ABSTRACT

Title of Thesis: EVALUATION OF COMPOST TOPDRESSING, COMPOST TEA AND CULTIVATION ON TALL FESCUE QUALITY, SOIL PHYSICAL PROPERTIES AND SOIL MICROBIAL ACTIVITY

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Compost topdressing, compost tea, and hollow tine cultivation are common cultural practices employed in organic lawn care programs. Restrictions on the amount of bagged fertilizer nitrogen and phosphorus applied to turf have raised questions about the need to place similar restrictions on compost turfgrass applications. In a three-year study the effect of reduced and common practitioner use rates of compost topdressing, the use of compost tea and of hollow tine cultivation on soil physical and biological properties and turfgrass quality were evaluated. Cultivation, monthly compost tea application and compost topdressing applied at rates consistent with annual bagged fertilizer nitrogen restrictions had little effect on soil organic matter, microbial activity, bulk density and infiltration. The use of a synthetic fertilizer resulted in higher turf quality than the use of compost on most

evaluation dates. Nutrient fertilizer restrictions if applied to compost will likely result in a decline in turf quality.

EVALUATION OF COMPOST TOPDRESSING, COMPOST TEA AND CULTIVATION ON TALL FESCUE QUALITY, SOIL PHYSICAL PROPERTIES AND SOIL MICROBIAL ACTIVITY

by

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List of Abbreviations

Full Meaning[†]	Abbreviation
Aerated compost tea	ACT
Analysis of variance	ANOVA
California Compost Quality Council	CCQC
Cation Exchange Capacity	CEC
Organic carbon	C_{org}
Fluorescein diacetate	FDA
lawn care operations	LCO’s
Municipal solid waste	MSW
Not-aerated compost tea	NCT
The USDA’s National Organic Program	NOP
Paint Branch Turfgrass Research Facility	PBTRF
Soil Organic matter	SOM

Chapter 1: Introduction

The Chesapeake Bay is the largest estuary in the United States. Its watershed encompasses six states and District of Columbia. It is a region with an expanding population base which has resulted in, and will continue to undergo for the foreseeable future, the conversion of forest and farmland into residential land uses. Residential land uses are typically characterized by the extensive presence of turfgrass. In the counties surrounding Washington DC, for example, 39 to 46% of the landscape is comprised of turfgrass (Schueler, 2010).

Residential construction activity frequently involves the removal and redistribution of topsoil and use of subsoil as fill material. These grading activities often result in compact infertile soil. Homeowners typically try to compensate for poor soil conditions by applying fertilizer to their lawns. Most fertilizers are applied as inorganic salts or as synthetic materials. However, there has been an emerging interest in the use of natural organic materials, such as compost, in place of salt and synthetic based fertilizers.

The use of compost as a soil amendment has been shown to improve the physical and chemical properties of soil as well as to improve turfgrass quality (Hornick et al., 1984; Angle, 1994; Landschoot and McNitt, 1994). Less is known about how these soil properties are altered when compost is used as fertilizer, particularly when applied to lawn turf. The slow nitrogen (N) release properties of compost have traditionally resulted in applications of compost at loading rates in excess of yearly turf N needs. The passage of turfgrass fertilizer laws in several states has resulted in restrictions on the amount of N and phosphorus that can applied to turf at any one time, and over the course of the year (Weinberg et al., 2011). Depending on the state, topdressing applications of compost may, or may not be bound to the same restrictions as bagged fertilizers. Given that it is likely additional states will pass fertilizer laws that will restrict the amount of N that can be applied to turf, it is important to determine how compost topdressing applications, when held to same N annual load rate restriction as bagged fertilizers, will effect turf quality and the properties of the underlying soil .

Stormwater is the primary source of nutrient impairment of surface waters in many urban areas (Weinberg et al., 2011). In a 2007 study on the health of Chesapeake Bay (Chesapeake Bay Program, 2008), stormwater in urban and suburban lands was listed as the only pollution source sector that was growing within the watershed. Core cultivation is sometimes cited as a best management practice to reduce runoff from turfgrass areas (Rice and Horgan, 2011). It is also a recommended practice for the incorporating materials such and sand and compost into existing lawns to improve the physical properties of the soil. Core cultivation of home lawns is a practice that is often limited to a single cultivation per year. The potential benefits to turf quality and soil properties at cultivation application frequencies that are typically followed by homeowners needs to be documented before promoting the use of such practices as a way to reduce runoff.

In recent years, the use of the water extract from fermented compost (compost tea) has become popular. Its use has been promoted as way to provide nutrients and biological benefits to plants and soil. Most reported studies involving the use of compost tea have been performed on agricultural crops, such as corn, bean, lettuce, tomato and potato for disease suppression (Scheuerell and Mahaffee, 2002; and Litterick et al., 2004). Microorganisms are essential to organic matter decomposition, nutrient cycling and other soil physical and chemical properties. They are very sensitive to small changes in management practices. The application of high quality compost materials is believed to increase the number of individuals and the species diversity of the microbial communities (Ingham, 2005).

The objectives of this thesis are to: 1) compare the quality of lawns that are topdressed with compost with those that receive an enhanced efficiency fertilizer when both are applied at the same annual N loading rate and subject to varying levels hollow tine cultivation; 2) to compare the quality of unfertilized lawns with those receiving an enhanced efficiency fertilizer or compost, with the compost applied at the same N loading rate as the enhanced efficiency fertilizer or at a rate of 1 cm of compost per year; 3) to determine the effect of the treatments listed in 1 and 2 above on soil organic matter content, microbial activity, bulk density and infiltration rate; and 4) to evaluate the effect of the monthly application of compost tea made during growing season on soil microbial enzyme activity and select aspects of turfgrass quality.

Chapter 2: Literature Review

Meeting the consumption demands of an ever increasing population has resulted in a commensurate increase in the production of agricultural, industrial and urban wastes. The production of municipal solid waste in the U.S., for example, tripled between 1960 and 2005 (USEPA, 2014). The large quantities of plant, animal and solid wastes are ongoing concerns of regulatory agencies, and to a lesser extent, the general public.

Agricultural animal production, the treatment of municipal sewage sludge, and the disposal yard debris generate substantial waste streams that need be managed in a way that does not harm air, land or water resources. The use of waste management procedures such as incineration, land filling and ocean dumping are viewed as undesirable approaches to organic waste management because they fail to meet one or more of the criterion associated with sustainable natural resource management. In order for a waste management practice to be sustainable it must be cost effective, energy saving, of acceptable environmental impact, and be beneficial to both current and future economic and social development (Lichtfouse et al., 2009; Diacono and Montemurro, 2010).

Composting is an aerobic biological process that accelerates and controls the natural process of organic matter decomposition by controlling mixtures of organic materials and the environment in which they are transformed. The end product of this process is a beneficial and stable product called compost. Composting is an efficient and economical way of utilizing waste and provides plants and soil with multiple benefits. The production and use of compost is considered a sustainable practice when applied to lands in amount that are not excessive.

Composting has been practiced for thousands of years in many forms. During the early civilization period, “compost” was somewhat like well-rotted manure or a mix of plant and animal wastes placed into plies or pits for an extended period of time (Diaz and de Bertoldi, 2007). Sir Albert Howard’s description of “Indore” method of composting is believed to be the first significant advance in the history of modern composting (Diaz and de Bertoldi, 2007). The Indore procedure provided some of the first criteria for making good quality compost, including the size of the pile, the type of material that should be in the pile, and listing some of the basic moisture, temperature and aeration properties required to produce a compost product. (Howard, 1943; Diaz and de Bertoldi, 2007).

The composting industry as we know it today began in the 1970’s. Its growth was prompted by the passage of the Clean Water Act. As part of this act, financial support was provided to local governments to improve the treatment of municipal waste water and to reduce the disposal of high organic content materials (Goldstein, 2001; Diaz, 2007). One of the most widely used composting methods at that time was Beltsville aerated pile method which was created and heavily promoted for use by the U.S. Department of Agriculture (USDA) (Willson et al., 1980; Goldstein, 2001). The composting industry expanded rapidly in 1980’s when technological advances in the treatment of waste water resulted in a dramatic increase in the production of high quality compost for agricultural and horticultural use (Hornick et al., 1984; Goldstein, 2001; Diaz, 2007).

2.1 Compost Type and Characterization

2.1.1 Source Materials Used to Produce Compost

The materials used to create compost generally fall into one of three categories. These categories are: 1) plant based materials, such as clippings, leaves, wheat straw, woody plant material, and food processing waste; 2) biosolids originating from municipal solid wastes such as domestic and industrial sewage sludge; and 3) manure based compost derived from animal and human feces or wastes. All three sources are high in organic matter content and contain measurable amounts of macro- and micro-nutrients. The fertilizer value of compost depends on the type of feedstock from which the compost organic matter originated and the process used to create the compost. Plant based compost typically are lower in nitrogen (N) than biosolids based compost. Compost made from biosolids generally contains higher N and phosphorus (P) contents than those made from animal manures and yard trimmings (Alexander, 2001). Barker (1997) pointed out the N content of yard trimmings compost on dry mass basis is generally less than 1%, while composts of farm manures, biosolids and food wastes are usually more than 1%. The P concentration of a biosolids compost is generally about 1 to 2 % while composts derived from plant material or farm manures generally contain 0.2 to 0.4% P (Barker, 1997). The composts of animal manures and yard trimmings have a higher potassium (K) concentration than biosolids compost (Alexander, 2001; Cogger, 2005).

The raw materials used to create compost sometimes need the addition of a supplemental material for the compost to meet its intended use. For N rich materials such as municipal solid waste, animal manure and grass chippings, carbonaceous materials and bulking agents such as wood chips, leaves, straw and sawdust are often added to the composting pile to absorb moisture and to decrease the bulk density of the pile (Golueke and Diaz, 1978; Stratton et al., 1995).

When composting municipal solids, the concern is often with removing undesirable physical contaminants, such as plastic, glass, rubber, leather, rocks and metals. When this is a concern, presorting prior to composting and screening after composting are often used to maintain the production of high quality composts.

2.1.2 Compost Production Practices

The composting process can be characterized as three successive stages of biological oxidation. The initial mesophilic stage involves rapid decomposition of the substrate accompanied by a commensurate increase in the microbial population and temperature of the material. More resistant substrate is consumed in the second thermophillic phase of the process. During this time the temperature reaches 60 to 75 °C killing any weeds seeds and pathogenic organisms present in the material. During the third stage decomposition slows down and the temperature of now largely decomposed material drops. At this point most of the material is near or at the end point of the decomposition process. During the third stage the material is said to be “curing”. This stage is characterized by a gradual rise in the portion of humic compounds present in the material. (Boulter et al., 2000a)

The regulation of temperature, aeration, moisture, carbon to nitrogen ratio and other physical factors are required for successful compost production. Temperature controls the microorganism population in the composting process as microbial activities are temperature dependent. A preferred temperature range is 54 to 60 °C (Rynk et al., 1992). Composting is an oxidation process. Adequate aeration and air flow are essential to support aerobic microbial activity and to remove the built up of carbon dioxide that occurs early in composting process. An oxygen concentration that exceeds 5% is a desirable range for composting (Rynk et al., 1992). Water acts as an essential element and solvent for microbial activity. A moisture content of 40 to 60% is preferred during the compost process. Excessive moisture will led to anaerobic decomposition and odor formation (Hamoda et al., 1998). A proper C/N ratio is crucial to efficient composting. A high C/N ratio reduces the rate of decomposition (Finstein and Morris, 1974), while low ratio results in the loss of N as ammonia (Morisaki et al., 1989). Rynk et al. (1992) have pointed out that a C:N ratio of 25:1 to 30:1 is ideal for composting. Particle size has an effect on the moisture retention, porosity and the surface to volume ratio of the compost. The desired particle size depends on the specific materials in the compost, pile size and anticipated weather conditions (Rynk et al., 1992; Rynk and Richard, 2001; Day and Shaw, 2001). Monitoring some factors such as heavy metal and salts contents during the composting process is also required for optimum composting.

