Compost Application Practices for Revegetating Disturbed Soils

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ABSTRACT

Urban development alters the physical and chemical properties of soil which presents challenges for vegetation establishment. Compost, when applied as a soil amendment, can help to ameliorate these challenges. In field trials, we evaluated the effect of surface-applied composts and standard hydroseeding applications on changes in soil properties and turfgrass stand on a highway roadside. The short-term effects of (1) no compost application; (2) 2.5 cm compost surface mulch; (3) 2.5 cm compost application, incorporated; (4) 5.0 cm compost application, incorporated; (5) 0.6 cm compost blanket; and (6) straw mat on turfgrass establishment, quality and changes in soil properties were measured on an urban soil devoid of topsoil. In greenhouse studies, we compared the effect of depth of planting of two variously-sized turfgrass seeds in compost. The soils of the disturbed roadside and the urban soil had increased Mehlich I-extractable soil K, Mg, and P following compost application. Analysis of botanical composition on the highway roadside demonstrated that the percentage of fescue decreased with time, while weed species increased inversely in both treatments. Compost amendments on the urban soil increased turfgrass color over time, whereas turfgrass density was not affected by time. Turfgrass density was greatest in applications of a 5 cm depth compost incorporated 7-10 cm into the soil. No differences were observed in biomass harvested among treatments. Tall fescue seeds had greater germination and establishment than smaller sized bermudagrass seeds when sown below the surface of compost, regardless of depth. Composts help to regenerate topsoil-like functionality in disturbed soils by promoting vegetation establishment, including weeds, on highway roadsides and improving turf quality on urban soils.

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LITERATURE REVIEW

1.1 Problem, Rationale and Significance

Urban development degrades the soil environment (Cogger, 2005). On construction sites across the United States, disturbed soils are created when all of the topsoil and its associated biological activity are removed (Box, 1978), exposing fresh subsoil. Oftentimes, these subsoils contain little to no organic matter, suffer from compaction caused by heavy machinery and are characterized by low nutrient status, high acidity and poor soil structure. Compacted soils typically exhibit increased bulk density, run-off and erosion, decreased microporosity, aeration and infiltration capacity, and restricted root growth (Cogger, 2005). All of these characteristics present challenges for turfgrass establishment (Landschoot and McNitt, 1994; DCR, 2003).

Compost, when utilized as a soil amendment, can alleviate these challenges and help to regenerate topsoil-like functionality in disturbed urban soils (Curtis and Claassen, 2009). Previous studies have demonstrated the value of composts for improving soil physical and chemical properties, but most findings have been based on the use of compost in agricultural systems (Cogger, 2005; Singer et al., 2006). Turfgrass research utilizing compost has been limited to investigating the effects of compost applications to established turfgrass on nutrient availability, disease control, and soil chemical properties (Garling and Boehm, 2001). The most common method for applying compost to turfgrass is topdressing existing turfs (Loschinkohl and Boehm, 2001), but unvegetated, disturbed soils also benefit from incorporated compost applications (Landschoot, 1995; Cogger, 2005; Curtis et al., 2009). More research is needed to assess alternative compost application practices to optimize turfgrass establishment and quality on disturbed soils. We hypothesize that surface-applications of compost will improve turfgrass establishment, cover and reduce weed populations when compared to standard hydroseeded soil treatments on highway roadsides. Furthermore, we hypothesize that compost incorporated into the soil will improve turf establishment and quality greater than surface applications of compost alone on an unvegetated urban soil. The results of these studies will provide valuable additions to practices for revegetating disturbed soils for roadside and construction managers, as well as new homeowners.

1.2 Literature Review

1.2.1 The Impacts of Disturbed Soils on the Environment

Nutrients and sediment found in urban runoff contribute substantially to the decline of the Chesapeake Bay (DCR, 2003) and are considered a significant source of impairment in Virginia's surface waters according to Reay et al. (1992) and the United States Environmental Protection Agency (USEPA, 2000). The impact of raindrops on bare soil surfaces facilitates the transport of sediment and its adsorbed nutrients into surface waters. Exposed soil surfaces are common immediately following construction and on locations where vegetation establishment is poor. These sites are highly susceptible to erosion, including slope stability (Harrell and Miller, 2005) if left unmanaged.

Increased urbanization in Virginia has culminated in a growing number of disturbed sites that include highway roadsides and recently completed construction sites. The environmental effects of urbanization and road construction includes the alteration of natural hydrological flows, introduction of chemicals, fragmentation of habitats, and growing concerns regarding roadsides as vectors of non-native and invasive plant species (Gelbard and Belnap, 2003; Rentch et al., 2005). Despite efforts to vegetate highway roadsides with low-maintenance, adaptive species of grasses, highway roadsides in Virginia are often characterized by poor vegetative establishment and large quantities of unsightly, weed species. The disturbed soils of these roadsides play a significant role in contributing to the failures of vegetation on such sites (Rentch et al., 2005; Curtis and Claassen, 2009).

Disturbed soils are often characterized by high clay content, low nutrient status, poor structure, low organic matter and low water-holding capacity (Cogger, 2005). Poor vegetation establishment on highway roadsides are compounded by the construction process because roadsides are constructed as linear strips which often transect a number of soil and geologic materials (Booze-Daniels et al., 2000). These soil and geologic materials may include mixtures of residuals of parent materials from road cuts (Miller et al., 2002). The poor structure of these soils and the lack of vegetation on such roadsides leave them highly susceptible to erosion (Curtis and Claassen, 2009). Urban development involves destructive practices that removes the existing vegetation, strips the land of its topsoil, compacts the exposed subsoil with heavy machinery and, in some instances, replaces the topsoil with a low-quality fill (Loschinkohl and Boehm, 2001; DCR, 2003; Cogger, 2005). These processes degrade the soil, resulting in an environment that is unfavorable for vegetative growth (Jim, 1998). Box (1978) terms soils that have had all of the topsoil and their associated biological activity removed as “disturbed soils.”

1.2.2 Best Management Practices for Erosion Control on Disturbed Soils

Practices which may either increase water infiltration, decrease runoff or improve vegetation establishment can have dramatic effects on erosion control (Persyn et al., 2004; Faucette et al., 2005; Singer et al., 2006; Spargo et al., 2006; Curtis et al., 2009). Erosion control on disturbed sites or highway roadsides is often accomplished by utilizing practices which establish vegetation as quickly and effectively as possible (Muzzi et al. 1997; DCR 1992; Rentch et al., 2005; Singer et al. 2006). Traditional approaches to controlling erosion such as straw blankets or mulches can be effective temporarily (Meyer et al., 1972; Carroll, 1992) for protecting the exposed soil surface. The roots of vegetation are ideal for keeping soil in place (Robinson et al., 1996); thus, permanent vegetation is considered to be the most desirable and cost effective solution for long-term erosion control (DCR, 2003; Curtis and Claassen, 2009). In lieu of these findings, most studies which evaluate erosion control techniques are based on results obtained from sites with steep or exposed slopes (Persyn et al., 2004; Faucette et al., 2005; Harrell and Miller, 2005; Singer et al., 2006).

Claassen and Zasoski (1993) and Larney et al. (2003) found the reapplication of topsoil to be an effective revegetation technique. Although topsoil reapplication is excellent as a growth medium, it is not always cost effective (DCR, 1992) or readily available (Curtis and Claassen, 2009). For site planning considerations, the benefits of preparing a seedbed in subsoil should be compared with those of topsoiling (DCR, 1992). Although subsoils are high in clay content, they provide adequate moisture and, if limed and/or fertilized appropriately, may provide a suitable growth medium for low maintenance grass species (DCR, 1992).

The most common practices recommended by the Virginia Department of Conservation and Recreation (DCR) for establishing vegetation on urban lands is the utilization of wood or straw mulches and mats (DCR, 1992). Straw mulches have been shown to increase the infiltration rate of the soil, reduce soil moisture loss due to evaporation, prevent surface crusting, prevent erosion and enhance herbaceous vegetative establishment when combined with binding materials such as synthetic glues (Brofas et al., 2007). Benik (2003) reported greater biomass for straw mats as compared to bare soils or wood fiber mats. Studies by Benik et al. (2003) and Tormo et al. (2007) reported that wood fiber mats did not promote the establishment of dense vegetation. Benik et al. (2003) determined that wood fiber blankets resulted in 10 percent less vegetative cover and 30 percent less biomass than bare soil two years after establishment. Straw mats are usually not preferred to other revegetation practices because costs and efforts to remove the mats may result in damage to the established vegetation (Harrell and Miller, 2005).

Traditional practices for seeding highway roadsides utilize hydroseeding operations in which a mixture of seeds, wood or paper fiber, dyes and tackifiers are sprayed onto the soil surface using water as a carrier (Rentch et al., 2005; Faucette et al., 2006). A drawback of hydroseeding operations is they do not address soil nutrient deficiencies or the poor physical and chemical properties of disturbed soils (Curtis and Claassen, 2009). Muzzi et al. (1997) reported that hydroseeding alone (without straw blankets) produced less ground cover and plants per area than did hydroseeding with blankets. On a suburban D.C. roadside, the Federal Highway Administration, the U.S. Department of Transportation and the U.S. EPA compared yard-trimmings compost to hydromulch (USEPA, 1997). Although hydromulch produced quick vegetative growth initially, the compost mulch produced a thicker, healthier vegetative stand and reduced erosion after six months (USEPA, 1997).

1.2.3 Composts as an Alternative Form of Waste Disposal

Equally as important as mitigating the negative consequences of urban development on the environment are the needs for alternative uses for municipal solid and agricultural wastes. Due to increasing landfill costs and public and regulatory pressures to reduce the incineration of organic wastes, composting offers an alternative to traditional waste disposal. Composts are defined as the product resulting from the controlled biological decomposition of organic materials (USCC, 1996). Composts can be utilized for their potential to regenerate topsoil-like functionality (Curtis and Claassen, 2009), including nutrient content, moisture, and structure, in disturbed soils (Cox et al., 2001; Cogger, 2005; Singer et al., 2006). In addition, composts may improve vegetative establishment and quality (Landschoot and McNitt, 1994). Discarding wastes that can be recycled or composted for land application is wasteful and promotes the widespread application of costly synthetic fertilizers. Utilizing composts is, thus, considered to be an environmentally-sound approach to nutrient management and the reclamation of disturbed soils.

1.2.4 Composts are Not All Created Equal

Composts made from different source materials vary in physical and chemical properties depending on both the source of the raw materials and on initial handling and processing methods that may alter the properties of the feedstocks (i.e. the raw materials to be mixed). For example, papermill sludges, which are the by-products of paper pulp manufacturing, can vary in their carbon to nitrogen ratios (C:N) depending on the proportion of primary and secondary residuals (Foley and Cooperband, 2002). In general, primary sludges contain high (i.e. 40-70%) water content (Norrie and Fierro, 1998) and consist primarily of wood fiber. Secondary sludges have been treated by biological processes to increase microbial mass, resulting in a material that is relatively high in N and P (Norrie and Fierro, 1998). In addition, secondary sludges are commonly combined with deinked sludges that have been chemically treated with lime amendments and have high pH values (Norrie and Fierro, 1998).

Another common source material for composts includes agricultural wastes, such as animal manures and poultry litter (USEPA, 2009). He et al. (2001) compared composts made from manures, poultry litter and yard waste to determine that the composts made from manure and poultry litter contained greater concentrations of P than the yard waste compost. Chen et al. (1996) found similar concentrations of P and higher concentrations of K in composts from cow manure than from biosolids. Composts derived from yard wastes may also contain substantial concentrations of plant-available K, above 1% on a dry basis, in comparison to composts derived from biosolids (Cogger, 2005).

Composts contain all of the essential nutrients required by plants for growth and survival (Cogger, 2005). Among the most important nutrients required is N. Regardless of the compost source material, the availability of N in composts is less than the source material due to conversion of N into organic forms, which must mineralize before becoming plant available (Cogger, 2005). As a consequence, crops fertilized with compost may require supplemental N for optimal crop yields (Landschoot, 1995; Evanylo and Daniels, 1999). Mamo et al. (1999) reported that municipal solid wastes composts applied at 90 Mg $ha^{-1}yr^{-1}$ at a C:N of 20:1 provided only half of the N requirements for corn grown. Cox et al. (2001) did not measure any beneficial effects from compost on crop yield until three years after application, which they attributed to the high (i.e. 32:1) C:N ratio of the compost used. Other research has suggested that composts with high C:N ratios (i.e. > 30:1) will result in N immobilization, requiring additional inputs of N for optimizing crop yields (Sims, 1990; Chen et al., 1996). Composts with C:N ratios less than 25:1 will generally supply adequate N to plants during the first few growing seasons (Sims, 1990; Chen et al., 1996). In lieu of these findings, composts are applied as slow-release, low-analysis fertilizers (Tester et. al, 1990; Maynard et al., 2000). When compared to inorganic fertilizers, composts contain relatively low levels of nutrients, ranging from 1 to 2% N and less than <1 % P in composts from non-manure sources (Sikora and Enkiri, 1999). Yet despite the low nutrients supplied from composts, nutrient supplements from composts may be substantial if applied in larger quantities.

1.2.5 Benefits of Compost Applications to Disturbed Soils

Compost provides other benefits besides macronutrient supply. Depending on whether compost originates from an alkaline or neutral feedstock, they can have an effect on soil pH (Cogger, 2005). Studies have shown increases up to 1 unit for soil pH's amended with composts (Alexander, 2001; Maynard, 1994; Sims, 1990). Provin et al. (2008) and Wright et al. (2007) reported that soil pH increased with compost applications for up to three months after application, beyond which no further increases were observed. Unamended soils were observed to increase in pH for up to twenty three months. Provin et al. (2008) concluded that composts acted as buffers against changes in soil pH over time. For soils low in pH, the results of the preceding studies suggest that composts may increase soil pH, but this increase is short-term after application.

