notice of intent (NOI), submit a storm water pollution prevention and/or erosion and sediment control plan, install and maintain approved best management practices (BMPs), follow established procedures for site inspections by the regulatory agency, monitor the site by storm water sampling and reporting results in accordance with 40 CFR Part 136 and EPA Method 180.1 (GA SWCC, 2002), follow sanctions for noncompliance (issuance of stop work order or fine up to $2,500/day and $100,000/day for noncompliance with the GA Erosion and Sediment Control Act and Federal Clean Water Act, respectively), and submit a notice of termination (NOT) (US EPA, 2003).

To monitor the effectiveness of specific projects building contractors are responsible for collecting and reporting storm water runoff samples from their sites. The first sample must be collected at least 45 minutes after the start of the first ½ inch (1.25 cm) or more rain event after soil disturbance. A final sample must be taken either 90 after the first sample or after major soil disturbance has commenced (Shahlaee, 2003). Samples must be drawn from receiving streams or from outfall before entering stream. Contractors are required to have all storm water samples tested for turbidity and are prohibited from impacting any warm water stream by more than 25 Nephelometric Turbidity Units (NTUs) and any trout stream by more than 10 NTUs (GA Soil and Water Conservation Commission, 2002). The results must be reported to the state regulatory agency, in Georgia, the Environmental Protection Division (EPD). Violation exemptions can be given if a storm event is equal to or greater than the 25-year/24-hour storm event for that given region and approved erosion and sediment control BMPs were utilized and installed correctly.

Coordination with State Agencies

There is considerable overlap between the EPA's NPDES program with state and even local programs, particularly because the EPA has passed the responsibility on to the states. The Georgia Erosion and Sediment Control Act has been amended to reflect Phase I and II of the NPDES program. In Georgia, the EPD is responsible for enforcement of the Federal Clean Water Act and the Georgia Erosion and Sediment Control Act, approving NPDES permits, reviewing erosion and sediment control and land disturbing activity plans, evaluating monthly storm water sample results, and accepting NOIs and NOTs (GA Soil and Water Conservation Commission, 2002).

The Georgia Soil and Water Conservation Commission (GA SWCC) has been charged to provide educational and technical assistance programs in storm water management and erosion and sediment control measures. The GA SWCC provides training and certification to Erosion and Sediment Control professionals, approves and publishes state BMPs for erosion and sediment control measures, and in some cases is responsible for reviewing erosion and sediment control plans. In some instances the approval of land disturbing activity permits, approval and review of erosion and sediment control plans, and site inspections has been given to a local issuing authority (county or municipality) through certification by the GA EPD and GA SWCC (Shahlaee, 2003). This is common in the Metropolitan Atlanta area and is a result of the Georgia Erosion and Sediment Control Act, not the NPDES program. The GA EPD has the ability to revoke this responsibility from the local issuing authority.

Local Soil and Water Conservation Districts (SWCD) and the Natural Resource Conservation Service (NRCS) are responsible for further technical and educational assistance, and the NRCS is also involved in reviewing erosion and sediment control plans (GA Soil and Water Conservation Commission, 2002). The NRCS, SWCD, EPD and SWCC are all involved during complaint resolutions (GA Soil and Water Conservation Commission, 2002). The EPD has the final word on submitted plans, violations and compliance statements (GA Soil and Water Conservation Commission, 2002).

Assessment of NPDES Storm Water Program

In response to a mandate of the Appropriations Act, EPA conducted a review on the status and effectiveness of the NPDES Phase I program. The sediment load reduction analysis projects that Phase I construction BMP compliance prevents 73.2 percent of the sediments generated during construction from reaching the nation's streams, rivers and lakes (US EPA, 2000b). An average of 57 metric tons of sediment may be eroded from each of the 62,755 construction sites regulated by Phase 1 in 1999 (US EPA, 200b). This reduction equates to 2.6 million metric tons of sediment (264,000 dump trucks of soil) from being kept out of our nation's waters (EPA, 2000b). An EPA study in Florida that looked at erosion and sediment control in eleven coastal watersheds, before and after Phase I BMPs were in place, found a 31% reduction in sediment loading after the BMPs were established (EPA, 2000b). The US EPA's NPDES Storm Water Program appears to be achieving its objectives.