Selection of a methodology to produce compost needs to consider the anticipated size of the composting operation, the availability of specialized equipment, and the needs that comply with regulations pertaining to the treatment of waste material. Compost production typically occurs in one of five ways (USEPA, 2015a): backyard or onsite composting is a method suitable for homeowners and involves producing small amounts of compost from yard trimmings and food residues. Backyard composting requires very little equipment but the process typically takes from 3 to 6 months with lots of manual turning necessary during this time. Backyard composting does not typically have a clearly defined high temperature thermophillic phase as a part of the composting process.

The aerated windrow composting method, also called turned pile composting, is practiced by placing organic waste into long rows with the rows being turned periodically. This practice allows for large scale production and is usually the approach used by local government and large food processing businesses to produce compost. It requires a large area, sturdy equipment and an intelligent workforce to monitor the production of the final product. A third approach that is used to produce compost is the aerated static pile method. In this method, air is pulled into pile or forced out through the pile using a blower system. It requires careful monitoring of temperature and moisture because no physical turning of the material takes place.

Vermicomposting is the process of relying on earthworms to convert organic wastes into compost or an organic fertilizer material. It requires only worms, worm bedding and bins. Physical turning is not necessary during composing but holes and mesh bins are usually needed to introduce oxygen into the decaying mass. This method can be used on small or large scale. Vermicomposting is quite efficient as one pound of mature worms (approximately 800-1,000 worms) can eat up to half a pound of organic material per day.

The fifth approach is In-Vessel Composting. With this approach organic wastes are placed within a silo or vessel-like container during which temperature, air and moisture conditions are tightly controlled by computer monitoring of the vessel. This method requires expensive equipment, but provides a relatively fast way of producing high quality compost.

2.1.3 Common Metrics Used to Assess Compost Quality

Acceptance in the use of compost in agricultural and horticultural systems requires that standards are established and met for the finished product (Zucconi and De Bertoldi, 1987). The criteria used to assess compost quality are largely driven by the end use of the product. Nutrient content is an important factor to consider when compost is used as a soil amendment or fertilizer verses being used as a surface mulch. The pH and soluble salt content of compost are also important chemical properties especially when the compost will serve as a medium to support plant growth (Sullivan and Miller, 2001). Generally, there are minimal standards for the presence of desirable constituents such as organic matter and N content in compost and more rigid standards for undesirable constituents such as trace elements, toxic organic chemicals, pathogens and the presence of foreign or inert materials (He et al., 1992, Sullivan and Miller, 2001). Beyond these minimal standards, there are also additional tests associated with physical and chemical properties of compost required by most compost quality assurance programs (Sullivan and Miller, 2001). These additional properties include moisture content, water holding capacity, bulk density, particle size, and man-made inerts, cation exchange capacity (CEC), pH, total nitrogen, inorganic nitrogen, electrical conductivity (soluble salts), macronutrients, micronutrients and heavy metals. Methods for testing the physical and chemical properties of compost have been further discussed by Sullivan and Miller (2001).

In addition to possessing specific physical and chemical properties, compost must be well-decomposed, stabilized and mature in order to be suitable for agricultural and horticultural uses (Bernal et al., 2009). The terms “Stability” and “Maturity” are sometimes used interchangeably, but each has a specific meaning. Stability refers to the point in the composting process when the bioavailability of the material is extremely low. Extremely low bioavailability effectively results in the cessation of the composting process. A stable compost product is desired because continuous microbial decomposition in compost can generate heat and flammable gases like methane, which can result in spontaneous combustion of stored compost. Gases generated by unfinished compost can also result in undesirable odors and may attract disease vectors (Mathur et al., 1993; Brinton, 2000).

Compost maturity is related to the degree of humification of the material and is an indicator of the suitability of compost for plant use (Mathur et al., 1993; Cooperband et al., 2003). Immature composts applied to soil can be inhibitory to seed germination, and plant growth. Immature compost with a high C/N ratio results in N immobilization in soil which leads to N deficiency in plants. Immature compost with an extremely low C/N ratio may produce ammonia which is toxic to plants (Inbar, 1990). Immature compost can also possess intermediate by-products such as acetic acid, phenolic acids and other short chain fatty acids that are toxic to plant growth (He et al., 1992; Stratton, 1995). Lastly, immature composts have a potential to support the regrowth of pathogens which are harmful to plants and may pose a risk to surface and ground water (Brodie et al., 1994).

Compost stability and maturity have become important parameters to evaluate compost quality in the United States (Brewer and Sullivan, 2001). There are three general approaches that are used to access compost stability and maturity. They can be categorized as: physical methods, chemical methods and biological methods.

Physical methods are based on the sensory evaluation of compost color, odor and temperature (He et al., 1992, Sullivan and Miller, 2001, Wichuk and McCartney, 2010). Physical methods are the simplest and most feasible to conduct, but are not a particularly sensitive way to identify compost stability and maturity. Composts that are stable and mature are dark in color and have an earthy smell. A standardized matric for evaluating compost color and odor is available from the US composting council (US composting Council, 2002). Monitoring the temperature of compost piles is another physical method that has been used to access stability and maturity (Strom, 1985, Tiquia and Tam, 2002, Boulter-Bitzer et al., 2006). However, many researches have reported that pile temperature can be a misleading indicator of compost stability and maturity as it is affected by ambient conditions, pile size, and other conditions that affect microbial activity within compost (Mathur et al., 1993, Lasaridi et al., 2000, Han et al., 2008, Wichuk and McCartney, 2010). Temperature is more often used as an indicator of how well composting process is proceeding.

Common chemical indicators used to assess compost stability and maturity include organic matter, dissolved organic carbon, humification, carbon: nitrogen (C:N) ratio, ammonia and nitrate content, CEC, pH and electrical conductivity (EC) (He et al., 1992; Bernal *et al*., 2009; Wichuk and McCartney, 2010). Composting is the biochemical transformation of organic matter, so analyses of the forms and amount of intermediates produced during the composting process are indicative of the stage of decomposition and the degree of stability and maturity of the compost. The rationales, methods, merits and faults of each method, and the standard for analyses of the chemical indicators have been elaborated in a literature review written by Wichuk and McCartney (2010).

Biological methods used to access compost stability and maturity rely on microbiological activity or the use of plant bioassays. Measurement of respiration, enzyme activity, ATP content, nitrogen mineralization/immobilization or microbial biomass, provide an evaluation of the biological activity in compost to estimate the degree of decomposition (Bernal et al., 2009, Wichuk and McCartney, 2010). Plant bioassays directly assess germination and/or plant growth. The basic premise of the plant bioassay is that if an adverse effect on seed germination or plant growth is not observed the compost is considered to be mature (Gilbert et al., 2001).

There is no single widely accepted stand-alone test that is used to determine compost maturity and stability. Some reasons for this include: the starting point of a parameter (e.g. C/N ratio) varies with origin of compost; the standards are different for different intended uses (e.g. plant potting media vs. soil amendment) and the interpretation of the test data can differ with the testing method employed. Because of this the most widely used approach is to evaluate two or more parameters to assess compost maturity and stability. For example, the California Compost Quality Council's (CCQC) maturity index requires that a finished compost sample meet a C/N ratio standard (i.e. C/N ratio $\leq$ 25) in addition to at least one parameter from Group A and B shown in Table 2.1 below. The thresholds values that would result in a compost being classified as being immature, mature or very mature for the tests specified in Table 2.1 are discussed in CCQC compost maturity index document (CCQC, 2001).

Table 2.1. The maturity assessment list of group A and group B (according to CCQC, 2001).

Group A	**Group B**
CO_2 evolution or respiration	NH_4^- : NO_3^-N Ratio
Oxygen demand	Total NH_3-N concentration
Dewar self-heating test	Volatile Organic Acids concentration
	Plant bioassays

It should be noted that even though “stability” and “maturity” are two aspects of compost that have been used to indicate compost quality, compost quality should not be confused with stability and maturity. Quality reflects stability and maturity, but it also dependent on the composition of the compost (Brodie *et al*., 1994). For example, a composted material may be mature but may also contain numerous contaminants such as glass, plastic and metal. Compost specifications for general landscape application, such as turf establishment or planting bed establishment, have been established by the EPA and are shown in Table 2.2. The table lists specific standards for a range of compost properties. For a compost to be acceptable for use it must meet the criterion specified in the table.

Table 2.2 EPA model compost specification for general landscape applications (USEPA, 2015b).

Parameters[1,6]	**Reported as (units of measure)**	**General Range**
pH[2]	pH units	5.0 - 8.5
Soluble Salt Concentration[2] (electrical conductivity)	dS/m (mmhos/cm)	Maximum 10
Moisture Content	%, wet weight basis	30 – 60
Organic Matter Content	%, dry weight basis	30 – 65
Particle Size	% passing a selected mesh size, dry weight basis	98% pass through 3/4" screen or smaller
Stability[3]		
Carbon Dioxide Evolution Rate	mg CO_2-C per g OM per day	< 8
Maturity[3] (Bioassay)		
Seed Emergence and	%, relative to positive control	Minimum 80%
Seedling Vigor	%, relative to positive control	Minimum 80%
Physical Contaminants (inerts)	%, dry weight basis	< 1
Chemical Contaminants[4]	mg/kg (ppm)	Meet or exceed US EPA Class A standard, 40 CFR § 503.13, Tables 1 and 3 levels
Biological Contaminants[5]		
Select Pathogens		
Fecal Coliform Bacteria, or	MPN per gram per dry weight	Meet or exceed US EPA Class A standard, 40 CFR § 503.32(a) levels
Salmonella	MPN per 4 grams per dry weight	

1. Recommended test methodologies are provided in Test Methods for the Examination of Composting and Compost (TMECC, The US Composting Council)
2. It should be noted that the pH and soluble salt content of the amended soil mix is more relevant to the establishment and growth of a particular plant, than is the pH or soluble salt content of a specific compost (soil conditioner) used to amend the soil.
3. Stability/Maturity rating is an area of compost science that is still evolving, and as such, other various test methods could be considered. Also, compost quality conclusions are not based on the result of a single stability/maturity test.
4. US EPA Class A standard, 40 CFR § 503.13, Tables 1 and 3 levels = Arsenic 41ppm, Cadmium 39ppm, Copper 1,500ppm, Lead 300ppm, Mercury 17ppm, Molybdenum 75ppm, Nickel 420ppm, Selenium 100ppm, Zinc 2,800ppm.
5. US EPA Class A standard, 40 CFR § 503.32(a) levels = Salmonella <3 MPN/4grams of total solids or Fecal Coliform <1000 MPN/gram of total solids.
6. Landscape architects and project (field) engineers may modify the allowable compost specification ranges based on specific field conditions and plant requirements.

2.2 Effect of Compost Use on Soil and Turfgrass

The use of organic approaches has long been utilized in turfgrass management to provide plant nutrients and to improve the chemical, physical and biological properties of soil (Piper and Oakley 1917). The development of Haber-Bosch process during World War I provided an inexpensive way to create ammonia-based fertilizers. By the 1930's the relatively low cost of synthetic based fertilizers, and the ease with they could be transported, stored and applied lead to a steady decline in the use of organic materials as fertilizes on turfgrass (NRC, 1989; Garling and Boehm, 2001). A resurgence in the use of organic materials as soil amendments and fertilizers in turfgrass management began in early 1980's as turfgrass was viewed as an ideal land use on which to spread the rapidly emerging production of biosolids and municipal waste based composts. Angle (1994) pointed out the benefits associated with the use of sewage sludge compost on turfgrass rather than agricultural land. Benefits included: 1) a potential reduction in transportation costs since agricultural lands are usually located in distant rural areas while lawn areas are generally located close to metropolitan compost treatment facilities; 2) a potential increase in nutrient uptake and reduction in nutrient runoff losses following the application of compost because of the presence of a perennial surface cover, and a dense root of system close to soil surface provided by turfgrass; 3) little concern about heavy metal and organic pollutants entering the food supply since turfgrass is not a food source for animal or human consumption.