Additions of soil organic matter directly influence micronutrient concentration with time as small fractions are degraded and become available to plants (Hadas et al., 1994; He et al., 2001). Large compost applications may lead to increased concentrations of micronutrients in soils that remain for years (He et al., 2001; Chantigny et al., 2002). Wright et al. (2007) reported that soil concentrations of Mn, Fe and Zn increased with increasing compost application rates. Although micronutrient concentrations increased after application, Wright et al. (2007) observed that extractable Mn, Fe, and Zn were found to decrease in concentration with time, which the researchers attributed to an increase in soil pH (Wright et al., 2007). Concentrations of micronutrients in soil are seldom found as free ions in solution at high pHs because micronutrients precipitate (Havlin et al., 2005). Soil pH is only one of several factors including organic matter content, interaction with other nutrients and climatic conditions which affect availability (Havlin et al., 2005).

Increasing applications of compost have been shown to increase soil organic matter (Cogger, 2005; Wright et al., 2008). Tester (1990) observed about 50% of the original soil organic C from biosolids compost applications of 60, 120, and 240 Mg ha^{-1} incorporated into a sandy loam soil remained after five years. Sullivan et al. (2003) reported that 18% of the C from compost applied at 155 Mg ha^{-1} in a fine sandy loam remained in the soil after seven years. Wright et al. (2008) observed higher soil organic C as compost application rates increased.

Composts can also improve soil physical properties (Cogger, 2005). Compost amendments have been studied extensively for their ability to increase the plant available water (PAW) in disturbed soils (Khaleel et al., 1981; Tester, 1990; Chambers et al., 2002; Singer et al., 2006; Curtis and Claassen, 2009). When investigating the effects of composts on PAW on roadcuts, Curtis and Claassen (2009) reported PAW increased with compost incorporation in a relatively coarse textured soil, but not in a fine-textured soil. Flint and Childs (1984) reported that coarse fragments from granitic parent materials held considerable PAW (1.6-4.1%). Khaleel et al. (1981) demonstrated that changes in PAW from organic amendments were dependent upon soil texture.

Improved soil physical properties, including bulk density, porosity and aggregate stability, have been observed with compost applications as low as 15 Mg ha^{-1} (He et al., 1992).

Decreases in bulk density associated with compost applications have been hypothesized to be due to the effects of diluting high-density mineral matter with low-density organic matter (Khaleel et al., 1981; He et al., 1992; Singer et al., 2006). Giusquiani et al. (1995) attribute decreased bulk density to increased porosity following compost additions. With subsequent additions of compost at 10, 30, and 90 Mg ha^{-1} for four years, Giusquiani (1995) observed increases in the proportion of pores with diameters of 50 to 500 μm. These results were confirmed by Pagliai et al (1981). Cox et al. (2001) observed that fresh organic matters stabilize soil aggregates by breaking down rapidly and producing carbohydrates that act as an adhesive for soil particles.

1.2.6 Compost Effects on Turfgrass and Weed Seed Establishment

Hydroseeding is the most widely accepted practice used by the Virginia Department of Transportation for applying seeds to roadsides (DCR, 1992), but soils seeded in this manner are susceptible to wind and water erosion. Murphy and Arny (1939) were among the first to study the emergence of grass seedlings planted at different depths in various soil types. The researchers found similar results in field and greenhouse trials. They observed kentucky bluegrass (*Poa pratensis* L.), a relatively small seed averaging 2.8 million seeds per kg (Beard, 2002), attained greatest germination and emergence when planted at a depth no greater than 2.5 cm (Murphy and Arny, 1939). Stoffella et al. (2000) compared the establishment of bermudagrass (*Cynodon dactylon* L.) seeds (4. 1 million seeds per kg) (Beard, 2002) planted at depths of 0, 2.5, 5.0 and 7.5 cm into an immature compost and found that bermudagrass establishment decreased quadratically as compost thickness increased. Harrell and Miller (2005) used a mature yardwaste compost to compare the establishment rates of grass and weed seeds applied above and below compost treatments. They observed the highest establishment rates in treatments where smaller seeds were applied to the surface (Harrell and Miller, 2005). Based upon these findings, the use of compost for weed seed suppression has received growing attention.

Composts applied as mulches to soil usually suppress weeds (Lloyd et al, 2002; Persyn et al., 2007; Menalled et al., 2005; Roe et al., 1993). The weed suppression activity of composts is believed to decrease with increasing maturity since aerobic processes degrade phytotoxic compounds which suppress weeds (Richard et al, 2002). Menalled et al. (2002, 2005) observed weed suppression by compost to be species-specific. The researchers hypothesized this was due in part to seed size and depth of planting. Weed suppression was greatest when compost was applied at application rates 16 and 24 Mg C ha^{-1} (Menalled et al., 2002). Despite the potential weed control benefit, immature composts are not widely utilized in roadside revegetation projects (Richard et al., 2002) because high quality, mature compost is desirable for establishing vegetation (Hartz and Giannini, 1998).

1.2.7 Compost Application Strategies for Improving Revegetation Efforts

Differences in the beneficial effects of compost on soil properties, vegetation growth and quality are often due to application practices. The benefits of incorporating compost into soil are illustrated by a number of studies. Singer et al. (2006) compared differences in moisture content between surface and incorporated applications of 5 cm of yard-waste. Greater soil moisture content in the incorporated treatments following rainfall resulted in greater biomass yields. Linde and Hepner (2005) observed that incorporating 5.0 to 7.5 cm composted biosolids improved turfgrass establishment on a disturbed soil. Landschoot and McNitt (1994) reported similar beneficial effects of soil-incorporated papermill sludge compost on turf quality (color and density), and soil bulk density and organic matter concentrations. Landschoot (1995) and Powell

(2000) recommended incorporating 2.5 to 5.0 cm of compost to a soil depth of 10 to 15 cm for establishing home lawns, while Farrell and Poe (1997) recommend incorporating 5 cm of compost as deep as possible into both fine and coarse textured soils. For degraded urban soils, Cogger (2005) recommends incorporating 5.0-8.0 cm of compost to a depth of 20-25 cm.

Although compost application rates vary considerably from one study to another, maximum application rates for compost range from about 100 to 400 Mg/ha/yr on a dry weight basis (Cogger, 2005). Studies for lawn establishment were conducted in subsoils with less than 2% organic matter by Landschoot and McNitt (1994) and Gentilucci et al. (2001). Farrell and Poe (1997) and Powell (2000) have similarly proposed higher recommendation rates for subsoils. Research has demonstrated improved physical benefits to soils with increasing compost application rates, with maximum rates as high as 1/3 soil volume (Cogger, 2005).

Surface compost applications have also shown to be valuable for benefiting soil and vegetation. Studies suggest that compost blankets ranging from 2.5 to 5.0 cm depth produce greater vegetative growth than that achieved with fertilized hydromulches (USEPA, 1997) and reduce erosion on sloping lands (Block, 2000; Curtis et al, 2007). Compost blankets are commonly used for erosion control on unvegetated sloping roadcuts (Faucette et al., 2004; Persyn et al., 2007). The capability of compost blankets to reduce weed competition has been identified as another benefit of compost mulches (Lloyd et al, 2002; Persyn et al., 2007; Menalled et al., 2005; Roe et al., 1993). However, after Singer et al. (2006) planted native prairie mixtures of perennial grasses in Iowa at a 5 cm depth of surface applied (143 Mg ha^{-1}) compost, they observed lower percentages of perennial grasses and increased populations of noxious weeds.

1.2.8 Turfgrass Species Selection for Revegetation

The key to successfully revegetating a highway roadside is to utilize grass species which are quick to establish, easy to maintain and tolerable to environmental stress (DCR, 2003). In addition, vegetation must provide erosion control and meet aesthetic demands (Booze-Daniels et al., 2000). This is often met by utilizing non-native species (Skousen and Venable, 2008) such as tall fescue (*Festuca arundinacea* Schreb.), which is quick to establish and can adapt to a variety of environmental stresses such as heat and drought (Burns and Chamblee, 1979; 2002). Tall fescue is often seeded onto larger areas than other grass species on disturbed roadsides in Virginia because of its tolerance to poorly drained, cool, clayey soils, and moderate tolerance to salts (Burns and Chamblee, 1979). Highway roadsides in Virginia receive minimal mowing, fertilization and weed suppression maintenance by VDOT. During initial vegetation establishment, roadsides are hydroseeded per recommendations set by the Virginia DCR (DCR, 1992). The DCR commonly prescribes mixtures of tall fescue (*Festuca arundinacea* Schreb.), hard fescue (*Festuca longifolia* Thuill.), kentucky bluegrass (*Poa pratense* L.), orchardgrass (*Dactylis glomerata* L.) and/or perennial ryegrass (*Lolium perenne* L.) for permanent seeding in the Piedmont regions of Virginia (DCR, 1992). Although the selection of grasses for roadsides is based primarily on geographical region, cost and availability are also major considerations for planning (DCR, 1992). Turfgrasses recommended for lawns in Virginia by the Virginia Cooperative Extension (Goatley and Askew, 2009) include selected varieties of kentucky bluegrass, tall fescue, bermudagrass, zoysiagrass (*Zoysia* spp.) perennial ryegrass, and fine fescues (*Festuca spp.)*.

The main use of compost for lawn establishment and revegetation efforts is to create a favorable environment for the establishment of a healthy root system (Stahnke et al., 2000). Turf with a healthy root system will continually supply the soil with organic matter through root exudates and sloughing of dead root tissue (Cogger, 2005; Porter et al., 1980; Qian and Follett, 2002). Turf studies from Pennsylvania, New Jersey and California evaluating the effects of various compost materials on soils devoid of organic matter have reported that compost applications were beneficial to turf establishment and growth (Landshoot and McNitt, 1994; Gentilucci et al., 2001, Ries et al., 2004). Linde and Hepner (2005) observed increased turf quality in terms of color and density in soils amended with 5 and 7.5-cm incorporated compost treatments. Landschoot and McNitt (1994) reported higher turf establishment after four months in compost treated soils than in bare soils treated with synthetic fertilizers. The vegetation of West Virginia roadsides was found to be represented by combinations of native and non-native species (Rentch et al., 2005). Planted species were mixed with species introduced by various sources, including wildlife, birds, wind, people and adjacent undisturbed lands.

1.2.9 Compost and Turfgrass Stress Tolerance

Environmental stresses such as high temperatures, low moisture and ultraviolet radiation can result in poor turf quality (Ervin et al., 2005). High temperature stress leads to the accumulation of oxy free radicals in plant cells that can damage membranes (Leshem et al., 1981) through lipid peroxidation and protein denaturation, resulting in an overall reduction in photosynthetic function and increased senescence (Jiang and Huang, 2001). The presence of biologically active substances (BAS), including humic substances, amino acids and hormones, may enhance crop production by providing growth regulators for plants and by stimulating microbial activity for hormone/substrate production (Zhang et al., 2009). Ervin et al. (2005)

reported that BAS enhanced turfgrass tolerance to such environmental stresses as temperature and UV radiation. Compost, which contains humic substances, may exhibit BAS properties and/or responses; thus, after periods of environmental stress, compost may enhance turfgrass resilience and maintain photosynthetic activity.

Photochemical efficiency, measured as the ratio of variable chlorophyll fluorescence to maximum fluorescence (Fv/Fm), is indicative of the photochemical efficiency of photosystem II or relative photochemical efficiency (Bjorkman and Demmig, 1987; Zhang and Schmidt, 2000). The underlying principle of chlorophyll fluorescence is based upon the fate of light energy once it is absorbed by the chlorophyll molecules inside a leaf. Once light energy is absorbed it may either be used to drive photosynthesis, be lost as excess energy in the form of dissipated heat or it may be re-emitted as light and defined as chlorophyll fluorescence (Maxwell and Johnson, 2000). Although only one to two percent of all light absorbed is fluoresced, with the peak of fluorescence emission having a longer wavelength than absorption; thus, a relative yield of fluorescence is obtained by exposing a leaf to a defined wavelength and measuring the amount of light emitted (Maxwell and Johnson, 2000). Certain biosolids which contain high concentrations of BAS improved tall fescue quality under sufficient and insufficient moisture regimes and reduced deleterious photochemical response under moisture stress (Zhang et al., 2009). Although BAS are shown to improve plant stress tolerance, the underlying mechanisms are not well understood (Zhang et al., 2005, 2009).

1.2.10 Summary

The establishment and quality of vegetation on disturbed sites are affected by soil properties and management practices. Disturbed soils devoid of topsoil and nutrients compounded by poor structure and high clay content have subsequently resulted in poor vegetative stands. Management practices such as hydroseeding and straw mats have mitigated poor vegetation establishment to a limited extent as they fail to improve the adverse soil properties. Composts, when applied as a soil amendment, can address these poor soil properties. Research has demonstrated composts increase soil nutrient content, organic matter, plant available water, and decrease bulk density. Composts have also been shown to enhance vegetation establishment and quality.

Rising fertilizer costs and alternative methods for waste disposal have fuelled interests for applying composts as a management practice on disturbed soils. Further research is warranted to find the optimal rates and incorporation practices necessary to improve soil properties, turfgrass establishment and quality on disturbed soils. The depth of planting seeds is also of critical importance for revegetation efforts. Most standard hydroseeding operations only spray seeds on the soil surface, which may be transported during rainfall events before the seeds ever establish. Evaluating compost application practices with seed depths will help to contribute information for roadside mangers and new home owners.

1.2.11 Objectives

1. To compare the effect of surface-applied composts with standard hydroseeding applications on changes in soil chemical properties, botanical composition, ground cover and biomass on a minimally managed disturbed roadside.

2. To compare the short-term effects of various compost application rates and incorporation practices on turfgrass establishment, quality and changes in properties of a disturbed urban soil.

3. To compare the effect of depth of planting on germination and establishment of two variously-sized turfgrass seeds in compost in a greenhouse study.