According to Karim Shahlaee (2003), Program Manager of Urban Water Resources for the Georgia Soil and Water Conservation Commission the NPDES storm water program has its share of strengths and weaknesses. Its strengths include its hefty fines of up to $100,000 day per violation, the stringent turbidity limits, the monitoring requirements – particularly the frequency of sampling, and the citizen lawsuits – where anyone can sue a violator not just someone who has been negatively impacted (Shahlaee, 2003). Shahlaee adds that the Phase II rule does require less sampling (frequency) but requires more site inspections which are funded through significantly increased erosion and sediment control plan application fees to the EPD (2003). The main weakness to the national program is that there is no provision for the review of erosion and sediment control plans, which subsequently is a strength of the state law (Shahlaee, 2003).

Program Strengths

Overall, this program appears to be consistent with the EPA's goals, cost effective and fair to building contractors. The true evaluation of this program will be its sustainability, i.e. flexibility to deal with changing storm water issues, and most important - will it really improve the water quality of the nation's, lakes, rivers and streams. Requiring approved BMPs, analytical analysis of storm water discharges based on the use of these BMPs, consistent monitoring, reporting and record keeping by the contractor, and making the contractor responsible for these actions is an appropriate protocol to achieve the goals of this pollution prevention program. Enforcement measures by the regulatory agency for negligence and/or non-compliance are also appropriate tools, particularly the option of a stop work order.

Program Weaknesses

Potential weaknesses of this program include the reliance of the contractor to submit analytical data of storm water turbidity results. While this reduces the cost to regulatory agencies in both time and personnel and transfers the cost to the contractor (which can be passed on to the buyer instead of the taxpayer), it leaves the ability of the contractor to misrepresent analytical results, particularly when the enforcement measure may end the entire construction project due to financial or time restraint issues. Other weaknesses include the potential cost of some approved BMPs and their potential ineffectiveness. To mitigate this an extensive third party research program to comparatively evaluate approved BMPs would be a good tool to determine how effective these BMPs are at keeping sediment out of surface water. A quantitative benchmark (ex. grams/soil loss per runoff quantity and/or grams/soil loss by rainfall duration/intensity) could be established where all BMPs must pass to be approved. This study should be easy and inexpensive to replicate so it is not a barrier to the approval of new and innovative erosion and sediment control measures and technologies. The agency in charge of approving BMPs and/or erosion and sediment control/storm water pollution prevention plans should have the ability to verbally approve new measures temporarily to assess their effectiveness in the field. This will not inhibit building contractors and designers of erosion and sediment control plans from trying new ideas, particularly in challenging situations.

Recommendations for Improvement of NPDES Program

Based on this inquiry the NPDES storm water program for construction activities appears to be effective at improving the nation's surface waters. However, there is always room for improvement, the following is a list of recommendations to further the goals of the NPDES storm water program related to construction activities:

- Instead of a set fine amount, fines could be based on the sediment concentration or load amount in storm water samples over the regulated limited. As the concentration or load increases over the allowable limit the fine amount multiplies. Leeway will continue to be given for extreme storm events and parties that have followed approved BMP measures and their correct installation.

- More site inspections by the regulatory body, particularly with construction sites that report storm samples over the allowable sediment limits (this appears to be happening in 2004-2005).
- Educational training and certification provided to building contractors that will be conducting their own storm water sampling, record keeping, and reporting. Third party agencies and companies sampling storm water must also be certified.
- Signs posted at all construction sites, once land disturbing activity has commenced, that includes an emergency contact number to the regulatory agency (or third party agency that is assisting) in the event of erosion and sediment control problems.
- Incentives provided to contractors who demonstrate improved stream water quality of water leaving their site over water entering their site. A partial or total refund of the erosion and sediment control plan application fee may be rewarded to the building contractor.
- Analyzing and reporting of storm water samples for nitrogen and phosphorus should be considered. Soil stabilization measures that include vegetation establishment often call for fertilizer applications. Over application, application near surface water, and/or just before a storm event can increase nutrient loading in lakes, rivers and streams. The agricultural industry faces increasing regulation in this area, the construction industry should be subject to the same standards.

Recommendations for Expanding Compost Use in Erosion and Sediment Control

In the fall of 2001 the University of Georgia's Engineering Outreach Program (EOP) completed a statewide composting survey designed to help expand the industry and organic materials recycling in Georgia. The survey found Georgia had 38 facilities actively composting that handle over 504,000 metric tons/year of organic materials in addition to 5 new facilities coming on line later that year. While half of those facilities were private operations they handled more than 80% of the recycled organics. More than 35% of the composted materials were handled through operations that manage a variety of feedstocks, while yardwaste composting operations handled the second most at nearly 20% of the total organic materials composted.