Typical uses of compost in turfgrass management include as a soil amendment in preparation phase of turfgrass establishment or as a fertilizer or liquid based extract applied to turf foliage. In the soil preparation phase of lawn establishment, compost is often mixed with top few inches soil to improve the physical and chemical properties of the soil. A recommended ratio is to apply compost at a rate of 2.5 to 5 cm to the soil surface after which it is evenly incorporated to a depth of 10 to 15 cm (Landschoot, 1995). In established lawns, it is not practical to incorporate compost into the soil, so a thin layer of compost is often sprinkled over turfgrass as a fertilizer. This practice is referred as topdressing. A common recommend thickness when compost is applied this way is 3 to 12 mm (Alexander, 2001). A heavy layer of compost may smother the grass. Successive application of a thicker layer of compost without soil incorporation will commonly result in the formation of organic matter layer at the soil surface that restrict rooting into the soil (Landschoot, 1995). The application of fermented extracts of compost, which is commonly referred to compost tea, is a relatively new turfgrass management practice with the desired goal being to broaden the diversity and activity of microorganisms in the soil and turfgrass sward (Ingham, 2000, 2003, 2005). Studies examining the various effects of composted materials on soil properties and turfgrass have been conducted since early 20th century. In general, these studies can be grouped into six categories. These are: 1) the effects of compost on soil physical characteristics; 2) the fate of compost applied carbon, nitrogen, phosphorus, potassium and micronutrients in soils; 3) the effect of compost on turfgrass development; 4) the suppression of plant disease and weeds by compost; 5) the dynamics of soil microbes affected by compost application; and 6) the effect of compost on runoff loss and water quality.

2.2.1 Soil Physical and Chemical Characteristics

Repeated application of compost materials to agricultural lands have been recognized as a reliable way to improve the physical and chemical properties of most soils, especially soils with poor structure, and low levels of soil organic matter (Bauduin et al., 1987; Stratton et al., 1995).

Documented changes in physical properties include aggregate stability, porosity, bulk density and soil water holding capacity. The primary positive effects of compost use on soil physical properties were discussed in a recent review by Martinez-Blanco et al. (2013). They concluded compost use on land could potentially increase soil aggregate stability, water holding capacity and plant available water by as much as 29 to 63%, 50% and 34% respectively. Additionally, a decline in bulk density of 0.7 to 20% could be expected (Martinez-Blanco et al., 2013). The effect of compost application on soil hydraulic conductivity and infiltration vary with time, method and rate of application (Tittarelli et al., 2007). Results from some representative studies are shown in the Table 2.3. These beneficial effects are interactive and are attributed in large to the nature of the compost materials applied into soil.

The high organic matter content of compost and the increase in microorganism activity that results from the addition of organic matter to soil increases the stability of soil aggregates which improves soil structure (Chesters et al., 1957; Gallardo-Lara and Nogales, 1987; Capriel et al., 1990; Hue, 1995; Stratton et al., 1995). Also, high organic matter levels improve soil quality by promoting favorable changes in soil bulk density, porosity, water holding capacity, and by reducing erosive losses of soil (Young and Onstad, 1978; Soane, 1990; He et al., 1992; Stratton 1995; Ros et al., 2006).

Table 2.3 Effect of compost materials on soil physical properties.

Property	Effect	Compost feedstock	Application method	Soil Type	Reference

Aggregation	stabilized	sludge and refuse	incorporation	sandy loam	Pagliai et al 1981
		mixed	incorporation	loamy	Aggelides and Londra 2000
		mixed	incorporation	clay	Aggelides and Londra 2000
Porosity	increased	sludge and refuse	incorporation	sandy loam	Pagliai et al 1981
		urban waste	incorporation	clay loam	Giusquiani et al.1995;
		mixed	incorporation	loamy	Aggelides and Londra 2000
		mixed	incorporation	clay	Aggelides and Londra 2000
		sludge and refuse	topdressing	Silty clay	Pagliai and Antisari 1993
		sludge and refuse	topdressing	Sandy loam	Pagliai and Antisari 1993
Bulk density	decreased	municipal wastes	topdressing	silt loam	Mays et al. 1973
		sewage sludge	incorporation	loamy sand	Tester 1990
		urban waste	incorporation	clay loam	Giusquiani et al.1995;
		mixed	incorporation	loamy	Aggelides and Londra 2000
		mixed	incorporation	clay	Aggelides and Londra 2000
		olive mill	mixture	sandy loam	Nektarios et al. 2011
Water holding capacity	increased	municipal wastes	topdressing	silt loam	Mays et al. 1973
		sludge	incorporation	silt loam	Epstein et al.1976
		olive mill	mixture	sandy loam	Nektarios et al. 2011
Water retention capacity	increased	sludge	incorporation	silt loam	Epstein et al.1976
		urban waste	incorporation	clay loam	Giusquiani et al.1995;
Penetration resistance	reduced	sewage sludge	incorporation	loamy sand	Tester 1990
		mixed	incorporation	loamy	Aggelides and Londra 2000
		mixed	incorporation	clay	Aggelides and Londra 2000
Unsaturated hydraulic conductivity	reduced	mixed	incorporation	loamy	Aggelides and Londra 2000
		mixed	incorporation	clay	Aggelides and Londra 2000
Saturated hydraulic conductivity	increased	mixed	incorporation	loamy	Aggelides and Londra 2000
		mixed	incorporation	clay	Aggelides and Londra 2000

Compost application directly affects soil chemical properties. The addition of large amounts of compost will usually result in an increase in soil organic matter (He et al., 1992, Bevacqua and Mellano, 1993). The long term benefits associated with compost use are primarily associated with the change in soil organic matter content that occurs with compost use (Alexander, 2001; Soumare et al., 2003). A noticeable positive effect on soil organic carbon (C_{org}) is often observed in plots treated with compost materials regardless of the feedstock from which compost originates (Giusquiani et al., 1988; Madejon et al., 2003; Zaman et al., 2004, Hartl and Erhart, 2005; Montemurro et al., 2006; Ros et al., 2006).

Compost materials undergo "humification" during the composting process which results in the end product having an elevated CEC compared to the feedstock (Saharinen, 1998). Cation exchange capacity is a result of dissociation of the H^+ ion from weak acids in organic matter and is an index of soil nutrient holding capacity (Stratton et al., 1995). It plays an important role in retaining nutrients for plant uptake and in reducing nutrient leaching losses. A high CEC also buffers changes in soil acidity (Barker. 1997). The addition of a mature compost, whose pH value is generally neutral or slightly alkaline will usually increase the pH of an acidic soil (Eghball, 2002; Butler and Muir, 2006). Godden et al. (1987) noted a quick alkalinizing effect on an acidic loamy soil with addition of 30 Mg ha^{-1} cattle manure compost. The pH of a Windthorst sandy loam soil increased from 4.5 to 7.0 as a single application rate of manure compost increased from 0 to 179.2 Mg ha^{-1} (Butler and Muir, 2006). Conversely, Nektarios et al. (2011) reported that incorporating an olive mill compost having a pH of 6.6 to soil at ratio of 12.5%, 25%

and 50% (V/V) decreased the pH of soil pH from 8.11 to 7.95, 7.78 and 7.15, respectively. Accordingly, compost use will raise or lower soil pH depending on the amount of compost used, the pH of compost and the pH of the native soil to which the compost is applied (US Composting Council, 2001). Hornick et al. (1984) also pointed out if compost was added to soils with pH below 4.5, additional lime would be required.

Compost is characterized as a valuable slow release nutrient source of macronutrient and micronutrient to soil. Most end users apply composts based on plant required N or P rates, however many composts also serve as a source of K, sulfur (S), calcium (Ca) and magnesium (Mg) (Chaney et al., 2001).

The N content in compost usually varies from 0.5% to 3% on a dry mass basis with 85 to 90% of N being present as organic N and the rest being immediately available to plant use (Barker, 1997; Tittarelli et al., 2007). Generally, 10 to 20% of the total N in compost is available in the first year with the remaining pool of N being mineralized at rate of 3 to 8% in subsequent years (Iglesias-Jimenez and Alvarez, 1993; Diacono and Montemurro, 2010).

Although the amount of N applied varies with different compost materials and rate of application, a significant increase in soil total N is often observed in compost treated soil in the both short and long terms (Zaman et al., 2004; Hartl and Erhart, 2005; Habteselassie ,2006; Ros et al., 2006; Zhang et al., 2006). The increase in soil N is directly derived from the added compost and is a consequence of elevated soil organic matter levels that result with the addition of compost to soil (Ros et al., 2006). The recovery or uptake of compost N is often observed to be less effective than mineral N fertilizer, particularly shortly after application of the compost (Iglesias-Jimenez, and

Alvarez, 1993; Erhart et al., 2008; Hartl and Erhart, 2005). Tester et al., (1982) observed about 76% of total fertilizer N and only 8% of total compost N were utilized by tall fescue during the course of a 167 day greenhouse pot study. The reduced rate of N uptake by plants was likely the result of a slow N mineralization rate of the organic pool of N in the compost (Tester et al., 1982; Hartl and Erhart, 2005). The mineralization of N in soil is dependent on the time of application, the C/N ratio of the compost, soil physical and biochemical characteristics, soil cultivation practices, and soil-plant interaction, such as N uptake and climatic conditions (Hartl and Erhart, 2005). Thus, relatively high application rates of composted materials are required if the compost is to serve as sole source of nutrient for the turf, especially nitrogen. Hornick et al. (1984) pointed out for some high N and/or P plant requirements, it is most appropriate to apply compost at the lower of two nutrient needs and to supply the remaining amounts needed using a synthetic fertilizer .

The P content in compost is normally 0.6% to 2.0% on a dry mass basis (Tittarelli et al., 2007) with up to 15% of P being available in first two years following incorporation (DeHaan, 1981 as cited by He et al., 1992; Soumare et al., 2003). Compost P uptake is usually 10 to 70% of the amount of mineral fertilizer P (i.e. superphosphate or triple superphosphate) taken up by plants (Mays et al., 1973; Sikora et al., 1982, Hornick et al., 1984). The availability of P in compost is affected by Fe, Al and Ca content in biosolids based composts (Hornick et al., 1984; Mccoy et al., 1986, Wen et al., 1997). These elements are introduced into the feedstock of this type of compost as part of sewage treatment process. For example, Mccoy et al. (1986) found that when the feedstock of biosolids based compost was treated with Fe and Al to precipitate P, or alternatively with lime, the P present in the finished product was a poor source for plant growth. In contrast, some reports have shown that P in other types of feedstock, or treatment methods which is mostly in organic from, is readily available for plant uptake (Zhang et al., 2006). He et al. (2000) showed the percentage of total P extracted by $NaHCO_3$ was higher in yard waste compost (3.7%) and a co-compost of biosolids and yard wastes (3.3%), than in a biosolids compost (0.2%) because biosolids P was primarily associated with Ca, Fe, or Al. He et al. (2001) also noted that P mineralization was greater in MSW compost and yard trimmings compost than biosolids compost when P availability was determined using Mehlich 3 as extractant. The use of MSW and yard trimmings composts has been observed to increase plant available P in the soil and to improve vegetable crop P use efficiency (Sikora et al., 1982; Buchanan and Gliessman, 1990; He et al., 2001). When plant P needs are used to guide compost applications, supplemental application of N fertilizer is usually required to meet plant needs (Hornick et al., 1984; Eghball, 2002).

The K concentration of compost is usually less than 1 %. This is substantially below the K concentration found in most agricultural soils and in healthy plant tissues (He et al., 1992; Angle, 1994; He et al., 2001; Tittarelli et al., 2007). Generally, when compost use is based on a plant's N or P requirement, the K requirement for the crop will not be met (Hornick et al., 1984; Angle, 1994). However, compost K availability can be effective as mineral K fertilizer (DeHaan, 1981 as cited by He et al., 1992), because compost K remains in water soluble forms and does not need to be mineralized prior to plant uptake (Barker 1997). Increases in soil and plant K content have been observed with the utilization of MSW compost (Giusquiani et al., 1988; Zhang et al., 2006).