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CHAPTER 2

Soil Nutrient and Fescue (*Festuca* spp.) Responses to Compost and Hydroseed on a Disturbed Highway Roadside

ABSTRACT

Excessive soil phosphorus (P) concentrations in Virginia's livestock- and poultry-rich Shenandoah Valley have resulted in the exploration of alternatives to land application of P-rich manures in the region. Composting poultry litter offers a potential value-added product that may be an economical substitute for hydroseeding on Virginia's low P, disturbed highway roadside soils. This research was conducted to compare compost to standard hydroseeding. Plots were established with either hydroseed or compost and measured for pH, Mehlich-I extractable K, Mg, Zn, P, Ca, Mn, total N, and organic C. The percent ground cover, botanical composition and biomass production of tall (*Festuca arundinacea* Schreb) and chewing fescue [*Festuca longifolia* ssp. *fallax* (Thuill.) Nyman] were measured for two years following establishment. In 2009, the compost treatment had increased Mehlich-I extractable soil K, Mg, Zn, and P. The greatest nutrient concentration was observed for extractable P which increased 566% in the compost treated soil but only 17% in the hydroseed treated soil. The percentage of fescue present in both treatments was highest in July 2008 and decreased with time. As the percentage of fescue in each treatment decreased with time, non-fescue species increased inversely. By late summer 2009, weed species comprised 55% and 53% of the average ground cover observed in the hydroseed and compost treatments, respectively. The beneficial effects of compost on the properties of the disturbed soils improved establishment of both the fescue and the non-fescue species.

Supplemental weed control is likely required to optimize the overall benefits of the compost application.

INTRODUCTION

Intensive poultry and dairy production in the Shenandoah Valley of Virginia has resulted in a surplus of nutrients from manure. The long-term application of animal wastes on agricultural lands at N-based rates results in surplus P that often exceeds agronomic requirements (Maguire et al., 2008) and poses threats for water quality. Composting poultry litter provides an alternative to direct land application in these highly concentrated areas of agricultural production, whereby a value-added product can be used in areas where soil P concentrations are low.

Increased traffic and road construction in Virginia has resulted in a growing number of disturbed roadsides characterized by poor vegetative establishment, quality and large quantities of undesirable weed species. The poor quality of the disturbed soils of these roadsides plays a significant role in the failures of vegetation on such sites (Curtis and Claassen, 2009). Disturbed soils are often characterized by high clay content, low nutrient status, poor structure, low organic matter and low water-holding capacity; thus, resulting in an overall environment that is unfavorable for plants. Traditional practices for seeding highway roadsides utilize hydroseeding and/or mulching in which a mixture of seeds, wood or paper fiber, dyes and tackifiers are sprayed onto the soil surface with water (Faucette et al., 2006). Although wood fiber mulches are excellent at providing temporary protection from soil erosion (Meyer et al., 1972), they may not stimulate the growth of dense vegetation (Tormo et al., 2007; Benik et al., 2003). Benik et al. (2003) reported wood fiber blankets used for controlling erosion resulted in 10 percent less vegetative cover and 30 percent less biomass than on soils without blankets two years after establishment. Another shortcoming of hydroseeding is that it does not address the poor physical and chemical properties of disturbed soils (Curtis and Claassen, 2009).

Soil conditioners, such as compost, can help restore the topsoil-like functionality of disturbed soils (Curtis et al, 2007). Compost applications can improve the disturbed soil physical properties, including soil aggregation, bulk density, and plant available water holding capacity (Cogger, 2005). Conserving water for plant growth is especially important in disturbed landscapes such as roadsides, since these sites are dependent upon precipitation to meet the vegetation water needs. Movahedi Naeini and Cook (2000) demonstrated that compost mulches reduced evaporation and increased soil water content. Singer et al., (2006) observed compost treatments increased soil water-holding content and decreased bulk density as compared to bare soil treatments as well as decreased bulk density. Landschoot and McNitt (1994) and Harrell and Miller (2005) showed that compost improves soil conditions which subsequently improves turfgrass establishment and quality on disturbed sites.

Nutrient additions to soil in compost are functions of compost application rate and composition, which typically varies by feedstock source(s). The carbon to nitrogen (C:N) ratio in composts vary with C and N properties of the feedstocks and controls fraction of organic N that mineralizes to become plant available. Thus, composts act as slow-release fertilizers that can sustain vegetation over time (Maynard et al., 2000). Poultry litter applications confound P accumulation in soils already high in P because composted litter contains high P (Sharpley and Moyer, 2000). Landschoot and McNitt (1994) observed subsoils deficient in P (50 kg ha^{-1}) increased in available P to 1708 kg ha^{-1} after four months with high rates of chicken-manure compost applications (510 m^3 ha^{-1}). Soils amended with composts containing high P have been shown to improve turf quality (Landschoot and McNitt, 1994), although additional P fertilization is not recommended for soils containing P above the agronomic requirements for turfgrass.

Composts have been shown to suppress weeds (Lloyd et al, 2002; Persyn et al., 2007; Menalled et al., 2005; Roe et al., 1993). Menalled et al. (2005), observed weed suppression by compost to be species-specific. The researchers hypothesized that this was due, in part, to seed size and depth of planting. Menalled et al. (2005) demonstrated weed suppression to be greatest when compost was applied at application rates of 16 and 24 Mg C/ha to weed seeds placed 2.5 cm under compost. Soil additions of C may decrease weed biomass by shifting the C:N ratio towards N immobilization (Blumenthal et al., 2003). As Persyn et al. (2007) demonstrated total biomass was lowest in biosolids compost blankets as compared to topsoil and bare subsoil treatments. They attributed this to the greater quantities of weeds present in the topsoil and bare subsoil treatments. Furthermore, they hypothesized the biosolids compost suppressed weeds as a result of the presence of phytotoxic compounds.

Highway roadside vegetation in Virginia is established and maintained under the auspices of the Virginia Department of Transportation (VDOT) with a primary goal of providing perennial vegetation that requires minimal inputs in mowing, fertilization and weed suppression. During initial vegetation establishment operations, roadsides are hydroseeded as per recommendations set forth by the Virginia Department of Conservation and Recreation (DCR, 1992). The key to successfully revegetating a highway roadside is to utilize grass species that are quick to establish, easy to maintain and tolerable to environmental stress. This requirement is often met in Virginia by utilizing non-native species such as tall fescue (*Festuca arundinacea* Shreb.), which is quick to establish and is adapted to a variety of environmental stresses such as heat, drought, moderate soluble salt content and poorly drained, cool, clayey soils (Skousen and Venable, 2008; Burns and Chamblee, 1979; 2002). The objective of this study was to compare the effects of surface-applied compost with hydroseeded wood fiber mulch to the surface of a disturbed roadside soil on soil properties, botanical composition, ground cover and biomass production.

METHODS AND MATERIALS

Site Description and Treatment Design

Field research was established on a disturbed roadside situated between two road cuts on Route 262 in Staunton, Virginia (38°07’37.35”N, 79°05’12.70”W) in March 2007. This site was selected for field trials since it contained poor vegetative establishment compounded by soils low in organic matter and nutrients based upon initial soil test reports. The soils contained on the site were considered to be relics of the roadcut construction processes and were sparsely vegetated by grass species and small forbs. The site was maintained by VDOT according to its standard management protocol, ensuring it represents similar low-maintenance roadsides throughout the Northern Virginia Piedmont region.

The climate in the Staunton/Harrisonburg area is temperate with annual temperatures ranging from 6.6 °C minimum to 29.4°C maximum (SERCC, 2009). The average total precipitation is 94 cm per year. The last spring frost occurs between February and April followed by the first fall frost between September and mid-October (SERCC, 2009). Precipitation between April and September averages 44 cm (SERCC, 2009). Vegetative species sown in this transition zone include those adapted to heat and drought tolerance such as tall fescue and chewings fescue (DCR, 1992; Funk et al., 1994).

In April 2007, two treatments consisting of compost surface applied at a rate of 235 m^3 ha^{-1} and wood cellulose fiber mulch ("hydroseed") hydroseeded at a rate of 1344 kg ha^{-1}were established on a 0-5% sloping roadside. To both treatments, 56 kg ha^{-1} each of tall fescue (*Festuca arundinacea* Shreb.) and chewings fescue [*Festuca longifolia* ssp. *fallax* (Thuill.) Nyman] were applied. The wood cellulose fiber mulch also included 503 kg ha^{-1} of 10-20-10 fertilizer. The treatments were replicated three times in a completely randomized block design. Six individual plots measured 30 m by 14 m each. Due to low establishment during the spring-summer of 2007, all plots were treated with a broadleaf herbicide (dicamba diglycolamine salt) and reseeded in September of 2007 according the previously described rates. The plots were mowed approximately once per year at a target height of 10 cm in 2007 and 2008 by VDOT.

The compost was made from a combination of poultry litter and woody waste by a local farmer (Ross Rhodes, Dayton, VA). The compost was analyzed for solids and total volatile solids via ashing (TMECC, 2001), total P via EPA 3050B (USEPA, 1986), bulk density (TMECC, 2001) and total organic C and total N via dry combustion on a VarioMax CNS analyzer (Elementar, 2000).

Soil Analysis and Biomass Sampling

The compost and hydroseeded soils were sampled during the study to assess the effects of time and treatment application on soil properties. Soil samples comprising ten cores sampled to a depth of 7.5 cm were collected prior to treatment application from each plot in March 2006 and at the conclusion of the study in October 2009. All soil samples were air-dried for 72 hours and ground to pass through a 2 mm sieve before routine analysis at the Virginia Tech Soil Testing Laboratory for pH, organic matter and Mehlich I (0.05 *M* HCl and 0.0125 *M* H_2SO_4) extractable

P, K, Ca, Mg, Mn, and Zn extractant analyzed by ICP-AES (Maguire and Heckendorn, 2009). Analyses of soil texture via the hydrometer method (Day, 1965) were conducted. In October 2009, the soil was analyzed for total organic C and total N via dry combustion on a VarioMax CNS analyzer (Elementar, 2000). Mineralogical analysis was conducted on a composite soil sample collected from all compost and hydroseed replications. Pretreatments for mineralogical analysis included the removal of organic matter with 30% H_2O_2 buffered at pH 5 with 1 M NaOAc (Kunze, 1965). Iron and aluminum oxides were removed with Dithionate citrate bicarbonate (DCB). Sand was removed by wet sieving the soil through a 300 mesh sieve and silt and clay were separated by centrifugation and decantation using a dispersant of 0.1 *M* Na_2CO_3 at pH 9.5. A Scintag XDS 2000 x-ray diffractometer (Scintag, Madison, WI) was used to determine the clay minerals present by analyzing samples saturated with K (KCl) with no heat treatment and after 4 hours heat treatment at 110, 300 and 550°C. Samples saturated with Mg ($MgCl_2$) were analyzed with no heat treatment and after 4 hours heat at 110°C. A random powder mount was prepared without cation saturation as a comparison. All samples were scanned at a fixed counting time of 4 seconds at 0.075° 2θ using CuKα radiation (40 mA, 45 kV).

Botanical Composition and Biomass

Botanical composition was determined visually twice a year in 2008 and 2009. A $0.05m^2$ quadrat was randomly placed in each plot so as to avoid edge effects and sampling overlap and replicated six times per plot. Ground cover (ranging from 0% for bare ground, no vegetation, to 100% for complete ground coverage) was measured for each quadrat. The percent of the total vegetation consisting of fescue and non-fescue (i.e. weed cover) were estimated in each quadrat. The total of fescue and non-fescue cover equaled 100 percent of the total vegetation by convention.

Biomass samples were collected on October 3, 2009. A 0.05m^2 quadrat was randomly placed within each plot and hand-harvested at a 5.0 cm height. All plant tissue harvested from each plot was separated in the field into one of two categories: fescues and non-fescues (weed species). Six quadrats were collected from each plot as either a fescue or a non-fescue composite sample. All biomass samples were dried in an oven at 65°C for forty-eight hours and subsequently weighed until constant mass was obtained.

Statistical Analysis

All statistical analyses were performed using SAS 9.2. Mean and standard error values were calculated for each variable. An analysis of variance (ANOVA) was performed using the SAS mixed procedure to test the treatment effects of compost and hydroseed on changes in botanical composition (fescue versus non-fescue species) with time (SAS Institute, 2008). To satisfy the convergence criteria of the model, the spatial power covariance structure was employed. Significant treatment differences were identified using the least squared means test. Treatment effects on soil properties and biomass were analyzed separately using an ANOVA with a Tukey multiple comparisons test in the GLM procedure (SAS Institute, 2008). A probability value of 0.05 was used for all analyses.

RESULTS AND DISCUSSION

Compost

The compost contained 723 g solids kg^{-1}, 668 g volatile solids kg^{-1}, 338 g total organic carbon kg^{-1}, 20.2 g total nitrogen kg^{-1}, 3.25 g total phosphorus kg^{-1}, and had a C:N ratio of 16.8. At a density of 622 kg m^{-3} and an application rate of 235 m^3 ha^{-1} (2.5 cm depth), the compost treatment supplied 106 Mg dry weight ha^{-1}, 35.7 Mg C ha^{-1}, 2.13 Mg N ha^{-1}, and 343 kg P ha^{-1}.

Composts are applied at 2.5 to 7.5 cm depths on marginal soils (USCC, 1996; Cogger, 2005). At an estimated N availability of 10-15% of the total N (Bowden et al., 2007), the compost would be expected to provide approximately 213-320 kg N ha^{-1} during the season after application.

Soil Properties

Prior to treatment application, the initial soils sampled at the Route 262 field site in March 2007 had uniform soil properties of pH 7.75, 8.7 mg kg^{-1} P, 70 mg kg^{-1} K, 1486 mg kg^{-1} Ca, 176 mg kg^{-1} Mg, 0.6 mg kg^{-1} Zn, 29 mg kg^{-1} Mn, 2.81g N kg^{-1} soil and 32.4 g C kg^{-1} soil. Results from the particle analysis identified silts between 4.5 and 40µ as comprising 60% of the soil. The remaining fractions included 30% clay and 10% sand. X-ray diffractograms identified the three major mineral constituents as kaolinite, HIV and illite with smaller peaks of quartz, soil smectite and goethite present.

Two years after the application of treatments, no differences in soil pH in the compost and hydroseed occurred due to treatment (Table 2-1). Studies have demonstrated increases in soil pH range from 0 to 1 unit in soils amended with near neutral to slightly alkaline pH (Cogger, 2005). With an initial pH of 8.2, the compost likely increased the soil pH, despite the generation of acidity due to the nitrification of the compost nitrogen. N mineralized from the composts were likely assimilated by the vegetation (Hadas et al., 1995). Treatment differences in organic C and total N were evident in soils amended with compost having values approximately double those measured in the hydroseed treatments (Table 2-1).