While standardizing finished compost products may help the composting industry in Georgia, it may only serve a handful of the largest private composting operations and certainly the consumer. The Georgia Composting Association (GCA) and the Engineering Outreach Service at UGA are interested in creating standards for compost products produced in Geogia, as well as specifications for various product applications. The Georgia Composting Association is considering endorsing the USCC's Seal of Testing Assurance (STA) program and may provide incentives for GCA composters to become STA certified. In addition, the GCA may also create their own stamp of approval for high quality compost products produced within the state. The stamp can be used as a marketing tool for GCA composters and can serve to insure consumers that the material they are buying is a certified, high quality material that was made in Georgia with materials recycled from Georgia industries and municipalities. Developing an expansive market infrastructure through continual research, demonstration projects, product and application specifications, and supporting product certification are the cornerstones to a successful and sustainable composting industry seeking to recycle ever more organic waste.

The following is a list of recommendations for the sustainable development of compost in erosion and sediment control applications and markets:

1. Research. As a relatively new technology there is a tremendous amount of research that can be done in this area. Here are a few ideas: how close to surface water can compost blankets be applied, what is the optimum particle size ratio for filter berms to filter sediment from storm water, is compost effective in areas on concentrated water flow, what is the optimum particle size ratio and lowest possible nutrient content of a compost blanket that can still provide a rapidly established and permanent vegetative cover, how steep of a grade can compost blankets be applied to, and will the addition of a tackifier significantly increase the physical stability of a compost blanket on a steep slope.

2. Demonstration sites. There is no better training and educational tool than to see how it works in the field. Strategically located demonstration sites can expose a large audience and significant stakeholders to this emerging technology.

3. Education. Educational and technical assistance through workshops, trainings, conferences, multi-media and personnel communication to architects, engineers, regulators, inspectors and other related professionals and stakeholders is essential to the widespread adoption of this material.

4. Development and Adoption of Specifications. During the short time period this study was conducted the development and adoption of specifications for this application has grown significantly. The Georgia Department of Transportation has developed and

adopted new specifications (with assistance from this project), the Georgia Soil and Water Conservation Commission is considering following suit. The American Association of State Highway Transportation Officials, supported by the Federal Highway Administration, has adopted specifications (with assistance from this project) that have been sent to the DOTs of the fifty states. The continued adoption of these specifications throughout state and federal agencies that deal with erosion and sediment control is essential.

5. Marketing. Compost operators need to be aggressive in marketing their material to this market. This may include hiring a marketing specialist and/or sales personnel, researching and making bids for erosion control jobs with the DOT, meeting with building architects who specify which erosion control measures will be employed on a particular project, and leading/participating in education and outreach activities.

6. Being Competitive. This application normally requires very large volumes of material per project with compost that can be blended with less expensive mulch or "overs" materials. With this in mind compost operators can charge less for their compost relative to other markets. If composters do not reduce their cost, on a cubic yard or tonnage basis, to a level that is competitive with industry standard measures, it will likely never be adopted on a large scale. If composters can demonstrate that their product is less expensive than standard measures, the financial rewards could be overwhelming. In addition, small operations may enter partnerships to fulfill the quantity demanded for large storm water projects.

7. Quality Products. Providing consistent, high quality compost that meets specification is essential to the growth of this application. One or two bad applications or failures can devastate the adoption of this technology. Most specifications include quality standards as insurance to all parties and the industry a whole.

8. Establishment of Storm Water Utilities. Storm water utilities that charge counties or municipalities based on the quantity of impervious surface under their jurisdiction could lead to a greater awareness and demand for the use of compost in storm water applications.

9. Polluter Pays Program. Erosion Control enforcement agencies could charge violators based on the turbidity unit increase to the ambient upstream flow of a designated surface water. This may help push the adoption of more effective BMPS, including compost.

10. E&SC Plan Fee Waiver. The EPD could offer reduced fees or no fee waivers to contractors or submitters of E&SC and storm water management plans that specify recycled materials in their plans, which helps the state achieve another goal – 25% waste reduction.

11. Evaluation of Current E&SC BMPs. Many industry and field specialists feel that some currently approved BMPs do not perform well in erosion and sedimentation applications.

Quantitative research that comparatively evaluates currently approved BMPs may show the ineffectiveness of many of these measures, particularly once compared to one another.

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