Soumare et al. (2003) have reported that about 50% of K present in compost is available for plant uptake shortly after application to soil.

Elevated concentrations of S, Ca and Mg have been observed in some soils with the application of compost in some studies (Villar et al., 1993; Wong et al., 1999). As part of composting process the C to S ratio declines with S being released for plant uptake once the compost is mature (Barker, 1997). The Ca concentration in compost is usually about 1% to 4% on dry mass basis, but may be up to 10% when the composts is made from lime stabilized biosolids (Barker, 1997). Compost can be used to alleviate Ca deficiencies and to increase Ca availability for plant growth in sandy and acidic soils (He et al., 2001). The Mg concentrations in compost typically vary from 0.2% to 0.4%. This is large enough that an increase in soil Mg will likely be observed with the application of compost (Barker, 1997; He et al., 2001).

While much of the N and P present in compost is not readily available for plant use, the application of compost can greatly enhance soil fertility. In a greenhouse pot study, soil amended with 4 to 6% sewage sludge compost provided nutrients to support tall fescue growth for over 100 days while nutrients provided by a NH_4NO_3 fertilizer were depleted after 100 days (Tester et al., 1982). The residual effect of compost on soil fertility due to the continuous release of nutrients has been reported in many long term studies. One time incorporation of 155Mg ha^{-1} food waste composts enhanced the uptake N of a forage type tall fescue from a total of 294 to 527 kg ha^{-1} over a 7 year period demonstrating the long lasting effect of amending a soil with compost (Sullivan et al., 2003). Ginting et al. (2003) reported soil microbial biomass C and potentially mineralizable N increased by 20 to 40% and 43 to 74% respectively when repeated compost and manure applications were made at rate of 151 kg N ha^{-1} yr^{-1} in a four year study.

Compost can also supply micronutrients (e.g., Zn, Cu, Fe and Mn). The addition of MSW compost has been observed to lead to an increase in soil total and extractable B Cu, Fe, Mo, Mn, Zn as well as other trace elements (Giusquiani et al., 1988; Petruzzelli et al., 1989; Villar et al., 1993; Ozores-Hampton et al. 1997; Zheljazkov and Warman, 2004a,b; Zhang et al., 2006). Increases in soil micronutrient levels do not always result in increasing plant uptake of micronutrients. The addition of compost either increases soil pH making heavy metals less available or the organic fraction of the compost tightly bonds the heavy metals making them less available for plant uptake (Wong and Lau, 1985; Stilwell, 1993; Sterrett et al., 1996; Warmen et al., 2004; Zheljazkov and Warman, 2004b).

The presence of trace elements in composted materials was an early concern that arose when compost started to be used on agricultural and horticultural land. The accumulation of heavy metals in particular was a concern, because their effect on plant health and the potential to enter into the food chain of animal and humans (Stratton et al., 1995; Diacono and Montemurro, 2010). The potential risks of accumulation of heavy metals from MSW compost to soil and water quality, public health and environment has been thoroughly reviewed by Chaney and Ryan (1993).

Some studies such as, Woodbury (1992) showed that field application of MSW compost is only a concern to sensitive plant species that readily accumulate heavy metals or when this type of compost is applied to highly acidic soils. Metals in compost can accumulate in soil, but they are generally present in an immobile state or are bound to organic matter/humic materials keeping them from leaching or being adsorbed by plants (Mays et al., 1973; Petruzzelli et al., 1989; Woodbury, 1992; Ozores-Hampton, 1997; He et al., 2001). The detrimental effects of trace elements are closely related to the mobility of the metals rather than their total concentration in soil. Risk management strategies and guidelines for limits on heavy metals in composts have been discussed by Stratton et al. (1995) and Chaney et al. (2001). Within this context, the use of compost may actually provide beneficial effects in reducing the availability of heavy metal in soils, particularly in soils with low organic matter content or pH (Woodbury, 1992; Stratton, 1995).

Another concern with the use of compost is the presence of soluble salts which are closely tied to the compost feedstock and the processing procedures used at a composting facility (Fitzpatrick, 2001). Leaching compost and blending it with low soluble salt content substrates are two common methods used to manage compost products that are initially high in salts (Fitzpatrick, 2001). Regular testing of compost prior to utilization is the best way to insure the compost is suitable for in use in managed plant systems

2.2.2 Soil Biological Properties

Microbial activity and composition are essential determinants of soil quality. Unlike soil chemical and physical parameters, soil biological properties are sensitive to small changes in the soil system thus providing an immediate way to detect changes in the soil environment (Pascual el at. 2000). Despite the heterogeneous character of compost materials, it is generally assumed that microbial biomass and enzyme activity are stimulated when compost is added to the soil. In general, changes in soil microbiological properties that occur with the addition of compost to soil are of three types. These are changes in 1) the total microorganism population, 2) microbial diversity and community structure, and 3) some specific microbiological activities such as nitrification (He et al., 1992).

Basically, beneficial microorganisms are spontaneously present in well decomposed compost and will be introduced to soil during the use of compost (Jodice and Nappi, 1987). Intermediate products produced by these original microorganisms can be taken by nitrogen fixers in soil whose population then increases (Jodice and Nappi, 1987). At the same time, these cellulolytic, pectinolytic, proteinolytic, nitrifier microorganisms in soil promote the soil nutrients cycling for the soil microbial community (Tittarelli et al., 2007). The organic matter in compost also serves as food for soil microorganisms. It is believed that addition of organic substance leads to an increase in heterotrophic microorganisms and soil enzyme activities as it provides carbon sources and basic materials for protoplasmic synthesis. Some studies reported composts can even sustain these increases for a long time as a result of continuous slow release of nutrients (García-Gil et al., 2000, Ginting et al., 2003). Some physical characteristics of compost can also be beneficial to soil microorganisms. For example, García-Gil et al. (2000) attributed the elevated catalase activity, an oxidoreductase associated with aerobic microbial activity, to the improved soil aeration in the compost amended soil.

Rutili et al. (1987) observed significant increases in microbial counts of cellulolytic microorganisms and autotrophic nitrifying bacteria in compost amended soil compared with the use of mineral fertilizer or manure two years after amending the soil with compost. The highest populations were observed in late summer during plant growth. They observed that soil microbial populations were tied to precipitation patterns and suggested that reduced oxygen in soil had been responsible for the decline in microbial populations. Positive correlations between organic substances present in composts and non-symbiotic nitrogen fixers, as well as between composts and vesicular arbuscular mycorrhizae were observed by Jodice and Nappi (1987). They highlighted the importance of compost composition on soil microbiological properties.

The influence of composts on microbial enzymatic activities, soil microbial biomass and basal respiration has been examined in several studies. Godden et al. (1987) reported that cattle manure compost applied at rate of 30 Mg ha^{-1} stimulated soil microflora and phosphatase and urease activities in a loamy acidic soil. The content of biomass C, N, P and S as well as the activity of phosphatase, urease, protease, deaminase and arylsulphatase were all increased by the addition of composted municipal solid wastes. The increases lasted from one to three months with the exception of biomass P and phosphatase activity which remained at elevated levels for 5 months in clay loam soil under laboratory conditions (Perucci, 1990). In a follow up field study, Perucci (1992) observed increases in biomass C, the rate of fluorescein diacetate hydrolysis (FDA) and many other enzymes activities (i.e. amylase, arylsulphatase, phosphodiesterase, phosphomonoesterase, protease, and deaminase) in a soil amended with municipal refuse compost, with most of aforementioned activities reaching a maximal level after one month of treatments. Tian et al. (2008) reported a sand based turf putting green mix containing 10% (v/v) yard waste compost had increased soil microbial biomass in the top 30 cm of soil when compared to a peat mix and the untreated control two and three years after first making the compost applications. Albiach et al. (2000) compared MSW compost, sewage sludge and ovine manure applied to a sandy silty loam soil at rate of 24

Mg ha^{-1} yr^{-1}, and found that MSW compost resulted in the greatest increase of soil enzymatic activity. An increased organic C supply and stimulated microbial activities might explain the increased biomass C, N, P, S and enzymatic activities after compost application (Garcia-Gil et al., 2000; He et al., 2001; Zaman et al., 2004; Ros et al., 2006).

The long term or residual effects of compost addition on microbial activities have also been examined. Garcia-Gil et al. (2000) observed inconsistent responses of different enzymes following the addition of compost to soil. Increases in oxidoreductase enzymes like dehydrogenase and catalase, and decreases of hydrolase enzymes like phosphatase and urease were observed over the course of their nine year field experiment (Garcia-Gil et al., 2000). Ros et al. (2006) reported increases of soil biomass C and basal respiration in soil treated with urban organic waste compost, green waste compost and sewage sludge compost when compared to the control and a mineral fertilizer treatment in a 12-year field experiment. In a 23-year field study conducted on silt loam soil, a soil surface compost application of 240 kg ha^{-1} yr^{-1} significantly increased microbial biomass C at the 0 to 15 cm soil depth, microbial biomass N up to a depth of 40 cm, and elevated the activities of protease, deaminase and urease in surface and sub-surface soil (0 to 50 cm) when compared with mixed fertilizer NPK treatment (Zaman et al., 2004).

Generally, the abundance of a microbial community and the activity of nutrient cycling microorganisms in soil are a function of the quantity and quality of organic materials added to the soil as well as the characteristics of soil itself (Jodice and Nappi, 1987; Diacono and Montemurro, 2010). Elevated total microbial biomass and enzyme activity resulting from the application of compost improves soil fertility over time (He et al., 2001). Negative effects of soil microbial activity on soil fertility occur when unstabilized and immature organic materials have an inappropriate C/N ratio, a high concentration of NH_4-N or high levels of heavy metals (Jodice and Nappi, 1987; Rutili et al., 1987; Garcia-Gil et al., 2000). Additionally, Perucci (1992) has pointed out the decreases in soil microbial activities may also be ascribed to a normal decrease of exogenous microorganisms carried in composts or the depletion of quickly biodegradable organic matter.

2.2.3 Turfgrass Growth

The value of compost as fertilizer is well known and has been shown to increase the growth and yields of agricultural crops including the forage yields of tall fescue (*Festuca arundinacea* cv. 'Marathon') and ryegrass (*Lolium multiflorum* L.) (Bauduin et al., 1987; Bevacqua and Mellano, 1993). Turfgrass management is unlike crop production in which an increase in yield is not always a desirable response. Turfgrass growth beyond that required to sustain adequate turfgrass density is not desired.

The application of compost has been shown to have positive effects on turfgrass seed germination, turfgrass establishment, root growth, and on turf color and density (Landschoot and McNitt, 1994; Loschinkohl and Boehm, 2001; Linde and Hepner, 2005; Mandal et al., 2013). Accordingly compost incorporation can be beneficially used in sod production as well as the establishment of turfgrass on disturbed urban soils (Hornick et al., 1984). For example, Loschinkohl and Boehm (2001) demonstrated amending disturbed urban soils with 130 m^3 ha^{-1} biosolids compost to a depth of 10 to 15 cm significantly enhanced the establishment and growth of Kentucky bluegrass and perennial ryegrass compared to an unamended control. The application of 99 to 298 Mg ha^{-1} (40% moisture) compost has been reported to result in optimal germination, establishment and initial growth of turfgrass (Hornick et al., 1984). Hornick et al. (1984) have also pointed out that application of 29 to 38 Mg $\cdot ha^{-1}$ compost, when applied as a mulch, was capable of enhancing the establishment of cool season grasses, especially in early spring and late fall seedings. Another known beneficial effect of surface applications of compost is weed control. The physical presence of compost on the surface suppresses the germination of soil born weed seeds.