Soil P concentrations in the composts were significantly greater than the hydroseed treatments in 2009 (Table 2-1). These differences are directly attributable to the higher rates of P applied in the compost (343 kg ha^{-1}). Fertilizer recommendations for tall fescue range from 0-62 kg P ha^{-1} for P deficient soils (Chalmers and Whitt, 2000) which indicates that the compost provides P greater than the agronomic rate. In 2009, the composts contained higher concentrations of Mehlich-I extractable K, Mg, and Zn than the hydroseed treatments. No differences in Ca (mean = 2756 mg kg^{-1}) or Mn (mean = 19.5 mg kg^{-1}) occurred due to treatment. Decreases in micronutrients are likely in high pH soils where metals precipitate. No rationale could be offered to explain the increase in soil Zn.

Botanical Composition and Ground Coverage

Overall ground coverage varied significantly with time ($P<0.0001$) and treatment ($P<0.0001$). The compost resulted in higher ground coverage (mean = 65%) than the hydroseed (mean = 44%) over the course of 2 years following application of treatments. No differences in ground coverage with time were observed between July of 2008 (mean = 71%), October of 2008 (mean = 56%), and June of 2009 (mean = 42%). Ground coverage in October of 2009 was significantly less than as reported in July of 2008 (mean = 30%). Overall ground coverage was greatest during July of 2008 (mean= 71%). No difference in ground coverage was observed between all dates sampled except in June of 2009 when ground coverage was lowest (Table 2-4).

The percent fescue observed in both the compost and hydroseed treatments decreased during the 15-month period from July 2008 to October 2009 as non-fescue species increased (Table 2-2). The percent fescue in the hydroseed treatment declined to its lowest percentage in June 2009. The percent of fescue present in the hydroseed treatments was less in June and October of 2009 than in July and October of 2008 (Table 2-2). The percent of fescue present in the compost treatments decreased from July 2008 to October 2008. No differences in the percent of fescue present in the compost treatments were observed between October 2008 and October

2009. By the final sampling in October 2009, fescue coverage was the same in both treatments and comprised about 50% of the total vegetation. Non-fescue species were lowest in the hydroseed treatment during July and October 2008 and increased in 2009. The percentage of non-fescue species in the compost treatments were lowest in July 2008 and increased in October 2008. Although species seeded on roadsides are adapted to local climate conditions, these species cannot compete with weeds species during periods of severe stress (Tormo et al., 2007). Likewise, Muzzi et al. (1997) reported hydroseed operations in Italy did not promote dense vegetation with non-native species of vegetation. Overall decreases in the percentage of fescue observed in both treatments were likely due to the early senescence of the tall and chewings fescues. Senescence of fescue is most commonly associated with high temperatures and moisture stress (Burns and Chamblee, 1979). As our results suggest, the environmental stresses had a greater impact on botanical composition than treatments.

Singer et al. (2006) reported initial plant densities were higher in non-composted than 5 cm-surface applications of compost. The 5 cm surface application of compost was observed by Singer et al (2006) to suppress annual grass germination and establishment, but not larger broadleaf weeds. In our study, we observed an increase in the percentage of weeds in the compost treatments after July of 2008, which remained constant until the conclusion of the study. Our compost plots were dominated by the broadleaf weed, spotted knapweed (*Centaurea stoebe* L.). Spotted knapweed is commonly found on roadsides and is easily transported on the undercarriage of vehicles or vehicles carrying hay with knapweed seeds (Lym and Zollinger, 1992).

Biomass

There were no treatment differences on dry matter yields of fescue or non-fescue for compost (16.7 Mg fescue ha^{-1} vs 21.5 Mg non-fescue ha^{-1}) or hydroseeding (5.5 Mg fescue ha^{-1} vs 5.6 Mg non-fescue ha^{-1}). The compost treatments produced greater biomass (38.2 Mg ha^{-1}) than the hydroseed treatments (11.1 Mg ha^{-1}). Faucette et al. (2006) and Richard et al. (2006) found seeded compost blankets had the same biomass of sown species as hydroseed treatments, but the compost blankets had significantly less weed biomass. Our sampling method using small 0.05 m^2 quadrats to identify random areas for collecting biomass may have underrepresented the lack of uniformity in vegetation present in the plots. Most of the plots contained patches of dense vegetation, including broadleaf weeds, in addition to patches of bare ground where erosion was evident.

CONCLUSIONS

Poultry litter compost applied to the surface of a disturbed highway roadside can improve soil properties, including total N, organic C, and Mehlich-I P. For disturbed highway roadsides which utilize low-maintenance plant species including fescues, the addition of P from poultry-based composts can be substantial. The application of compost can increase macronutrient and micronutrient content in soils previously deficient in nutrients to concentrations adequate for long-term plant growth. Although composts can promote greater grass establishment, they also provide conditions (i.e. nutrients, moisture-holding capacity) that promote the establishment of competing broadleaf weeds. Environmental stresses including high temperatures and low moisture compounded by highly compacted soils with a shallow root zone may have contributed to the decrease of fescue over time. It is recommended that roadside mangers desiring to optimize the establishment and aesthetic qualities of roadside vegetation with compost use herbicide applications to keep weed populations in check. Our results indicate that composts improve soil properties over traditional hydroseeding practices, creating conditions which facilitate the establishment and growth of vegetation on disturbed highway roadsides.

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Table 2-1.Mean values of soil pH, total N, organic C and Mehlich I-extractable P, K, Mg, and Zn for the treatments sampled two years after amendment application.

	pH†	Total N†	Organic C†	P†	K†	Mg†	Zn†
		g N/kg soil	g C/kg soil				
Hydroseed	7.91 ± 0.05 ab	1.12 ± 0.05b	14.4 ± 1.47b	41.7 ± 4.8 b	111 ± 13 b	291 ± 53 b	1.17 ± 0.1 b
Compost	8.08 ± 0.06 a	2.81 ± 0.25a	32.4 ± 4.36a	277.7 ± 15.7 a	376 ± 146 a	422 ± 40 a	4.47 ± 0.6 a

†Means with standard errors followed by the same letter in each column are not statistically different at P <0.05.

Table 2-2. Mean values with standard errors of fescue and non-fescue for the compost and hydroseed treatments during summer and fall, 2008-2009.

	Fescue†	Non-Fescue†
	%	
July 2008		
Hydroseed	92.4 ± 2.4 a	7.6 ± 2.4 c
Compost	76.7 ± 6.8 a	23.3 ± 6.8 c
October 2008		
Hydroseed	78.2 ± 5.4 a	21.8 ± 5.4 c
Compost	53.9 ± 7.2 b	46.1 ± 7.2 b
June 2009		
Hydroseed	25.6 ± 8.0 c	74.4 ± 8.0 a
Compost	45.2 ± 9.3 bc	54.0 ± 9.5 ab
October 2009		
Hydroseed	45.2 ± 9.7 b	54.8 ± 9.7 b
Compost	47.3 ± 9.8 b	52.7 ± 9.7 b

†Means with standard errors followed by the same letter in each column are not statistically different at P <0.05.

CHAPTER 3

Compost Application Practices for Improving Turfgrass Establishment and Quality on a Disturbed Urban Soil

ABSTRACT

New home construction degrades the soil environment by stripping lands of their fertile topsoil, thereby creating a soil environment that is unfavorable for vegetation establishment. Field studies were conducted between March and October 2009 to compare the effects of various compost rates and incorporation treatments including: (1) fertilizer control; (2) 2.5 cm compost surface applied; (3) 2.5 cm compost incorporated; (4) 5.0 cm compost incorporated; (5) 0.6 cm compost blanket; and (6) straw mat. Turfgrass growth and quality, resilience to environmental stress, and soil properties were evaluated. A corollary greenhouse study was conducted to compare the effects of seed size and depth of placement in the soil-compost media on germination and emergence. Turfgrass density increased with compost rate applied whereas color (greenness) increased with time. The straw mat and 0.6 cm compost blanket produced comparable color and density observations during the five months of study. The biomass harvested was affected by time and not by treatment. No difference in photochemical efficiency measurements occurred due to treatments. In greenhouse trials, the germination and emergence of smaller bermudagrass seeds were less than 10% when planted at depths greater than 1.3 cm. Fescue seeds germination and establishment was overall unaffected by depth in topsoil but poor below the surface of compost in a low-pH subsoil. Compost

applications greater than 0.6 cm improved soil properties and turfgrass quality over longer periods of time than fertilizer alone.

INTRODUCTION

Urban development degrades the soil environment (Cogger, 2005). On construction sites across the United States, disturbed urban soils are created when previously native lands are stripped of topsoil and the associated biological activity is removed (Box, 1978). Furthermore, this process involves removing the existing vegetation, stripping the land of its topsoil, compacting the exposed subsoil with heavy machinery and, if applicable, replacing the topsoil with a low-quality fill (Cogger, 2005). In response to these processes, the soil environment is degraded considerably and poses challenges for new homeowners to establish turfgrass (Landschoot and McNitt, 1994; Loschinkohl and Boehm, 2001).

Straw mulches or mats are recommended by the Virginia Department of Conservation and Recreation (DCR) as a best management practice for establishing vegetation on disturbed soils (DCR, 1992). Straw mats are designed to increase seed establishment by protecting seeds, maintaining moisture, permitting root development through the mat into the soil and reducing weed seed germination (Hensler et al., 2001). Straw mats may produce dense vegetative cover (Muzzi et al., 1997) when compared to other revegetation techniques, but oftentimes are not preferred because costs and efforts to remove mats that may result in damage to the established vegetation (Harrell and Miller, 2005). The usage of straw mats does not address the poor physical and chemical properties of disturbed soils.

The use of composts for improving soil properties and vegetation establishment (Reinsch et al., 2007) has been shown to vary by application rate. Landschoot and McNitt (1994) observed that the available nutrients in yardwaste composts helped to improve Kentucky bluegrass establishment. A compost application rate of 510 m^3 ha^{-1} provided faster establishment than 255 m^3 ha^{-1} (Landschoot and McNitt, 1994). Compost application rates vary depending upon the soil type and the nutrient status of the soil needing revegetation. Landschoot (1995) and Powell (2000) recommend applications of 5.0 cm depth incorporated 10-15 cm for loam soils whereas Farrell and Poe (1997) recommend incorporating compost as deep as possible into both fine and coarse textured soils. Although research has demonstrated increasing physical benefits to soils with increasing compost applications with rates as high as 1/3 volume of soil, the maximum application rates for compost range from about 100 to 400 Mg/ha/yr^{-1} on a dry weight basis (Cogger, 2005).

Various practices for applying composts exist including the usage of composts as blankets for erosion control and as a media for seeding. When applied as blankets over seeds, composts offer a protective cover for turfgrass seeds which may be otherwise eroded before establishment. When comparing the establishment and quality of fescue sown under straw mats to 5 cm compost blankets, Reinsch et al. (2007) observed greater turf color and biomass in the compost treatments. Persyn et al. (2007) found 5 cm surface applications of compost were equally as effective for vegetation establishment as 10 cm surface applications. Not all studies have observed greater establishment or turfgrass quality in surface applications of compost. Harrell and Miller (2005) demonstrated composts applied as blankets did not increase the germination and establishment of turfgrass on disturbed slopes.

Studies have investigated compost for regenerating topsoil functionality in disturbed soils (Curtis and Claassen, 2009) by shifting their focus to incorporating the compost into the soil for improving turfgrass establishment and quality (Landshoot and McNitt, 1994). Singer et al. (2006) applied 5.0 cm of yard-waste compost and compared soil moisture responses to unincorporated and incorporated treatments in Iowa on soil moisture. This study suggested that the moisture content was greatest in incorporated treatments after significant rainfall events, resulting in overall greater biomass than non-composted treatments. Similarly, Landschoot and McNitt (1994) and Linde and Hepner (2005) found 5.0 to 7.5 cm incorporated composted biosolids performed well as a turfgrass amendment on a disturbed soil.

Regardless of soil amendment practice, another consideration for homeowners establishing turfgrass is the placement (or depth) of turf seed. The germination and emergence success of smaller-sized seeds are decreased with increased depth sown (Benvenuti et al., 2001; Stoffella and Patterson, 2000). Menalled et al. (2005), observed seed germination and establishment for weeds sown in compost to be species-specific. The researchers hypothesized that this was due, in part, to seed size and depth of planting (Menalled et al., 2005).

Following establishment, environmental stresses such as high temperatures, low moisture and ultraviolet radiation can result in an overall reduction in photosynthetic function, increased senescence and poor turf quality (Ervin et al., 2005). Rapid root growth, turfgrass recovery and maintenance of photosynthetic activity are important for the survival of establishment of turfgrass species following environmental stress (Ervin et al., 2005; Goatley and Schmidt, 1991). Few studies have addressed the effects compost has on established turf resilience to environmental stress. According to Zhang et al. (2009) the presence of biologically active substances (BAS) including humic substances, amino acids and hormones may enhance crop production by providing growth regulators for plants and by stimulating microbial activity for hormone/substrate production. Ervin et al (2005) reported plant growth regulators enhanced turfgrass tolerance to such environmental stresses as temperature and UV radiation. Compost, which contains BAS, may exhibit properties of plant growth regulators; thus, compost may enhance turfgrass resilience and maintain photosynthetic activity after periods of environmental stress.

With various compost sources and application practices available for improving soil properties and turfgrass establishment and quality, further research is warranted to determine which practice is most effective for establishing turfgrass on disturbed soils. The objective of this study was to evaluate various compost application practices for improving the germination and establishment, quality, and resilience of turfgrass to environmental stress on a disturbed urban soil.

METHODS AND MATERIALS

Field Site Description and Treatment Design

The field site was located in Lynchburg, Virginia on a parcel of land adjacent to a recently constructed apartment complex (lat 37º21’16.40” N, long 79º14’32.06” W). The site was chosen because its soils were severely disturbed by urbanization and lacked topsoil, creating nutrient-deficient conditions which proved unfavorable for initial turfgrass revegetation efforts.