In addition to the growth responses listed above, the addition of compost has been reported to increase nitrogen uptake and foliar nitrogen content of turfgrass (Tester et al., 1982; Garling and Boehm, 2001), and to enhance the growth and quality of Kentucky bluegrass, perennial ryegrass, creeping bentgrass, tall fescue and bermudagrass (Sikora et al., 1980; Schumann et al., 1993; Garling and Boehm, 2001; Geisel et al., 2001; Johnson et al., 2006b). Improved turf green up (recovery from dormancy or disease) and a reduction in the formation of thatch have also been reported (Boulter et al., 2000b; Dinelli, 2009).

The aforementioned improvements in turf performance have been ascribed to the quantity of nutrients in compost, especially nitrogen (Stratton et al., 1995), but they are also associated with changes in soil physical and biological properties that occur with the incorporation compost into the soil. Compost induced changes to the soil can improve the drought resistance and water use efficiency of turfgrass (Alexander, 2001). Johnson et al. (2009) suggested compost topdressing after core cultivation of an established Kentucky bluegrass lawn could lower irrigation water requirements by increasing volumetric soil water content and reducing temperature of the turfgrass canopy. Recent studies have extended into molecular and cell biological aspects of the effect of compost application on plant's drought and salt tolerance. For example, Zhang et al. (2009) pointed out IAA and cytokinin content can be altered by the application of biosolids thereby improving the drought resistance of turfgrass.

Most positive turfgrass responses are associated with large compost applications (i.e. Mg ha^{-1}) or the use compost as a supplement to synthetic fertilizer. There are some results suggesting that compost materials when used alone are not effective as synthetic fertilizer for maintaining turf visual color and quality. (Landschoot and Waddinton, 1987; Barker, 1997; Gardner, 2004). Unlike conventional synthetic fertilizer, the nutrients in compost are stabilized during composting and thus are provided in slow release form.

2.2.4 Diseases

Composts are currently recognized as effective products for the control of crop and ornamental plants diseases caused by soilborne plant pathogens (Hoitink et al., 2001). Public concern with the use of synthetic pesticides to control plant diseases along with the cost associated with use of these products have heighten interest in using compost as a disease suppressing material (Boulter et al., 2000b; Noble, 2011). During the 1960s, suppression of phytophthora root rots was first noticed when composted tree bark was used in potting mix as a substitute for peat in the U.S. (Hoitink et al., 1975, 2001). One of the first well documented experiments on the use of plant disease suppressive compost was conducted by Hoitink et al. (1977) (as cited by VanElsas and Postma, 2007). They found the inhibitive effect of hardwood bark compost on sporangium and zoospores production of *Phytophthora cainnamomi* (Hoitink et al., 1977). This research was followed by a number of studies that examined the disease suppressing capability of compost derived from different types of organic waste (Noble and Coventry, 2005).

Disease occurrence in response to the application of compost materials to soil can be positive, negative, or neutral. In a review of the risks and benefits associated with the use of compost as a medium that affects pathogenic organisms, Noble (2011) reported when container media were amended with more than 20% compost by volume, enhanced suppression of soilborne diseases was noted in 59 out of 79 studies while an increase in disease incidence was seen in 6 of the studies. When compost was applied at rate of more than 15 Mg ha^{-1}, disease suppression occurred in 45 of 59 field trials, while in one case promotion of the disease was seen. The effects of various compost materials on crop and ornamental plant diseases caused by different soil borne pathogens have been reviewed by several researchers (Hoitink & Fahy, 1986; Noble and Coventry, 2005; Noble, 2011). Compost amendment of soils has been shown to lower the severity of some foliar diseases such as powdery mildew and anthracnose, and can lower the population of some nematodes (Stratton et al., 1995; Hoitink et al., 2001).

Reduced incidence of several turfgrass diseases have been reported when compost is used as top-dressing material. Suppression of foliar diseases such as brown patch (*Rhizoctonia solani*), dollar spot (*Sclerotinia homoeocarpa*), damping-off (*Pythium graminicola*), fusarium patch (*Microdochium nivale*), pythium blight (*Pythium aphanidermatum*), red thread (*Laetisaria fuciformis*), snow mould (*Typhula ishikariensis*), Typhula blight (*Typhula incarnata*) and leaf rust (*Puccinia* sp.) have been reported as well as root infecting diseases such as necrotic ringspot (*Leptosphaeria korrae*), pythium root rot (*Pythium graminicola*) and summer patch (*Magnaporthe poae*) (Nelson and Craft. 1992; Nelson et al., 1994; Craft and Nelson, 1996; Nakasaki et al., 1998; Boulter et al., 2000b, 2002a, 2002b; Loschinkohl and Boehm, 2001; Nelson and

Boehm, 2002; Dinelli, 2004; Paplomatas et al., 2004). Disease suppressions with various composts on different types of turfgrass have been discussed in several papers (Nelson et al., 1994; Boulter et al., 2000a; Noble and Coventry, 2005).

The most widely accepted mechanisms for the disease suppressive properties of compost are: 1) the physical and chemical attributes of compost, which aid in improving soil properties that promote plant health (Litterick et al., 2004; VanElsas and Postma, 2007); 2) the microbes, which are present in the compost or stimulated after the addition of compost in soil, suppress pathogens by the means of nutrient competition, antibiosis, hyperparasitism and the introduction of plant systemic acquired resistance (Hoitink et al., 2001; VanElsas and Postma, 2007).

Most reports on the inhibition of soil borne plant pathogens by compost are associated with biological control mechanisms (Serra-Wittling et al., 1996; Litterick et al., 2004; Noble and Coventry, 2005; Noble, 2011). Microorganism suppression can be subdivided into “general” and “specific” suppression (Hoitink et al., 2001). General suppression is ascribed to the activity of many different microorganisms (Litterick et al., 2004). These microorganisms function as biological control agents against pathogens whose propagules are sensitive to microbiostatic agents. General microbial activity and biomass in compost and soil also inhibit the growth of pathogens (Hoitink et al., 2001). The germination of Phytophthora and Pythium spp. spores are inhibited in this way (Chen et al., 1988; Boehm et al, 1993). Specific suppression takes place when a limited group of microorganisms acts on a specific pathogen (Hoitink et al., 2001). The suppressions of *Rhizoctonium solani*, *Sclerotium rolfsii* and *Sclerotinia sclerotiorum* fall into this category (Jones and Watson, 1969; Nelson et al., 1983; Hadar and Gorodecki, 1991;

Litterick et al., 2004). Large propagules, known as sclerotia, produced by these pathogens are colonized by hyperparasites which results in lysis or death of these structures. *Trichoderma* spp, *Penicillium* spp and *Contothyrium minitans* are the main parasites that have been isolated from compost. They are known to target the sclerotia of *Rhizoctonium solani*, *Sclerotium rolfsii* and *Sclerotinia sclerotiorum*, respectively (Nelson et al., 1983; Hoitink and Fahy, 1986; Hadar and Gorodecki, 1991; Litterick et al., 2004). Other aspects of specific suppression include antibiosis produced among microorganisms and plant systemic resistance induced by microorganisms to specific pathogens (Stratton et al., 1995; Litterick et al., 2004).

The suppressive effects of compost in a field setting is more variable than container systems (Noble and Coventry, 2005). A factor that may contribute to the inconsistent results observed in field is that different types of compost may have been applied to the site (Hoitink and Fahy, 1986). Compost composition, particle size and degree of decomposition/maturity of the compost can affect the disease suppression ability of the compost (Litterick et al., 2004; VanElsas and Postma, 2007; Lozano et al., 2009). Hoitink, el al. (1987) pointed out that high cellulose content (high C/N ratio) composts have an adverse effect on Rhizoctonia damping-off severity. The nutrient release properties of compost can also affect severity of many plant diseases since some diseases are caused by high level of fertility while others are as a result of a nutrient deficiency. The methods and rate of compost application as well as the cultural practices used following the application of compost will affect extent of disease control that is achieved with the use of compost (Litterick et al., 2004; Noble and Coventry, 2005).

Higher rates of compost application usually result in increased disease suppression (Noble and Coventry, 2005).

Soil physical, chemical and biological characteristics and environmental conditions can have a substantial impact on the ability of compost to suppress diseases. The type and amount of beneficial and pathogenic organisms present in soil are diverse making difficult to obtain consistent results with the use of compost materials. The use of single compost can be suppressive to one pathogen but conducive to another (Hoitink, el al., 1987; Litterick et al., 2004).

Both beneficial and plant pathogenic organisms are killed by the heat generated during composting process (Hoitink et al., 2001). Although most beneficial microorganisms may recolonize compost after the high temperature phase of composting is finished, inoculation of composts with beneficial agents is suggested as a means to ensure the suppressive effect of the final product (Stratton et al., 1995; Noble, 2011).

2.2.5 Compost in Liquid Form

Compost based sprays have been applied to soil and plants since at least the 1920s (Koepf 1992 cited by Scheuerell and Mahaffee, 2002). The terms compost tea (Ingham, 2000), compost extracts (Weltzien, 1989), compost steepages (Hoitink et al., 1997) and compost slurries (Cronin et al., 1996) have been used to define compost applications made in liquid form. According to Scheuerell and Mahaffee (2002), and Litterick et al. (2004) the stated usage of the terms just mentioned is related to the oxygen status of the material. Currently the most common terms used to describe liquid compost are compost tea and compost extract.

Compost tea is a solution that contains microbes and nutrients obtained from compost that has been placed in water, while a compost extract is a solution that contains organisms and soluble nutrients that have been obtained by running water with significant pressure through compost (Ingham, 2005). Compost tea can be classified as aerated compost tea (ACT), not-aerated compost tea (NCT) and anaerobic tea (Scheuerell and Mahaffee, 2002; Ingham, 2005). Compost placed into water and subjected to aeration with or without the presence of additives that may spur microbial growth is called aerated compost tea. If a water and compost solution is not subjected to introduced oxygen during the period of time the compost is present in water the final product is referred to not-aerated compost tea. When microbial growth in a liquid compost solution is spurred by the addition of one or more additives, this leads to dramatic reduction in the oxygen in the solution. The resulting solution is referred to as anaerobic tea (Ingham, 2005).

Substances that are typically added to liquid compost solutions to increase the presence of beneficial organisms in the compost include kelp, rock dust, fish hydrolysates and humic acids. All of these have often been used to encourage the growth of fungi (Ingham, 2003). The production of compost can involve the use of 19 L (5 gallon) bucket for small amounts of tea or a much large container up to 1893 L (500 gallons) for commercial tea production. Various pump designs and aeration devices can be used to produce ACT. A typical production time for this type of tea is 24 to 48 hours (Ingham, 2003). The production of NCT typically involves mixing compost with water in an open container for at least three days with (Brinton et al., 1996) or without periodical stirring (Weltzien, 1992). Currently there are no accepted standards for producing NCT (Ingham, 2005). The properties of compost are influenced by aeration, compost feedstock and quality, added food source, brewing time, water ratio, temperature and pH (Scheuerell and Mahaffee, 2002; Ingham, 2005). The final product can be variable, thus periodical testing of the oxygen concentration, or total and active bacteria and fungi are usually needed to ensure consistency of compost tea used (Scheuerell and Mahaffee, 2002; Ingham, 2005).

Compost tea is usually used as a foliar spray or a soil drench (Ingham, 2000). Compost tea has two key characteristics that benefits soil and plants: it contains beneficial organisms and it provides soluble nutrients. The beneficial organisms cultivated in compost tea can inhibit the growth of disease causing organisms by competing for nutrients and infection sites or by outright consumption of the disease causing organisms (Scheuerell and Mahaffee, 2002). Beneficial organisms preserve nutrients in their biomass and have the ability to decompose plant-toxic materials. The nutrients in compost tea are available for plant uptake. Uptake of these nutrients can result in improved plant health which may reduce the need for supplemental chemicals products to sustain plant growth (Ingham, 2005). The suppression of disease through compost tea application has been extensive documented and summarized by Scheuerell and Mahaffee (2002), and Litterick et al. (2004). The use of compost teas for controlling foliar diseases and soil-borne diseases mostly has been reported on agricultural crops such as corn, wheat, bean, tomato, lettuce, potato, cucumber, strawberry and grape etc. (Weltzien, 1992; Yohalem et al., 1994; Zhang et al., 1998; Scheuerell and Mahaffee, 2002; Al-Dahmani et al., 2003; Litterick et al., 2004; Koné et al., 2010). Ingham (2005) has outlined the appropriate strategies for the use of compost tea on horticultural plants such as turf, ornamental trees, and fruit crops.

2.2.6 Environmental Impact

In the early days of the composting industry, the presence of pathogenic organisms, heavy metals and hazardous organic substances were common issues of concern (Epstein and Epstein, 1989, Rosseaux et al, 1989, He et al., 1992, Noble and Roberts, 2004). However, as improvements have been made in the design of composting facilities and management of waste, these problems have largely disappeared with production of high quality compost becoming available throughout the United States. Compost production is now viewed as a desirable way to manage much of the organic waste that is produced by municipalities (He et al., 1992).

One of the agronomic benefits associated with the use of compost as a soil amendment is that it generally acts as slow-release fertilizer which results in reduced nitrate leaching and ammonia volatility when compared to a water soluble nitrogen fertilizers (e.g. urea) (Stratton et al., 1995; Barker. 1997). However when applied at rates in excess of plant uptake the use of compost is often no better than many types of N-source fertilizer in limiting nutrient loss to ground and surface water (Li et al., 1997; Plaster, 2013). The fact that most nutrients from compost are not available unless microbial activity decomposes the compost leads to relatively high rate application of the compost, especially in the first year. Such practice may result in an excessive accumulation of some nutrients in the soil when the compost is applied to meet a specific nutrient need of the plant. In such a situation it is sometimes advantageous to blend a synthetic fertilizer into compost so that the application rate of compost can be lowered while nutritional needs of the plant are still met.

Compost is known to support organisms that can degrade hazardous organic compounds. For this reason, compost has been used to remediate contaminated sites (Stratton et al., 1995; Savage and Diaz, 2007). Listing of microorganisms that have been inoculated into compost to degrade specific hazardous wastes substrates is available in papers published by Savage et al. (1985) and Stratton et al. (1995).

There is an emerging interest in use of compost as a biofiltration media for air and liquids (Stratton et al., 1995). Various composts have been used as biofilters to treat NO_3^- contamination in agricultural runoff, acid and soluble salts present in mine drainage, and noxious odors and aromatic compounds in air (Blowes et al., 1994, Stark et al., 1994, Liu et al., 1994). The efficiency of some biofilters can be improved when a compost filter bed is included as part of filter and is inoculated with microorganism that metabolize the pollutant of interest (Stratton et al., 1995).

2.3 Organic Lawn Care

Organic lawn care is a frequently used phrase that lacks a precise definition. Unlike organic farming, there are no standards that have been defined and are subsequently regulated by a federal agency such as the USDA's National Organic Program (NOP). This has allowed lawn care companies that specialize in providing organic lawn services to self-define what constitutes an organic lawn care program. Adding to the confusion is the frequent use of the terms natural lawn care and sustainable lawn care management which have many conceptual elements in common with organic lawn care, but also lack a formal working definition. As a result, the three terms have been used interchangeably by some in the turf industry and those who purchase services from this industry.

The USDA's National Organic Program (NOP) restricts the use of the organic label on agricultural foodstuffs to those that have been produced using approved methods that integrate cultural, biological and mechanical practices that foster cycling of resources, promote ecologic balance and conserve biodiversity (USDA, 2015). The use of compost in place of synthetic fertilizers is one of the primary cultural practices used to meet these criteria. A further restriction placed on the certification of organic products by the NOP is that use of sewage sludge based composts materials is not permitted. The use of biosolids composts as a soil amendment in the establishment of turfgrass has been researched and promoted for at least 4 decades (Sikora et al., 1980; Hornick et al., 1984; Angle, 1994; Cheng et al., 2007), however certain segments of the general population are concerned with child ingestion of soil treated with biosolids which has limited the appeal and use of this type of compost in residential settings (Ritter, 2008; Snyder, 2008).

The National Sustainable Agriculture Information Services has summarized organic and least-toxic turf care practices as consisting of practices that do the following (Bellows, 2003): 1) establish and maintain a healthy soil environment, 2) keep a diversity of species in the lawn environment, 3) reduce stress on turf growth, 4) utilize biological pest control methods, and 5) reduce or eliminate the use of synthetic chemicals. Additionally this organization has stated that organic lawn care needs to include an understanding of the climatic and soil based limitations that are inherent with maintaining a lawn in a given area.

Natural Lawns of America, which is one of the first lawn care operations (LCO's) to provide organic lawn care services to homeowners, distilled organic lawn care down to three simple steps (Catron, 1994). These steps are to: 1) use organic based fertilizers derived from natural organic sources, 2) implement a strong IPM based system for lawn care but avoid a see and spray mentality, and 3) use biological control measures in place of synthetic compounds if weed or insect populations need to be controlled. A common practice followed by most organic LOC's is to educate the client to accept the presence of some weeds and insects in the lawn and to emphasize that the development of a "healthy lawn" using organic lawn care practices is many year commitment (Catron,. 1994).

Interest in providing an organic or natural lawn care option has grown over the past few decades. A survey conducted in Atlanta, GA in mid 1990's reported that less than 25% of the LCO's had an organic fertility option as part their service offerings. About one quarter of clients selected this option to fertilizer their lawn (Beverly et al., 1997). A more recent survey released in 2013 reported that 44% of lawn care companies that responded to the survey offered organic or natural lawn care programs (Jacobs, 2013). In this same survey it was reported that 57% of clients were willing to pay a premium for organic/nature lawn care services.

The challenges of transitioning from a synthetic chemical lawn care option to an organic/natural one include the higher costs and a lower effectiveness in controlling pests. However, as public familiarly with concepts of sustainability grows it is likely that, the demand for organic lawn care will continue to increase in the future.

Chapter 3: Effects of Compost Topdressing, Compost Tea Application and Cultivation on Color, Quality, and Weed Encroachment

The implementation of turfgrass fertilizer legislation in several mid-Atlantic states in recent years has placed restrictions on the timing and amount of nitrogen and phosphorus fertilizer that can be applied to lawns (Maryland's Law Fertilizer Law, 2011; The Senate and General Assembly of the State of New Jersey. 2011; New York State Department of Environmental Conservation, 2012). In Maryland, both and homeowners and professional turfgrass managers have restrictions on fertilizer applications that include the amount of nitrogen that can be applied annually to a site, the amount of nitrogen that can be applied per application (dependent on the percentage water soluble nitrogen in a given nitrogen fertilizer product), and the time of year nitrogen and phosphorus containing fertilizers can be applied.

Due to previous regulations on pesticide use to minimize pesticide exposure to humans and the environment (Connecticut General Assembly, 2009; New York State Department of Environmental Conservation, 2010; Maryland's Pesticide Regulation Section) and the more recent turfgrass fertilizer regulations, there has been an increased interest in approaches to turfgrass management that have potentially reduced impacts on the environment and particularly water quality. One area of turfgrass management receiving increased attention due to these restrictions is the use of organic products and management techniques. Organic products that may be used for turfgrass maintenance include plant-based composts, biosolids composts, and compost tea (water extracts of fermented composts).

The use of compost products on turfgrass sites has several potential benefits. Composting has increasingly been recognized as promising method of waste management and use (He et al., 1992), and as a beneficial end use of a waste product on turfgrass versus agricultural land (Angle, 1994). In addition, composts used as soil amendments and nutrient sources generally act as a slow release fertilizer, which may result in reduced nitrate leaching and ammonia volatility when compared to water soluble nitrogen fertilizers (Stratton et al., 1995; Barker, 1997).

The effects of compost applications on turfgrass performance have been evaluated in several studies. The value of using compost on established turfgrass include improving turfgrass quality and color (Sikora et al., 1980; Schumann et al., 1993; Boulter et al., 2000b; Garling and Boehm, 2001; Geisel et al., 2001; Johnson et al., 2006b), increasing nitrogen uptake, increasing foliar and root nitrogen content (Tester et al., 1982; Garling and Boehm, 2001), reducing weed encroachment (Geisel et al., 2001; Mandal et al., 2013), suppressing root and foliar diseases (Nelson and Craft. 1992; Nelson et al., 1994; Craft and Nelson, 1996; Nakasaki et al., 1998; Boulter et al., 2000b, 2002a, 2002b; Nelson and Boehm, 2002; Dinelli, 2004; Paplomatas et al., 2004; Noble and Coventry, 2005), and improving soil water holding capacity and thereby reducing irrigation water use (Johnson et al., 2009; Nektarios et al., 2011). However, most studies involved only the evaluation of organic materials (they were not compared to synthetic fertilizers), were performed on high maintenance turfgrass sites such as golf course turf where composts were used as supplemental nutrients sources to regular fertilizer, and/or were not performed in the unique environmental conditions of the turfgrass transition zone. Thus, further studies are needed to compare compost products to conventional nitrogen sources on lawn-type turf in the transition zone.

The addition of a thin layer of compost over the surface of turf may also make it possible to gradually improve soil physical and chemical properties without severely disturbing the soil or existing turf (Agresource, 2013). However, one potential drawback of the use of composts in this fashion for turfgrass maintenance is the possibility of creating an organic layer on top of existing soil from repeated surface applications of compost. Although generally employed as a way to increase soil aeration and reduce soil compaction, core cultivation is often used prior to or after compost topdressing to achieve penetration of compost into the soil and thus prevent a layering problem. However, little research exists studying the efficacy of this practice and the subsequent effects of turfgrass quality.

In recent years, water extract from fermented compost (compost tea) has gained popularity as a liquid spray to provide nutrients, potential soil microbiological benefits, and reduction in disease incidence in agricultural and horticultural crops (Scheuerell and Mahaffee, 2002; Ingham, 2003; Litterick et al., 2004). However, little information in the literature is available on the use of compost tea and its effects on turfgrass. Rossi (2007) found that foliar compost tea (360 L ha^{-1}) applied to a mix annual bluegrass (*Poa annua* L.) and creeping bentgrass (*Agrostis stolonifera* L.) sand based putting green was able to suppress dollar spot in one of three years when compared to untreated plots. Miller and Henderson (2012) found that compost tea, when applied at 408 L ha^{-1} on 3 week intervals over a period of 4 months, had no effect on the color, quality or cover of Kentucky bluegrass (*Poa pratensis* L.). Therefore, the effect of regular compost tea applications on turf maintained under home lawn conditions in high disease pressure and environmental stress regions such as Maryland needs to be documented to determine if such practices should be promoted within the mid-Atlantic region of the United States.

The objectives of this study were 1) to evaluate the effect of the surface application of two different compost materials compared to a synthetic slow release fertilizer on turf-type tall fescue quality, color, and potential pest problems, 2) to evaluate the effect of repeated compost tea applications on turf-type tall fescue quality, color, and potential pest problems and 3) to determine the extent to which cultivation procedures affect the performance of compost materials and an enhanced efficiency synthetic fertilizer applied to turf-type tall fescue.