The climate in the Virginia piedmont is characterized as humid, sub-tropical with annual temperatures ranging from -2.7°C minimum to 30° C maximum (SERCC, 2009). The average annual precipitation in the Lynchburg area is 104 cm (43 cm snowfall) with precipitation between April and September averaging 55 cm (SERCC, 2009). The first frost occurs around mid to late October and the last frost between late March/early April (SERCC, 2009). The piedmont region is often referred to as the transition zone whereby species of warm and cool season grasses are adapted. Common species of turfgrass recommended for the establishment of residential lawns in this region include tall fescue (*Festuca arundinacea* Shreb.), kentucky bluegrass (*Poa pratenis* L.), and perennial ryegrass (*Lolium perenne* L.) (DCR, 1992). All soils on the site were classified as a truncated Cecil (Fine, kaolinitic, thermic Typic Kanhapludult) subsoil (B-horizon).

Plot Establishment and Maintenance

Prior to plot establishment in March of 2009, the field site was graded to a 2-3% slope and all vegetation was removed. Twelve plots measuring 18.2 m x 4.6 m (83.6m^2) and six plots measuring 9.1 m x 2.3 m (21 m^2) were established. Five treatments were replicated three times each in a randomized complete block design. In March 2007, five treatments were established consisting of various application rates and incorporation practices. The treatments included: (1) fertilizer control, (2) 2.5 cm (depth) compost (39.2 Mg ha^{-1}) surface applied (3) 2.5 cm compost depth applied (39.2 dry Mg ha^{-1}) incorporated to a depth of 7-10 cm (4) 5.0 cm compost depth applied (78.4 Mg ha^{-1})

incorporated with an aerovator to a depth of 7-10 cm, (5) 0.6 cm depth compost (9.8 Mg ha^{-1}) surface applied blanket and (6) a straw mat. The fertilizer control, 0.6 cm compost blanket and the straw mat treatments received fertilizer according to the Virginia Tech Soils Testing Lab recommendations (Maguire and Heckendorn, 2009): 45 kg ha^{-1} of urea, 172 kg ha^{-1} of triple super phosphate, and 134 kg ha^{-1} of potash.

All treatments were seeded with "Landscaper's Choice Mixture" (Evergreen Seed, LLC, Rice, VA, USA) at a rate of 448 kg ha^{-1}. The seed consisted of a 70% mixture of four varieties of tall fescue *Festuca arundinacea* Shreb.: 'Magellan','Coronado Gold', 'Regiment' and 'Tomcat', 14% perennial ryegrass *Lolium perenne* L. 'Linn' and 10% Kentucky bluegrass *Poa pratenis* L. 'Baron'. The fertilizer control was seeded and aerovated in one pass. To the 2.5 cm surface compost application, seeds were broadcast on the compost surface without any tillage using a compost spreader (Earth and Turf, New Holland, PA, USA). Seeds applied on the 2.5 cm and 5 cm depth compost incorporated treatments were applied after each of the plots were aerovated twice with a Ventrac 31 aerovator (Venture Products Inc., Orrville, OH, USA) and subsequently rolled. For the 0.6 cm compost blanket and the straw mat, seeds were applied immediately after fertilizer applications then covered with either the compost blanket or the straw mat. The straw mat was staked into the soil.

The fifth and sixth treatments were a split plot design in which the entire plot was first seeded and fertilized according to the same Virginia Soil Testing Lab recommendations used for the fertilizer treatment. To half the plot, 0.6 cm depth compost (9.8 Mg ha^{-1}) was surface applied as a blanket over the seeds and to the other half of the plot, a 100% straw fiber mat (North American Green® S150, Poseyville, IN, USA) was pinned into the soil surface. After establishment, all plots were mowed monthly to 5 cm height and clippings were kept within their respective plots. A broadleaf herbicide, 'trimec' (2-4 D, MCPP, dicamba) was applied in July 2009 at a rate of 0.57 L ha^{-1}. In August 2009, 23 kg/ha application of urea fertilizer was applied per recommendations for cool-season grass establishment in Virginia (Goatley et al., 2009).

The compost used was obtained locally (Royal Oak Farm, LLC, Lynchburg, VA, USA) and consisted largely of a 1:2 mixture of primary:secondary processed paper mill sludge and additional smaller fractions of complementary feedstocks, including woody waste, wood ash, food processing wastes from an infant formula manufacturing plant and dissolved air flotation sludge from a potato food processing plant. Composts analyses were performed by A&L Laboratories, Inc. (Memphis, TN) and included pH (US EPA, 2004), electrical conductivity (EC; 1:2 compost to water), total organic C and total N via dry combustion on a VarioMax CNS analyzer (Elementar, 2000) and P, Ca and Mg by extraction in an ammonium acetate (pH 7) extract solution and analyzed on a AES-ICP (NCRRP, 1998). Compost maturity was determined using Solvita maturity index for CO_2 and NH_3 (Woods End, Mt Vernon, ME, USA).

Soil Analysis

Soil samples comprising ten cores sampled to a depth of 7.5 cm were collected prior to treatment application from each plot in March 2009 and six months after application in August 2009. All soil samples were air-dried for 72 hours and ground to pass a 2 mm sieve before routine analysis at the Virginia Tech Soils Testing Laboratory for pH, cation exchange capacity (CEC) and Mehlich I-extractable P, K, Ca, Mg, Mn, and Zn (Maguire and Heckendorn, 2009). The soil was analyzed for total organic C and total N via dry combustion on a VarioMax CNS analyzer (Elementar, 2000).

Biomass and Turf Quality

Biomass was harvested once a month during May, July, September and October of 2009 from a 0.5 m × 18 m (9 m^2) strip mowed in the center of each plot (0.5m x 9 m or 4.5 m^2 for straw mat and compost blanket split plots) at a 5 cm height using a lawn mower equipped with a detachable bag. All biomass samples were dried in an oven at 65°C for forty-eight hours and subsequently weighed until constant mass was obtained.

Visual assessments of turf color and density were made for all plots using a scale of 1 to 9 (1=worst, 9=best) according to the methods described by the National Turfgrass Evaluation Program (NTEP, 2009). All assessments were made by the same researcher in June, September and October 2009.

Photochemical Efficiency

In September 2009, chlorophyll fluorescence (Fv/Fm) was measured on all plots with a handheld dual wavelength fluorometer (OS-50 II, Opti-Sciences, Inc., Tyngsboro, MA) as an indicator of photochemical response. The ratio of variable fluorescence to maximum fluorescence at 690 nm (Fv/Fm) is indicative of Photosystem II or relative photochemical efficiency (Zhang et al., 2009). Ten readings were measured from each plot canopy in areas that were deemed visually representative of the entire plot. Senesced areas were avoided as measurements were too low for detection by the fluorometer. The

Fv/Fm measurements from each plot were calculated based on the average of the ten readings.

Greenhouse Study

In June 2009, we initiated a greenhouse study to compare the effects of seed size and depth sown in growth media on seed germination and emergence. Five treatments were replicated five times in a completely randomized design. Hulled bermudagrass 'Numex Sahara' (*Cynodon dactylon* L.) and tall fescue 'Greenkeeper,' 'Coyote II' and 'Dynasty'(*Festuca arundinacea* Shreb.) were used to compare seed two seed sizes (bermudagrass being much smaller than fescue). The five treatments were seeds (1) applied on the surface of 2.5 cm deep compost; (2) sown under 0.6 cm of compost; (3) sown under 1.3 cm of compost; (4) sown under 2.5 cm of compost; and (5) placed on soil surface covered by a straw mat.

The studies were conducted in 475cm^3 plastic cups modified with six, 4.8 mm holes for drainage on the bottoms. Each cup was filled half-way with 400 g of Orangeburg series (Fine-loamy, kaolinitic, thermic typic Kandiudults) topsoil, air dried and ground to pass through a 2 mm sieve. The air-dried and ground samples were analyzed for routine soil test methods at the Virginia Tech Soils Testing Laboratory for pH and Mehlich I-extractable soil P, K, Ca, Mg, Z, and Mn for analysis by ICP-AES (Maguire and Heckendorn, 2009). Total organic C and total N were analyzed via dry combustion on a VarioMax CNS analyzer (Elementar, 2000). Estimated CEC was reported as the addition of the Mehlich I-extractable Ca, Mg, K and exchangeable acidity

(Maguire and Heckendorn, 2009). The soil properties of the Orangeburg soil are presented in Table 3-6.

The cups with soil were thoroughly moistened with tap water and allowed to drain of free water before adding the treatments. After draining, twenty-five tall fescue or bermudagrass seeds were sown in each cup. All cups were randomly placed on a bench in the greenhouse for four weeks beginning June 12, 2009 and allowed to germinate under natural light conditions. The ambient temperature in the greenhouse was set at 22°C. Growth media in the cups were watered six times a day with overhead misters. Germination and emergence of the grass seeds were counted daily for one month, by which time no additional seedlings emerged.

In July 2009, we initiated a second greenhouse study to compare the effects of depth of fescue sown in growth media on seed germination and emergence. Seven treatments were replicated five times in a completely randomized design. Thirty-five cups were filled with 400 g of a Bt horizon of a Shottower series (Fine, kaolinitic, mesic Typic Paleudult) sampled from Virginia Tech's Kentland Farm. The soil was air-dried and ground to pass through a 2 mm sieve. In addition to the five treatments used in the previous study, two additional treatments were included and all treatments were replicated five times. The seven treatments were tall fescue seeds (1) applied on the surface of 2.5 cm deep compost, (2) sown under 0.6 cm of compost, (3) sown under 1.3 cm of compost, (4) sown under 2.5 cm of compost, (5) placed on soil surface covered by a straw mat (0.73 kg m^3 by weight), (6) sown under 1.3 cm of soil, and (7) sown under 1.3 cm compost-amended soil. Treatment #7 was made by incorporating 2.5 cm depth of compost into a 2.5 cm depth of soil. Germination and emergence of the tall fescue seeds were counted daily for one month, by which time no additional seedlings emerged. Air-dried and ground samples were analyzed for routine soil test methods at the Virginia Tech Soils Testing Laboratory for pH, CEC and Mehlich I-extractable soil P, K, Ca, Mg, Zn, and Mn for analysis by ICP-AES (Maguire and Heckendorn, 2009). Total organic C and total N were analyzed via dry combustion on a VarioMax CNS analyzer (Elementar, 2000). The soil properties of the Shottower soil are presented in Table 3-6.

Statistical Analyses

Statistical analyses were performed using SAS 9.2. Mean and standard error values were calculated for each variable. To evaluate the effects of treatments on soil properties, an ANOVA with a Tukey multiple comparisons test in the GLM procedure was used (SAS Institute, 2008). An analysis of variance (ANOVA) was performed using the SAS mixed procedure to test the treatment effects of the 2.5 cm compost surface application, 2.5 cm compost incorporated, 5.0 cm compost incorporated and fertilizer control on changes in turf color, turf density and biomass with time (SAS Institute, 2008). A separate ANOVA was performed in the SAS mixed procedure to test the treatment effects of the 0.6 cm compost blanket and the straw mat on changes in turf color, density and biomass with time. To satisfy the convergence criteria of the model, the spatial power covariance structure was employed. All variables were log-transformed. Significant treatment differences were identified using the least squared means test. To compare the five treatment effects on soil properties and photochemical efficiency, an ANOVA with LSD multiple comparisons test in the GLM procedure was used (SAS Institute, 2008). To compare seed size and depth sown on germination and emergence in the first greenhouse trial, an ANOVA with Tukey multiple comparisons test in the GLM procedure was used

(SAS Institute, 2008). Treatment effects on fescue establishment for the second greenhouse trial were analyzed using an ANOVA with Tukey multiple comparisons test in the GLM procedure was used (SAS Institute, 2008). A probability value of 0.05 was used for all analyses.

RESULTS AND DISCUSSION

Compost Properties

The compost contained 440 g solids kg^{-1} and had a pH 7.9 and EC 2.97 ds m^{-1}. The compost was determined as very mature by Solvita CO_3 and NH_3 respiration tests. The application rates of total P, total N, organic C, Ca, and Mg supplied by the compost treatments are presented in Table 3-1 by rate of application.

Soil Properties

The initial soil properties of the truncated Cecil soil on the field site were pH 7.1, CEC 7.3 cmol kg^{-1} soil, and Mehlich I-extractable nutrients: 6.7 mg kg^{-1} P, 178 mg kg^{-1} K, 2734 mg kg^{-1} Ca, 269 mg kg^{-1}Mg, 1.2 mg kg^{-1}Zn, and 15 mg kg^{-1}Mn. The initial P and K concentrations were considered inadequate for establishing and providing nutrients for one year of turfgrass growth (Maguire and Heckendorn, 2009). Five months after plot establishment, treatment effects were observed for all soil properties except pH (mean= 7.7) between the 2.5 cm compost surface, 2.5 cm compost incorporated, 5.0 cm compost incorporated and fertilizer control treatments (Table 3-2). With the exception of Mn, no differences between the 0.6 cm compost blanket and the straw mat in pH (mean= 7.4), cation exchange capacity (mean= 7.1 cmol kg^{-1}), P (mean= 33.8 mg kg^{-1}), K (mean= 332 mg kg^{-1}), Ca (mean= 2356 mg kg^{-1}) Mg (mean= 201 mg kg^{-1}), Zn (mean = 3.0 mg kg^{-1}), total N (mean=665.3 mg kg^{-1}) and organic C (11.1 g kg^{-1}) occurred due to treatment. Manganese concentrations were higher in the 0.6 cm compost blanket (26.5 mg kg^{-1}) than the straw mat (15.0 mg kg^{-1}). No logical explanation could be offered as to why the only nutrient to increase between the 0.6 cm compost blanket and the straw mat was Mn.