3.1 Materials and Methods

3.1.1 Site Locations

Turf color, quality and weed cover in response to hollow tine cultivation, compost tea application and compost topdressing were examined on established lawns at two sites in Maryland. The first site was a 4-year-old stand of ‘Titanium’ tall fescue (*Festuca arundinacea* Schreb.) and ‘Raven’ Kentucky bluegrass (*Poa pratensis* L.) located at the University of Maryland Paint Branch Turfgrass Research Facility (PBTRF) in College Park, MD. The soil at this site was a Russett (fine-loamy, mixed semiactive, mesic Aquic Hapludults) and Christiana (fine, kaolinitic, mesic Aquic Hapludults) complex. The top 10 cm of soil consisted of 3.4% organic matter, 21% clay, 48% silt 31% sand, and had soil pH of 5.5. Mehlich III soil test levels for this soil were 87 mg P kg^{-1}, 159 mg K kg^{-1}, 154 mg Mg kg^{-1}, and 896 mg Ca kg^{-1}. This site was seeded on 21 October 2007. Prior to initiation of the study, turf received 49 kg N ha^{-1} kg (1 pound per thousand square feet) as urea on 9 Apr. and 24 Sept. 2009 and on 15 Apr. and 8 Sept. 2010. The turf was mowed at least twice a month during the growing season at a height of 6.2 cm (2.5 inch). Broadleaf weeds and patches of creeping bentgrass (*Agrostis stolonifera* L.) present in the test area in advance of the study were removed by spot treating the bentgrass with glyphosate [N-(phosphonomethyl)glycine, $C_3H_8NO_5P$] and by applying a broadleaf herbicide containing 2,4-D (2,4-dichlorophenoxyacetic acid, $C_8H_6C_{l2}O_3$), mecoprop [2-(4-Chloro-2-methylphenoxy) propanoic acid, $C_{10}H_{11}ClO_3$] and dicamba (3,6-dichloro-2-methoxybenzoic acid, $C_8H_6C_{l2}O_3$) in the summer of 2011. Glyphosate treated areas were seeded with 'Titanium' tall fescue once death of the bentgrass was apparent.

The second site was located at the Glenstone art museum in Potomac, MD on a hillside having a 5.6 % slope. The soil at the site was mapped as Glenelg silt loam (fine-loamy, mixed, mesic Typic Hapludults), however, substantial grading of the site took place prior to turf establishment. The grading activity severely altered the natural pedology of the native soil resulting in the creation of a disturbed type soil at the site. The soil within the study area contained 29% clay, 43% silt, 28% sand, 4.3% organic matter content and had a soil pH of 5.5. Mehlich III soil test levels for the upper 10 cm of soil were 21 mg P kg^{-1}, 184 mg K kg^{-1}, 195 mg Mg kg^{-1}, and 1145 mg Ca kg^{-1}. The site was seeded with 'Confederate' tall fescue in 2006 and was maintained at 10 cm (4 inch) in the year prior to the initiation of the study.

3.1.2 Compost and Fertilizer Treatments

Fertilizer treatments in the study included a sewage sludge based biosolids compost from Baltimore, MD, (Orgro, Veolia Water North America Baltimore City Composting Facility, Baltimore, MD), a plant based yard trimmings compost from suburban MD (Leafgro, Maryland Environmental Services/Dickerson, Dickerson, MD), an enhanced efficiency synthetic nitrogen fertilizer (polymer coated urea 'Signature' 35-0-10, Loveland Products, Inc. Greeley, CO) and an untreated control treatment. Each material was applied at the rate of 156 kg N ha^{-1} once per year in the fall. Two additional fertilizer treatments were also included in the study, consisting of a once a year application of 1 cm of a biosolids compost and yard trimmings compost. The latter two compost treatments are consistent with typical compost topdressing amounts applied to lawns by practitioners while the former compost and synthetic fertilizer treatment amounts are slightly above the annual nitrogen cap of 146 kg N ha^{-1} established for lawn turf fertilizer use in the State of Maryland (Turner, 2013). The chemical properties of the two composts (Table 3.1, 3.2, 3.3) were analyzed annually before application to ensure each material was broadcasted at the desired rate. Based on the results of the analyses of compost, a surface application of 1 cm of the biosolids and yard trimmings compost applied ,on average, 1108 and 584 kg N ha^{-1} yr^{-1}, respectively. Compost topdressing applications were made in late September or October of each year for three years with the initial application made in 2011. At PBTRF site, treatments were applied on 5 and 6 Oct. 2011, 5 Oct. 2012, 3 Oct. 2013. At Glenstone site, treatments were applied on 12 Oct. 2011, 26 Sept. 2012. In 2013 the compost treatments at this site were applied on 9 Oct. 2013, while the synthetic fertilizer treatment was applied on 16 Oct. 2013.

Table 3.1 Chemical properties of the biosolids compost Orgro and the yard trimmings compost Leafgro applied in 2011. All values are reported on a dry weight basis†.

	Units	Orgro	Leafgro
Moisture As Rcvd	%	23.4	60.1
Moist Bulk Density	g cm^{-3}	0.48	0.44
pH	-	5.8	7.3
Soluble Salts (Elec. Cond.)	S m^{-1}	0.835	0.158
Total Nitrogen	% / (kg m^{-3})	2.92 / 10.7	1.8 / 3.1
Nitrate-N	mg kg^{-1}	5	0
Ammonium-N	mg kg^{-1}	4348	21
Organic Matter	%	54.6	64.1
Estimated Organic Carbon	%	29.5	34.6
C/N Ratio	-	10.1	19.3
Phosphorus (P)	mg kg^{-1}	314	528
Potassium (K)	mg kg^{-1}	1526	4557
Calcium (Ca)	mg kg^{-1}	3331	10648
Magnesium (Mg)	mg kg^{-1}	1411	2681
Extractable Micronutrients			
Boron (B)	mg kg^{-1}	12.9	11.8
Manganese (Mn)	mg kg^{-1}	76.5	170.5
Zinc (Zn)	mg kg^{-1}	18.9	6.5
Copper (Cu)	mg kg^{-1}	4.5	2.1
Iron (Fe)	mg kg^{-1}	43.5	6.7
Extractable Heavy Metals			
Lead (Pb)	mg kg^{-1}	1.6	2.2
Cadmium (Cd)	mg kg^{-1}	0.2	0.1
Nickel (Ni)	mg kg^{-1}	0.4	0.2
Chromium (Cr)	mg kg^{-1}	0.2	0.2

† Analysis was conducted by the University of Massachusetts Soil Testing Laboratory.

Table 3.2 Chemical properties of the biosolids compost Orgro and the yard trimmings compost Leafgro applied in 2012. All values are reported on a dry weight basis†.

	Units	Orgro	Leafgro
Moisture As Rcvd	%	19.0	35.5
Moist Bulk Density	g cm^{-3}	0.43	0.56
pH	-	6.2	7.6
Soluble Salts (Elec. Cond.)	S m^{-1}	0.495	0.170
Total Nitrogen	% / (kg m^{-3})	3.12 / 10.8	2.12 / 7.7
Nitrate-N	mg kg^{-1}	93	219
Ammonium-N	mg kg^{-1}	1562	6
Organic Matter	%	51.0	58.3
Estimated Organic Carbon	%	27.5	31.5
C/N Ratio	-	8.8	14.9
Phosphorus (P)	mg kg^{-1}	102	25
Potassium (K)	mg kg^{-1}	1112	509
Calcium (Ca)	mg kg^{-1}	2880	40192
Magnesium (Mg)	mg kg^{-1}	926	351
Extractable Micronutrients			
Boron (B)	mg kg^{-1}	10.8	6.7
Zinc (Zn)	mg kg^{-1}	16.9	29.5
Copper (Cu)	mg kg^{-1}	3.0	1.1
Iron (Fe)	mg kg^{-1}	45.5	127.5

† Analysis was conducted by the University of Massachusetts Soil Testing Laboratory.

Table 3.3 Chemical properties of the biosolids compost Orgro and the yard trimmings compost Leafgro applied in 2013. All values are reported on a dry weight basis†.

	Units	Orgro	Leafgro
Moisture As Rcvd	%	11.8	28.1
Moist Bulk Density	g cm^{-3}	0.50	0.47
pH	-	7.0	7.2
Soluble Salts (Elec. Cond.)	S m^{-1}	0.920	0. 177
Total Nitrogen	% / (kg m^{-3})	2.91 / 12.8	2.14 / 7.3
Nitrate-N	mg kg^{-1}	116	244
Ammonium-N	mg kg^{-1}	4613	13
Organic Matter	%	45.3	54.6
Estimated Organic Carbon	%	24.5	29.5
C/N Ratio	-	8.4	13.8
Phosphorus (P)	mg kg^{-1}	243	659
Potassium (K)	mg kg^{-1}	1068	6490
Calcium (Ca)	mg kg^{-1}	4246	12699
Magnesium (Mg)	mg kg^{-1}	1165	3106
Extractable Micronutrients			
Boron (B)	mg kg^{-1}	14.7	11.7
Zinc (Zn)	mg kg^{-1}	19.2	3.3
Copper (Cu)	mg kg^{-1}	3.3	0.8
Iron (Fe)	mg kg^{-1}	42.4	13.0

† Analysis was conducted by the University of Massachusetts Soil Testing Laboratory.

3.1.3 Cultivation Treatments

Cultivation treatments consisted of 0, 1 or 2 passes of Ryan GA 30 aerator (Ryan, Div. of Schiller Grounds Care, Inc., Johnson Creek, WI). The aerator was equipped with 1.9 cm by 12.7 cm tines that were spaced 6 cm apart from one another. The cultivation treatments were imposed once per year immediately prior to compost spreading. Plots receiving 156 kg N ha^{-1} yr^{-1} were subjected to one of the three cultivation treatments, while plots receiving 1 cm of compost and the untreated control did not receive hollow tine cultivation.

In 2011, the turf was mowed to 5 cm (2.0 inch) at PBTRF and to 5.7 cm (2.25 inch) at Glenstone, with clippings the being collected prior to hollow tine cultivation. Plots that were aerated were verticut two ways to break cores before compost application. In 2012, the turf was mowed to 6.4 cm (2.5 inch) at both sites immediately before applying the treatments. No plots were verticut but all plots were lightly raked using a metal leaf rake to remove foliar debris after aeration. In 2013, the turf was mowed to 6.4 cm (2.5 inch) at PBTRF and to 8 cm (3 inch) at Glenstone. All plots were lightly raked to remove foliar debris prior to applying the fertilizer and cultivation treatments.

3.1.4 Compost Tea Treatments

The effect of compost tea on turfgrass growth and soil biological properties was evaluated by splitting the study main plots in half and making monthly applications of compost tea to one half of each main plot during the growing season. Compost tea applications were made in August, September and October of 2012 and from March through October in, 2013, and 2014. The compost tea was created using a recipe recommended by and based on microbial analysis of the soil conducted by the Soil Foodweb, Inc. laboratory in Corvallis, OR. The brewing process consisted of mixing 18.9 L water with 454g yard trimmings compost (Leafgro), 30 ml Bio-Brew fish hydrolysate (Nature’s Pro ®), 15 ml Bio-Brew Humic Acid (Nature’s Pro ®) and 14 g Kelp extract (Nature’s Pro ®). The mixture was aerated for at least 24 hours after which 4.7 L brewed product was mixed with 89 ml fish hydrolysate, 89 ml humic acid and 85 g kelp extract. After adding all materials the solution was diluted with 10.4 L water.

Compost tea applications in 2012 and 2013 were made using a bicycle sprayer having TeeJet 6510 nozzles located 0.3 m above the canopy. The sprayer was operated at a pressure of 372 K Pa (54 PSI) resulting in a compost tea application rate of 1630 L ha^{-1} (4 gallons per 1000ft^2). In 2014 a Gregson Clark spreader mate™ single nozzle style sprayer (Model SM-A, Gregson-Clark Spraying Equipment, Caledonia, NY) operating at a pressure of 248 K Pa (36 PSI) was used to deliverer the compost tea at the same application rate used in 2012 and 2013.

3.1.5 General Turf Maintenance

Field plots at both locations were maintained in manner similar to that of a home lawn. At PBTRF site, the turf was mowed at least twice a month during the growing season at 6.4 cm (2.5 inch) in 2011 and 2012, and at 7.6 cm (3 inch) in 2013 and 2014. The turf at Glenstone was mowed weekly at 10 cm (4 inch) throughout the growing season in all years of the study. The clippings were returned at both locations and the plots were irrigated only when needed to prevent the turf from entering water stress induced dormancy. No pesticides were utilized throughout the course of the study at either location.