Composts applied to disturbed soils have been documented to improve soil properties and provide all of the necessary nutrients for plant growth (Cogger, 2005). No differences were observed between the 2.5 cm and the 5.0 cm compost incorporated treatments for cation exchange capacity, K, Ca, Mg, Zn, Mn and total N (Table 3-2). Similarly, Linde and Hepner (2005) demonstrated similar pH, cation exchange capacity and concentrations of Mg, and Ca in soils incorporated with 2.5. 5.0 and 7.5cm of biosolids compost. They attributed these similarities in soil properties to soil dilution and turfgrass uptake (Linde and Hepner, 2005). As compared to the 2.5 cm compost surface application, the 5.0 cm compost incorporated treatment had greater cation exchange capacity and higher concentrations of P, K, Ca, total N and organic C due to a greater application of compost. No differences were observed between the 2.5 cm compost surface application and the 2.5 cm compost incorporated in cation exchange capacity, P, K, Ca, Mg, Zn, Mn, total N or organic C due to treatment. Thus, incorporation had no effect on soil properties when compared to surface applications applied at a similar rate (2.5 cm depth).

One of the main limitations for growing turfgrass in disturbed soils is the availability of soil nutrients. Readily-available fertilizers can be consumed within weeks (Chalmers and Whitt, 2000) whereas composts can supply nutrients over time (Cogger, 2005). Five months after treatment application, the fertilizer control had lower cation exchange capacity, P, K, Mg, Zn, Mn and organic C than the 2.5 cm compost surface, 2.5 cm compost incorporated, and 5.0 cm compost incorporated treatments (Table 3-2). Despite the N supplied by the compost treatments and since no soil N tests exist for homeowners, all treatments received N fertilization in the fall of 2009 based upon visual assessments of color (Landschoot and McNitt, 1994).

Turf Quality and Biomass

Turf color varied significantly with time ($P<0.0001$) but not with treatment ($P=0.413$) among the fertilizer control, 2.5 cm compost surface, 2.5 cm compost incorporated, and 5.0 cm compost incorporated treatments. The average turf color ratings increased over time to the highest color assessment (5.6 out of 9) in October 2009 (Table 3-3). No differences in turf color assessments were observed in the straw mat and 0.6 cm compost blanket, as both treatments were unaffected by time or treatment. All color ratings assigned to the treatments were below 6, which are considered unacceptable turf by the NTEP (NTEP, 2009). Prior to N fertilization in September, there were no differences in color assessments between July and September 2009. However, after N fertilization in September to the entire field site, all treatments with the exception of the straw mat and the 0.6 cm compost blanket increased turfgrass color in October as readily-available N fertilizers were consumed.

Turfgrass density in the fertilizer control, 2.5 cm depth compost surface, 2.5 cm depth compost incorporated, and 5.0 cm depth compost incorporated treatments was affected significantly by treatment ($P=0.034$) but not by time ($P=0.250$). The highest average rating of turfgrass density (4.9 out of 9) belonged to the 5.0 cm compost incorporated treatment (Table 3-4). Interestingly, the fertilizer control had density ratings comparable to the 2.5 cm depth compost surface and the 2.5 cm depth compost incorporated treatments (Table 3-4). As with turf color ratings, no differences in density ratings were detected between the straw mat and the 0.6 cm compost blanket as neither were affected by treatment (P= 0.434) or time (P=0.424). All average turfgrass ratings of density were below the minimum 6 required by the NTEP as acceptable turf (NTEP, 2009). Linde and Hepner (2005) demonstrated improved turfgrass density on soils amended with biosolids compost was due in part to the chemical differences between the compost and non-compost treatments, despite the need for supplemental N fertilizer.

Only time effects (P<0.0001) were significant for turfgrass biomass harvested during 2009 among the fertilizer control, 2.5 cm depth compost surface, 2.5 cm depth compost incorporated, and 5.0 cm depth compost incorporated treatments. Over time, the amount of biomass harvested decreased from an average of 211.8 Mg ha^{-1} in May to 77.25 Mg ha^{-1} in October (Table 3-3). Biomass harvested from the straw mat and 0.6 cm compost blanket were not significant for treatment (P=0.880) but were significant for time effects (P=0.0005). Differences in biomass harvested from the straw mat and 0.6 cm compost blanket decreased from the initial May harvest and remained unchanged throughout the duration of the study from July to October (Table 3-5).

Photochemical Efficiency

Differences in photochemical efficiency measurements collected from the canopies of the five treatments were not statistically significant (P=0.162). The average photochemical efficiencies (Fv/Fm) for all treatments was 0.62. According to Bjorkman and Demmig (1987) Fv/Fm values are optimal at 0.83 for most plant species with values below 0.83 evidence of stress. In greenhouse studies, Zhang et al. (2009) demonstrated tall fescue amended with biosolids showed improved photochemical efficiency after being subjected to moisture stress. Zhang et al. (2009) attributed this improvement to the presence of plant hormones including indole-3-acetic acid (IAA) and cytokinens which they quantified in the biosolids. Based upon our results, environmental stress had a greater effect than the application of compost treatments and their associated BAS on photochemical efficiency.

Greenhouse Seed Germination and Emergence

Both turfgrass species ($P<0.0001$) and treatment ($P=0.0074$) effects were observed during trial 1. The germination and establishment of tall fescue was similar when seeds were sown at all depths (Table 3-7). Bermudagrass seed germination and establishment were the less than tall fescue with the exception of bermudagrass seeds placed on the surface of compost. The lowest establishment and germination rates were observed when bermudagrass seeds were placed under 1.3 cm or 2.5 cm depths of compost. Overall, higher percentages of fescue seeds established than bermudagrass seeds during trial 1. These results are similar to those reported by Stoffella et al. (2000) that germination and emergence of bermudagrass decreases quadratically as compost thickness increases. This may be due to the small seed size of bermudagrass, as studies by Benvenuti et al. (2001) and Murphy and Arny (1939) suggest seed size establishment is poorest in smaller sized seeds sown at deeper depths. Although the biological explanation is not clear, Benvenuti et al.(1995) hypothesizes poor germination is due to either a lack of light or poor gas diffusion. An alternative explanation for why smaller seeds suffer from poor establishment at greater sowing depths is due to the energy reserves stored within the seed, i.e. smaller seeds do not have the energy required for the time it takes to germinate and emerge from deeper planting depths.

Treatment effects ($P<0.0001$) on the germination and establishment of tall fescue were observed in trial 2. The germination and establishment of tall fescue decreased when seeds were placed deeper in soil and compost. These results confirm our results from trial 1, in which the greatest percentages of tall fescue seeds germinated and emerged from the straw mat and compost surface.

CONCLUSIONS

With increasing urbanization and development of native lands, disturbed soils with unfavorable conditions for vegetation establishment are created. As our research demonstrated, five months after treatment application, increases in soil properties were observed in all of the compost treatments as opposed to the fertilizer control. Compost surface applied or incorporated at similar rates of 2.5 cm had similar effects on soil properties in CEC, all Mehlich-extractable nutrients, total N and organic C. With increased application rates of 5.0 cm, higher concentrations of P and organic C were observed as compared to the 2.5 cm incorporated treatment. Thus, the soil properties of the disturbed urban soil were more affected by rate of application than by surface versus incorporated practices. Straw mats and compost blankets had similar effects on soil properties to one another.

The establishment of turfgrasses with high quality color and density may be achieved with time by applying compost. Although our results suggested the 5.0 cm compost incorporated treatment produced the greatest density between the 2.5 cm compost surface, 2.5 cm incorporated and fertilizer control treatments, these results are based upon short-term observations. Turfgrass color was demonstrated to increase (in greenness) with time, not treatment. Despite the added nutrient content, composts made from papermill sludge may require small quantities of supplemental N to meet turfgrass requirements. N is immobilized in composts with C:N ratios < 25:1, where supplemental N may be required. The amount of biomass harvested in all treatments decreased with time but not with treatment. Straw mats provided comparable turfgrass quality (color and density) to 0.6 cm compost blankets which do not require removal and are intended for permanent vegetative establishment, making them convenient for new homeowners to utilize.

Poor turfgrass establishment and quality may result from severe environmental stress. The use of organic amendments containing BAS have been demonstrated to improve the resilience of turfgrasses grown under environmental stress. Although no differences were observed between any of the treatments for photochemical response, one likely explanation is that the compost contained very little BAS. Few studies have documented the quantification of BAS in composts from various source materials. It is plausible that environmental stress had a greater impact on photochemical response than did the treatments themselves. All treatments contained photochemical responses less than 0.83, which is indicative of stress.

When considering the benefits of sowing turfgrass seeds in compost, greenhouse studies were conducted to evaluate turfgrass establishment and germination at various depths. Smaller sized bermudagrass seeds decreased in germination and establishment when sown at any depth other than on the surface of the compost. The larger-sized tall fescue seeds were overall, not affected by the depth sown during the first greenhouse trial. However during the second greenhouse trial when tall fescue was sown in a low-pH (pH= 4.6) Shottower series subsoil, germination and establishment decreased when seeds were sown below the compost and/or soil surface. It is recommended that homeowners apply seeds, especially those containing mixtures of variously-sized seeds to the soil surface to maximize germination and establishment.

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Table 3-1. Compost properties and rates of carbon, nitrogen and phosphorus for each field application rate.

	Application Rate				
	Total P	Total N	Organic C	Ca	Mg
Thickness applied	kg ha^{-1}		Mg ha^{-1}	mg kg^{-1}	
0.64 cm	98	131	3.2	54.4	71.6
2.54 cm	392	524	12.8	217.7	286.4
5.0 cm	784	1048	25.6	435.4	572.8

Table 3-2. Soil properties five months after treatment applications on a disturbed field site in Lynchburg, VA (August 2009).

Treatment	CEC†	P†	K†	Ca†	Mg†	Mn†	total N†	organic C†
	cmol kg^{-1} soil	mg kg^{-1}					g N kg^{-1} soil	g C kg^{-1} soil
Fertilizer	6.2 ± 1.6c	25.0 ± 6.4c	272 ± 13c	2056 ± 614c	173 ± 15b	15.6 ± 2.9b	0.7 ± 0.1c	10.0 ± 1.6c
2.5 cm surface compost	12.5 ± 1.3b	54.3 ± 4.7b	531 ± 18b	4095 ± 456bc	378 ± 32a	52.0 ± 5.3a	1.1 ± 1.0bc	22.3 ± 1.9b
2.5 cm compost incorporated	15.6 ± 1.5ab	54.7 ± 2.6b	558 ± 32ab	5291 ± 555ab	412 ± 22a	52.8 ± 3.1a	1.4 ± 0.1ab	27.3 ± 2.0b
5.0 cm compost incorporated	18.9 ± 1.0a	75.3 ± 1.8a	708 ± 55a	6410 ± 325a	500 ± 37a	66.9 ± 4.4a	1.8 ± 0.1a	36.9 ± 2.6a

†Means with standard errors followed by the same letter in each column are not statistically different at $P < 0.05$

Table 3-3. Effects of time on turfgrass color and biomass harvested in 2009 from the fertilizer control, 2.5 cm depth compost surface, 2.5 cm depth compost incorporated, and 5 cm depth compost incorporated treatments. Color and biomass were averaged over treatment.

Time	Color †‡	Biomass†
	Scale 1-9	kg (dry) ha^{-1}
May	--	211.8 ± 2.8a
July	3.2 ± 0.4b	88.6 ± 5.9b
September	3.9 ± 0.3b	122.3 ± 57.6ab
October	5.6 ± 0.2a	77.3 ± 13.5b

†Means with standard errors followed by the same letter in each column are not statistically different at P <0.05.

‡ Color measured visually on a scale of 1-9 where 1 is brown (no green) turf and 9 is dark green.

Table 3-4. Effects of treatments on turfgrass density in 2009 from the fertilizer control, 2.5 cm depth compost surface, 2.5 cm depth compost incorporated, and 5 cm depth compost incorporated treatments. Density was averaged over time.

Treatment	Density †‡
	Scale 1-9
Fertilizer	3.2 ± 0.4b
2.5 cm surface compost	3.2 ± 0.3b
2.5 cm compost incorporated	3.6 ± 0.2b
5.0 cm compost incorporated	4.9 ± 0.4a

†Means with standard errors followed by the same letter in each column are not statistically different at P <0.05.

‡ Density measured visually on a scale of 1-9 where 1 is bare ground and 9 is dense turf.

Table 3-5. Effects of time on turfgrass biomass harvested in 2009 from the 0.6 cm compost blanket and the straw mat treatments. Biomass was averaged over treatment.

Time	Biomass†
	kg (dry) ha^{-1}
May	91.5 ± 4.23a
July	37.7 ± 5.95b
September	27.4 ± 11.27b
October	19.0 ± 3.00b

†Means with standard errors followed by the same letter in each column are not statistically different at P <0.05.

Table 3-6. Selected properties Orangeburg and Shottower soils used in greenhouse germination and emergence studies.

Soil series	pH	Mehlich 1 extractable P	K	Ca	Mg	Zn	Mn	Organic C	Total N	CEC
		mg/kg^{-1}						g N/kg soil	g N/kg soil	cmol$_c$kg^{-1}
Orangeburg Ap horizon	6.4	26	72	258	33	5.0	3.5	5.66	0.373	2.3
Shottower Bt1 horizon	4.9	2	21	107	51	0.2	1.7	1.31	0.126	4.6

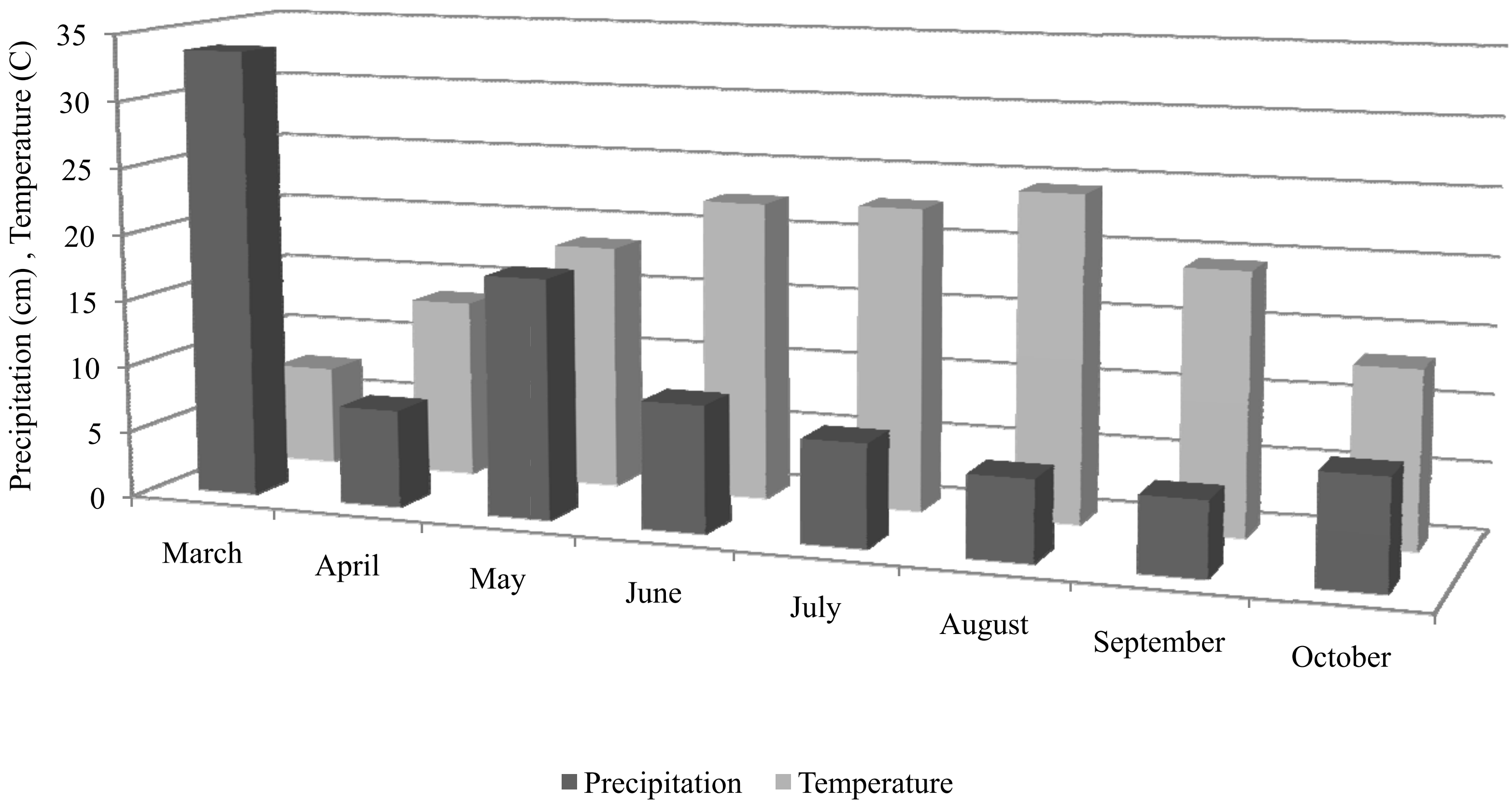
Table 3-7. Total germination and emergence of tall fescue and bermudagrass from greenhouse trial 1 and tall fescue from trial 2.

	Trial 1†		Trial 2‡
Treatment	Tall Fescue	Bermudagrass	Tall Fescue
	Number of seeds		Number of seeds
Straw mat	19.8 a	4.4 cd	21.0 a
Compost surface	20.8 a	13.8 ab	22.6 a
0.6 cm compost depth	11.0 bc	3.8 cd	4.2 b
1.3 cm compost depth	13.4 ab	2.4 d	1.0 b
1.3 cm soil depth	—	—	6.0 b
2.5 cm compost depth	15.0 ab	0.2 d	2.0 b
1.3 cm soil/compost incorporated depth	—	—	5.4 b

†Trial 1: Total establishment followed by the same letter in the Trail 1 columns 'Tall Fescue' and 'Bermudagrass' are not significantly different at P<0.05.

‡Trial 2: Total establishment followed by the same letter in the Trial 2 column 'Tall Fescue' are not significantly different at P<0.05.

Figure 3-8. Average monthly precipitation and temperature at the Summit site during 2009.



APPENDICES

Appendix 1: Rt 262 Botanical Composition
Rt 262 Survey of Botanical Composition for July 2008

Treatment	Plot	Sample	Fescue†	Non-fescue†	Cover‡
				%	
Hydroseed	1	1	85	15	60
Hydroseed	1	2	80	20	40
Hydroseed	1	3	70	30	40
Hydroseed	1	4	95	5	50
Hydroseed	1	5	100	0	25
Hydroseed	1	6	100	0	80
Hydroseed	2	1	95	5	70
Hydroseed	2	2	100	0	80
Hydroseed	2	3	98	2	90
Hydroseed	2	4	90	10	20
Hydroseed	2	5	70	30	45
Hydroseed	2	6	90	10	75
Hydroseed	3	1	90	10	60
Hydroseed	3	2	100	0	55
Hydroseed	3	3	100	0	30
Hydroseed	3	4	100	0	25
Hydroseed	3	5	100	0	40
Hydroseed	3	6	100	0	10
Compost	1	1	90	10	15
Compost	1	2	85	15	45
Compost	1	3	70	30	40
Compost	1	4	90	10	90
Compost	1	5	95	5	95
Compost	1	6	85	15	70
Compost	2	1	97	3	85
Compost	2	2	98	2	35
Compost	2	3	95	5	85
Compost	2	4	90	10	90
Compost	2	5	100	0	98
Compost	2	6	100	0	75
Compost	3	1	25	75	40
Compost	3	2	90	10	50
Compost	3	3	10	90	60
Compost	3	4	60	40	65
Compost	3	5	20	80	35
Compost	3	6	80	20	65

Rt 262 Survey of Botanical Composition for October 2008

Treatment	Plot	Sample	Fescue†	Non-fescue†	Cover‡
				%	
Hydroseed	1	1	85	15	75
Hydroseed	1	2	45	55	90
Hydroseed	1	3	20	80	40
Hydroseed	1	4	95	5	70
Hydroseed	1	5	40	60	75
Hydroseed	1	6	90	10	85
Hydroseed	2	1	65	35	25
Hydroseed	2	2	90	10	60
Hydroseed	2	3	90	10	90
Hydroseed	2	4	95	5	85
Hydroseed	2	5	100	0	20
Hydroseed	2	6	90	10	90
Hydroseed	3	1	85	15	70
Hydroseed	3	2	95	5	40
Hydroseed	3	3	90	10	75
Hydroseed	3	4	75	25	60
Hydroseed	3	5	60	40	35
Hydroseed	3	6	98	2	35
Compost	1	1	60	40	30
Compost	1	2	80	20	95
Compost	1	3	90	10	40
Compost	1	4	70	30	98
Compost	1	5	80	20	100
Compost	1	6	25	75	85
Compost	2	1	95	5	95
Compost	2	2	50	50	85
Compost	2	3	100	0	90
Compost	2	4	25	75	95
Compost	2	5	60	40	95
Compost	2	6	85	15	98
Compost	3	1	50	50	90
Compost	3	2	5	95	50
Compost	3	3	40	60	60
Compost	3	4	30	70	90
Compost	3	5	10	90	40
Compost	3	6	15	85	90

Rt 262 Survey of Botanical Composition for June 2009

Treatment	Plot	Sample	Fescue†	Non-fescue†	Cover‡
				%	
Hydroseed	1	1	0	100	5
Hydroseed	1	2	25	75	50
Hydroseed	1	3	50	50	50
Hydroseed	1	4	0	100	10
Hydroseed	1	5	30	70	40
Hydroseed	1	6	5	95	85
Hydroseed	2	1	0	100	5
Hydroseed	2	2	5	95	10
Hydroseed	2	3	0	100	20
Hydroseed	2	4	30	70	65
Hydroseed	2	5	0	100	30
Hydroseed	2	6	0	100	10
Hydroseed	3	1	60	40	35
Hydroseed	3	2	100	0	75
Hydroseed	3	3	95	5	25
Hydroseed	3	4	0	100	45
Hydroseed	3	5	60	40	25
Hydroseed	3	6	0	100	30
Compost	1	1	0	100	40
Compost	1	2	97	3	50
Compost	1	3	99	1	50
Compost	1	4	85	1	85
Compost	1	5	25	75	95
Compost	1	6	50	50	95
Compost	2	1	50	50	75
Compost	2	2	0	100	15
Compost	2	3	90	10	25
Compost	2	4	95	5	10
Compost	2	5	40	60	5
Compost	2	6	98	2	15
Compost	3	1	20	80	35
Compost	3	2	50	50	50
Compost	3	3	10	90	85
Compost	3	4	5	95	80
Compost	3	5	0	100	50
Compost	3	6	0	100	45

Rt 262 Survey of Botanical Composition for October 2009

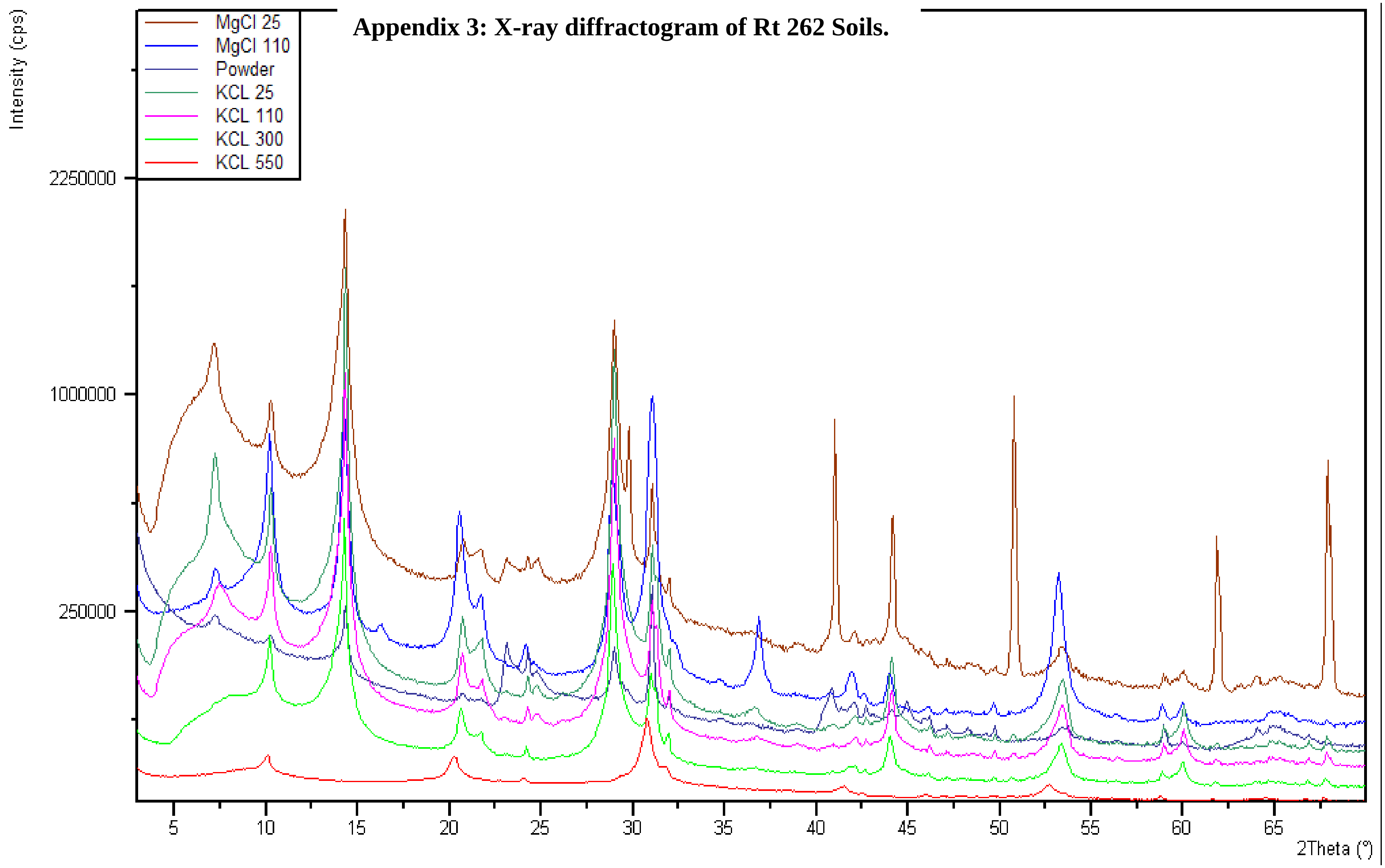
Treatment	Plot	Sample	Fescue†	Non-fescue†	Cover‡
				%	
Hydroseed	1	1	20	80	40
Hydroseed	1	2	2	98	20
Hydroseed	1	3	0	100	5
Hydroseed	1	4	0	100	10
Hydroseed	1	5	75	25	80
Hydroseed	1	6	10	90	15
Hydroseed	2	1	90	10	50
Hydroseed	2	2	95	5	20
Hydroseed	2	3	60	40	5
Hydroseed	2	4	0	100	20
Hydroseed	2	5	5	95	15
Hydroseed	2	6	97	3	75
Hydroseed	3	1	10	90	20
Hydroseed	3	2	85	15	30
Hydroseed	3	3	95	5	10
Hydroseed	3	4	85	15	25
Hydroseed	3	5	10	90	80
Hydroseed	3	6	75	25	15
Compost	1	1	50	50	75
Compost	1	2	0	100	30
Compost	1	3	10	90	50
Compost	1	4	100	0	90
Compost	1	5	0	100	60
Compost	1	6	99	1	75
Compost	2	1	100	0	95
Compost	2	2	90	10	100
Compost	2	3	50	50	80
Compost	2	4	95	5	90
Compost	2	5	95	5	85
Compost	2	6	75	25	90
Compost	3	1	5	95	5
Compost	3	2	10	90	45
Compost	3	3	0	100	30
Compost	3	4	30	70	70
Compost	3	5	2	98	75
Compost	3	6	40	60	90

† Percent of Fescue and Non-fescue were combined to equal 100%. Fescue includes tall and chewings fescue. All other species were considered Non-fescue or weeds. ‡ Cover is a visual assessment of ground cover based on a scale of 0-100% where 0% is bare soil and 100% is complete coverage.

Appendix 2. Rt 262 biomass harvested in October of 2009.

Treatment	Plot	Fescue	Non-fescue
		kg DM ha^{-1}	
Hydroseed	1	2400	8400
Hydroseed	2	8200	8400
Hydroseed	3	5800	108
Compost	1	12600	182
Compost	2	35600	21400
Compost	3	2000	43000

Appendix 3: X-ray diffractogram of Rt 262 Soils.



Appendix 4: Summit Site Biomass- May, 2009

Plot ID	Plot #	Replicate	Treatment	biomass (g)
1	1	1	1" compost surface	111.7
2	2A	1	straw blanket	66.5
3	2B	1	0.25" compost blanket	128.3
4	3	1	Fertilizer	294.9
5	4	1	1" compost incorporated	219.1
6	5	1	2" compost incorporated	236.7
7	6	2	Fertilizer	252.9
8	7	2	2" compost incorporated	238.3
9	8	2	1" compost incorporated	157.6
10	9A	2	0.25" compost blanket	106.3
11	9B	2	straw blanket	87.0
12	10	2	1" compost surface	176.6
13	11A	3	straw blanket	105.4
14	11B	3	0.25" compost blanket	55.4
15	12	3	1" compost surface	155.5
16	13	3	2" compost incorporated	243.6
17	14	3	1" compost incorporated	168
18	15	3	Fertilizer	286.8

Appendix 4: Summit Site Biomass- July, 2009

Plot ID	Plot #	Replicate	Treatment	biomass (g)
1	1	1	1" compost surface	111.78
2	2A	1	straw blanket	37.91
3	2B	1	0.25" compost blanket	68.42
4	3	1	Fertilizer	70.03
5	4	1	1" compost incorporated	93.83
6	5	1	2" compost incorporated	113.41
7	6	2	Fertilizer	122.75
8	7	2	2" compost incorporated	82.36
9	8	2	1" compost incorporated	69.49
10	9A	2	0.25" compost blanket	49.15
11	9B	2	straw blanket	27.98
12	10	2	1" compost surface	90.20
13	11A	3	straw blanket	25.20
14	11B	3	0.25" compost blanket	17.26
15	12	3	1" compost surface	76.62
16	13	3	2" compost incorporated	84.02
17	14	3	1" compost incorporated	59.98
18	15	3	Fertilizer	88.91

Appendix 4: Summit Site Biomass- September, 2009

Plot ID	Plot #	Replicate	Treatment	biomass (g)
1	1	1	1" compost surface	271.70
2	2A	1	straw blanket	14.90
3	2B	1	0.25" compost blanket	80.60
4	3	1	Fertilizer	176.40
5	4	1	1" compost incorporated	223.20
6	5	1	2" compost incorporated	237.70
7	6	2	Fertilizer	55.60
8	7	2	2" compost incorporated	232.40
9	8	2	1" compost incorporated	70.00
10	9A	2	0.25" compost blanket	35.00
11	9B	2	straw blanket	22.00
12	10	2	1" compost surface	85.00
13	11A	3	straw blanket	3.90
14	11B	3	0.25" compost blanket	8.00
15	12	3	1" compost surface	40.60
16	13	3	2" compost incorporated	34.70
17	14	3	1" compost incorporated	19.60
18	15	3	Fertilizer	20.70

Appendix 4: Summit Site Biomass October, 2009

Plot ID	Plot #	Replicate	Treatment	biomass (g)
1	1	1	1" compost surface	81.0
2	2A	1	straw blanket	27.0
3	2B	1	0.25" compost blanket	36.3
4	3	1	Fertilizer	76.1
5	4	1	1" compost incorporated	122.4
6	5	1	2" compost incorporated	116.2
7	6	2	Fertilizer	39.8
8	7	2	2" compost incorporated	110.1
9	8	2	1" compost incorporated	65.0
10	9A	2	0.25" compost blanket	22.3
11	9B	2	straw blanket	13.7
12	10	2	1" compost surface	109.4
13	11A	3	straw blanket	6.5
14	11B	3	0.25" compost blanket	10.3
15	12	3	1" compost surface	84.1
16	13	3	2" compost incorporated	67.6
17	14	3	1" compost incorporated	31.0
18	15	3	Fertilizer	27.6

Appendix 5: Summit Site Turf Color and Density Ratings, June-October, 2009

Time	Treatment	Color†	Density†
June 2009	2	4	3
June 2009	6	2	5
June 2009	5	3	3
June 2009	1	2	3
June 2009	3	3	3
June 2009	4	4	5
June 2009	1	2	3
June 2009	4	3	5
June 2009	3	2	5
June 2009	5	2	4
June 2009	6	2	4
June 2009	2	3	2
June 2009	6	3	5
June 2009	5	4	6
June 2009	2	3	3
June 2009	4	5	6
June 2009	3	4	4
June 2009	1	3	2
September 2009	2	4	3
September 2009	6	4	6
September 2009	5	4	5
September 2009	1	4	3
September 2009	3	3	3
September 2009	4	4	5
September 2009	1	3	2
September 2009	4	4	5
September 2009	3	3	2
September 2009	5	3	3
September 2009	6	3	5
September 2009	2	4	4
September 2009	6	2	5
September 2009	5	2	6
September 2009	2	3	3

Appendix 4: Compost Greenhouse Establishment Trial 1

September 2009	4	6	6
September 2009	3	5	5
September 2009	1	4	4
October 2009	2	4	2
October 2009	6	5	3
October 2009	5	5	3
October 2009	1	6	4
October 2009	3	5	2
October 2009	4	6	2
October 2009	1	6	3
October 2009	4	6	4
October 2009	3	6	4
October 2009	5	6	3
October 2009	6	5	2
October 2009	2	6	5
October 2009	6	5	4
October 2009	5	6	5
October 2009	2	6	4
October 2009	4	6	6
October 2009	3	5	4
October 2009	1	5	5

† Color and Density ratings are based on a scale of 1-9 (1= poor, 9= ideal).

Appendix 6: Compost Greenhouse Establishment Trial 1

				DATE/ DAYS												
				22-Jun	24-Jun	25-Jun	26-Jun	27-Jun	28-Jun	29-Jun	1-Jul	2-Jul	3-Jul	6-Jul	8-Jul	
Pot #	Treatment	Replicate	Grass Species	7	9	10	11	12	13	14	16	17	18	21	23	Total
9	2.54 cm compost	4	Bermuda	0	0	0	0	0	0	0	0	0	0	0	0	0
11	2.54 compost	3	Bermuda	0	0	0	0	0	0	0	0	0	0	0	0	0
30	2.54 compost	1	Bermuda	0	1	1	1	1	1	1	1	1	1	1	1	1
43	2.54 compost	2	Bermuda	0	0	0	0	0	0	0	0	0	0	0	0	0
46	2.54 compost	5	Bermuda	0	0	0	0	0	0	0	0	0	0	0	0	0
28	2.54 compost	4	Fescue	0	9	11	14	13	15	14	14	15	15	15	15	15
33	2.54 compost	1	Fescue	7	18	19	21	21	22	21	21	22	22	22	22	22
40	2.54 compost	2	Fescue	0	9	14	14	17	17	17	17	17	1	17	17	17
45	2.54 compost	5	Fescue	0	0	0	0	0	0	0	0	0	0	0	1	1
47	2.54 compost	3	Fescue	6	14	18	18	19	20	19	18	19	18	19	19	20
16	1.27 cm compost	2	Bermuda	0	2	2	2	2	2	2	2	2	2	2	2	2
18	1/2" compost	3	Bermuda	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1/2" compost	5	Bermuda	0	2	3	4	7	5	6	6	6	6	5	4	7
31	1/2" compost	1	Bermuda	1	2	2	2	2	2	2	2	2	2	2	2	2
38	1/2" compost	4	Bermuda	0	0	1	1	1	1	1	1	1	1	1	1	1
2	1/2" compost	2	Fescue	13	19	20	20	21	22	23	22	22	22	23	23	23
3	1/2" compost	3	Fescue	16	18	21	18	20	20	20	19	20	20	20	20	20
20	1/2" compost	4	Fescue	0	0	0	0	0	0	0	0	0	0	0	0	0
42	1/2" compost	1	Fescue	16	24	23	24	23	23	23	23	24	24	24	24	24
50	1/2" compost	5	Fescue	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1/4" compost	2	Bermuda	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1/4" compost	5	Bermuda	0	0	0	0	0	0	1	1	1	1	1	1	1
21	1/4" compost	1	Bermuda	0	0	0	0	1	1	1	1	1	1	1	1	1
35	1/4" compost	4	Bermuda	2	4	4	4	4	4	4	4	4	4	4	4	4
49	1/4" compost	3	Bermuda	2	10	11	11	12	13	12	12	13	13	13	13	13
4	1/4" compost	3	Fescue	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1/4" compost	4	Fescue	1	3	6	7	7	7	7	9	9	9	9	9	9
36	1/4" compost	1	Fescue	8	8	10	10	10	10	10	10	11	11	12	12	12

37	1/4" compost	5	Fescue	2	12	12	12	12	12	12	12	12	12	12	12	12
41	1/4" compost	2	Fescue	20	20	22	22	22	22	22	22	22	22	21	22	22
				22-Jun	24-Jun	25-Jun	26-Jun	27-Jun	28-Jun	29-Jun	1-Jul	2-Jul	3-Jul	6-Jul	8-Jul	
Pot #	Treatment	Replicate	Grass Species	7	9	10	11	12	13	14	16	17	18	21	23	Total
5	Control- straw blanket	1	Bermuda	0	0	0	0	0	0	0	0	0	0	0	0	0
23	Control- straw blanket	2	Bermuda	3	4	5	5	5	4	5	5	4	4	4	4	5
29	Control- straw blanket	3	Bermuda	0	1	1	0	2	3	3	3	3	3	3	3	3
32	Control- straw blanket	4	Bermuda	1	1	2	1	1	1	1	1	1	1	1	1	2
48	Control- straw blanket	5	Bermuda	2	12	4	6	7	8	8	8	8	8	8	8	12
6	Control- straw blanket	5	Fescue	15	18	19	21	21	21	23	23	21	22	23	23	23
24	Control- straw blanket	2	Fescue	14	17	15	17	17	17	18	17	17	18	19	19	19
25	Control- straw blanket	3	Fescue	12	15	14	17	18	17	17	20	20	20	20	20	20
26	Control- straw blanket	1	Fescue	13	16	15	17	19	18	19	18	19	19	19	19	19
34	Control- straw blanket	4	Fescue	17	17	18	18	18	18	17	18	17	18	18	18	18
1	Surface	2	Bermuda	4	8	12	18	18	18	18	18	18	18	18	18	18
10	Surface	5	Bermuda	0	0	0	2	4	4	4	5	5	6	5	6	6
13	Surface	3	Bermuda	4	10	11	17	17	18	17	18	18	18	18	18	18
27	Surface	1	Bermuda	3	10	11	14	14	14	14	14	14	14	15	15	15
39	Surface	4	Bermuda	1	3	5	9	9	10	10	11	11	11	12	12	12
7	Surface	3	Fescue	11	15	16	19	19	21	21	21	21	21	21	21	21
12	Surface	4	Fescue	0	0	1	5	9	14	15	18	19	19	22	22	22
15	Surface	2	Fescue	6	6	6	7	10	11	12	15	17	16	17	18	18
17	Surface	1	Fescue	11	13	14	14	14	14	16	15	17	19	20	20	20
44	Surface	5	Fescue	5	7	8	9	11	12	14	14	15	19	23	23	23

Compost Greenhouse Establishment Trial 2

				DATE/ DAYS					
				25-Jul	28-Jul	30-Jul	3-Aug	10-Aug	
Pot #	Treatment	Replicate	Grass Species	9	12	14	18	25	Total
1	Control	1	Tall fescue	15	16	18	18	18	18
2	Control	2	Tall fescue	17	17	18	20	20	20
3	Control	3	Tall fescue	17	18	20	22	22	22
4	Control	4	Tall fescue	20	18	23	23	23	23
5	Control	5	Tall fescue	14	13	19	19	22	22
6	1/2" soil	1	Tall fescue	0	3	3	3	4	4
7	1/2" soil	2	Tall fescue	2	2	2	2	2	2
8	1/2" soil	3	Tall fescue	0	4	4	5	6	6
9	1/2" soil	4	Tall fescue	0	0	0	0	0	0
10	1/2" soil	5	Tall fescue	3	15	16	17	18	18
11	1/2" compost	1	Tall fescue	0	0	0	0	0	0
12	1/2" compost	2	Tall fescue	0	0	0	0	0	0
13	1/2" compost	3	Tall fescue	0	1	1	1	1	1
14	1/2" compost	4	Tall fescue	0	0	0	0	1	1
15	1/2" compost	5	Tall fescue	2	3	3	3	3	3
16	1/4" compost	1	Tall fescue	1	2	3	4	4	4
17	1/4" compost	2	Tall fescue	0	1	2	2	3	3
18	1/4" compost	3	Tall fescue	0	3	3	4	6	6
19	1/4" compost	4	Tall fescue	1	1	2	5	6	6
20	1/4" compost	5	Tall fescue	0	0	0	2	2	2
21	1" compost	1	Tall fescue	1	5	5	5	5	5
22	1" compost	2	Tall fescue	1	3	3	4	4	4
23	1" compost	3	Tall fescue	0	0	0	0	0	0
24	1" compost	4	Tall fescue	0	0	0	0	0	0
25	1" compost	5	Tall fescue	0	0	0	0	1	1
26	compost surface	1	Tall fescue	19	24	24	24	24	24
27	compost surface	2	Tall fescue	12	23	24	24	24	24
28	compost surface	3	Tall fescue	15	19	22	23	23	23
29	compost surface	4	Tall fescue	15	21	22	22	20	20
30	compost surface	5	Tall fescue	16	21	21	22	22	22

Pot #	Treatment	Replicate	Grass Species	25-Jul 9	28-Jul 12	30-Jul 14	3-Aug 18	10-Aug 25	Total
31	1/2" compost incorporated	1	Tall fescue	1	5	6	6	6	6
32	1/2" compost incorporated	2	Tall fescue	0	0	0	0	0	0
33	1/2" compost incorporated	3	Tall fescue	14	19	19	20	21	21
34	1/2" compost incorporated	4	Tall fescue	0	0	0	0	0	0
35	1/2" compost incorporated	5	Tall fescue	0	0	0	0	0	0