3.1.6 Data Collection

With the exception of the July 2012 at the Glenstone site, monthly ratings of turf visual quality and color were collected from March to November in 2012, 2013 and 2014 at both sites. Visual assessment of the percent cover of specific weeds was performed when the presence of weeds became apparent within several of the plots. Visual turf quality was assessed as an evaluation of the integrated effect of turf density, uniformity and weed encroachment on the appearance of the turf. Quality was based on criteria established by the National Turfgrass Evaluation Program and was rated on a 1 to 9 scale with a rating of 6 being considered commercially acceptable turf density and uniformity. Visual assessment of color was evaluated by using a 1 to 9 rating scale with 1 representing a 100% brown or dead turf and 9 equaling a very dark green colored turf. Weed cover (0 to 100%) was visually evaluated as the percentage surface area of an individual plot covered by annual grass and broadleaf weeds.

3.1.7 Statistical Analysis

Fertilizer and cultivation treatments were arranged as a randomized complete block design with each treatment being replicated three times within 3 m × 3 m whole plots. When compost tea was added as a third treatment in the second year of the study, the structure of the treatments was a randomized complete block spit plot design.

Data analysis consisted of analysis of variance (ANOVA) of the factorial arrangement of treatments present within the experiment design, and mean contrasts that compared the control treatment with the five other treatments where no cultivation of whole plots occurred throughout the study. Data were analyzed using Proc Mixed (SAS 9.3, SAS Institute, 2012) except in instances when the convergence criteria were not met (i.e. too many likelihood evaluations in SAS operation) . In these cases, data were analyzed using Proc Glimmix (SAS 9.3, SAS Institute, 2012). Treatments means were separated at $P \leq 0.05$ level unless otherwise indicated. Mean separations were conducted using Tukey’s honestly significantly different test.

3.2 Results

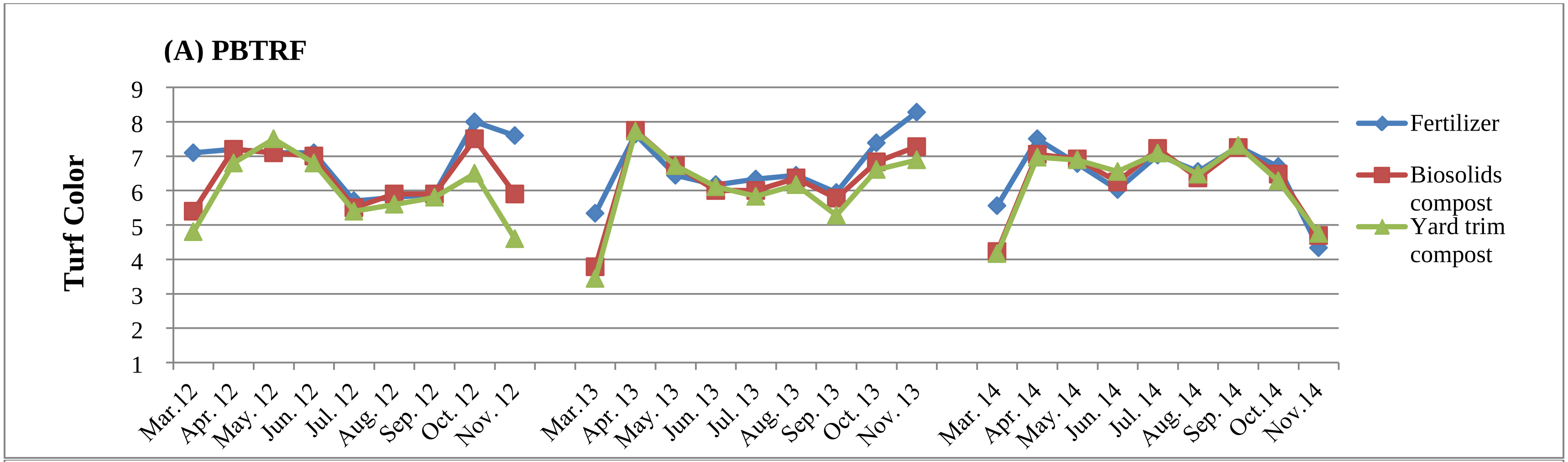
3.2.1 Turf Color

3.2.1.1 Paint Branch Turfgrass Research Facility

Figure 3.1 shows the simple effect of nitrogen source on tall fescue color over the three year evaluation period. The synthetic nitrogen fertilizer (Signature) promoted quicker early spring (i.e. March) green up and longer late fall (i.e. November) color retention when compared to the two compost sources except in the fall of 2014 (Table 3.4). All individual date mean separations tests are shown in the thesis appendix. Plots receiving Signature also had a darker green color on two (2012, 2013) of the three October ratings at TBTRF when compared to the two compost sources. With exception of the July 2013 rating date when Signature had a higher color rating than the two compost sources, there was little difference in the turf color among the three N sources during the summer (June, July August) in all three years of the study.

Cultivation in the fall resulted in quicker early spring green up in all three years of study at the TBTRC with interactions between nitrogen source and cultivation treatment occurring in 2013 and 2014 (Figure 3.2). In these two cases, increasing intensity of cultivation had a positive effect on tall fescue turf color in plots receiving either the synthetic nitrogen fertilizer or biosolids compost (Orgro). The effect of cultivation on color was limited to early spring with no consistent color response being seen with the use of this practice after the month of March in all three years of the study. Compost tea applications initiated at the beginning of 2013 growing season had no effect on color at PBTRF in 2013. In 2014, color responses to compost tea were recorded in the months of June, August and September with the response dependent on the nitrogen source applied the prior fall (Figure 3.3). Generally, cultivation had no significant effect on plots receiving synthetic nitrogen fertilizer and yard trimmings compost, whereas it had positive effect on plots treated with biosolids compost (Figure 3.3).

Mean contrasts comparing the effect of all non-cultivated treatments receiving N with the control treatment (i.e., no N, no tea, no cultivation) on color are shown in Table 3.5. Improved color compared to the control treatment was most frequently seen with the application of 1 cm of the biosolids compost. Color responses seen with this treatment were most dramatic in the early spring. The 1 cm of the biosolids compost treatment was the only non-cultivated treatment that had acceptable (i.e., color > 6, data shown in thesis appendix) early spring color in all three years of the study. Less dramatic but clearly noticeable improvements in turf color were seen in early spring and late fall with the application of synthetic nitrogen fertilizer and 1 cm of yard trimmings compost, except in the late fall of 2014. When compared to the control treatment, sporadic improvements in turf color were seen in 2012 with the use two compost materials applied at rate of the 156 kg N ha^{-1} yr^{-1}. After April of 2013 turf receiving the two compost treatments had color that was similar to that of the untreated control.



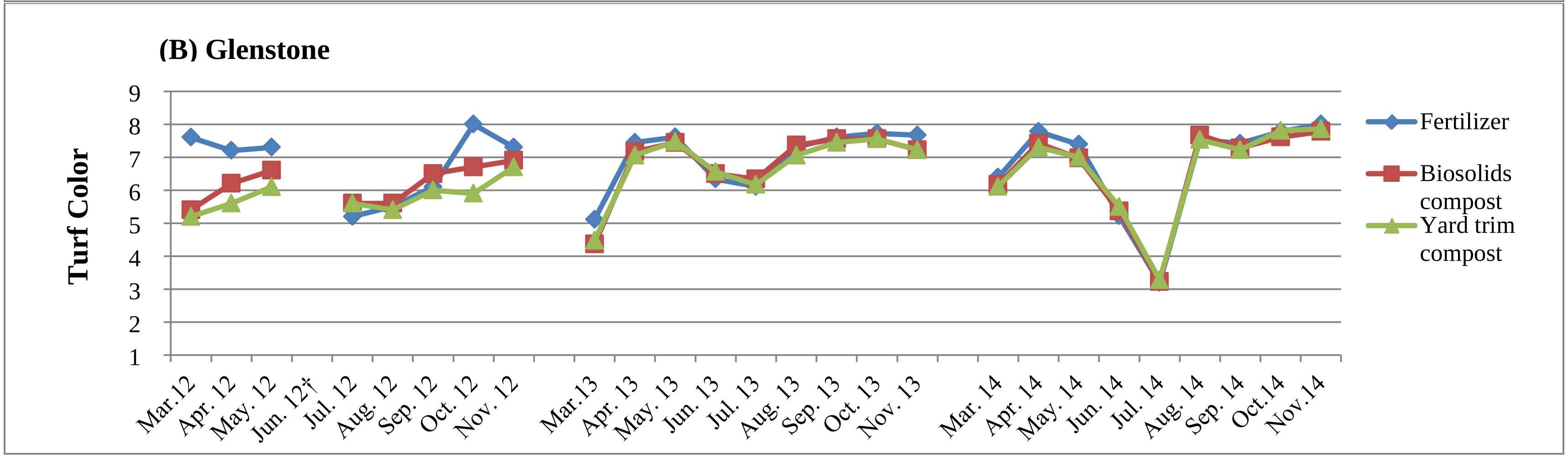


Figure 3.1. The effect of nitrogen source on tall fescue color at (A) the Paint Branch Turfgrass Research Facility and (B) Glenstone. Turf color on a scale of 1-9: 1 = brown turf, 9 = dark green turf. Values are averaged across cultivation treatments. † No data was collected in this month.

Table 3.4. Analysis of variance for the effect of nitrogen source, cultivation and compost tea on tall fescue color at the Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

Paint Branch Research Turfgrass Facility										
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Treatment	df					P				
						2012				
N source (N)	2	<.0001	0.0236	0.0366	0.1470	0.1393	0.1393	0.4736	<.0001	<.0001
Cultivation (C)	2	0.0056	0.0722	0.7773	0.3365	0.2467	0.4566	0.0461	0.2296	0.5432
N×C	4	0.5723	0.9768	0.6416	0.7942	0.7566	0.9743	0.9531	0.4748	0.6943
						2013				
N	2	<.0001	0.5921	0.0388	0.2259	0.0001	0.2012	0.0004	<.0001	<.0001
C	2	0.0002	0.1985	0.5396	0.0762	0.4650	0.7035	0.7159	0.5491	0.0033
N×C	4	0.0187	0.3885	0.8052	0.0486	0.5406	0.3106	0.1637	0.1178	0.8515
Tea (T)	1	1.0000	0.1744	1.0000	1.0000	1.0000	0.5709	1.0000	1.0000	1.0000
N×T	2	1.0000	0.6147	1.0000	1.0000	1.0000	0.7209	1.0000	1.0000	1.0000
C×T	2	1.0000	0.6147	1.0000	1.0000	1.0000	0.2884	1.0000	1.0000	1.0000
N×C×T	4	1.0000	0.3256	1.0000	1.0000	1.0000	0.2958	1.0000	1.0000	1.0000
						2014				
N	2	<.0001	0.0060	0.6887	0.0116	0.2914	0.2034	0.8280	0.1164	0.0124
C	2	0.0002	0.9774	0.8505	0.5659	0.6703	0.0505	0.0502	0.6439	0.0766
N×C	4	0.0234	0.3534	0.9244	0.4130	0.2252	0.5652	0.4584	0.4257	0.2660
T	1	1.0000	0.3306	0.1964	0.4595	1.0000	0.3942	1.0000	0.6677	0.6601
N×T	2	1.0000	0.3874	0.5594	0.0093	0.1256	0.0431	0.0217	0.0807	0.2393
C×T	2	1.0000	0.3874	0.1938	0.1848	0.2884	0.1122	0.2875	0.0807	0.7094
N×C×T	4	1.0000	0.4332	0.6674	0.4332	0.3583	0.5636	0.1229	0.1112	0.3256
Glenstone										
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Treatment	df					P				
						2012				
N source (N)	2	<.0001	0.0029	<.0001	NA	0.3897	0.9719	0.2908	<.0001	0.1031
Cultivation (C)	2	0.0028	0.7992	0.0502	NA	0.4349	0.9719	0.9086	0.9352	0.5319
N×C	4	0.4273	0.9191	0.2588	NA	0.7081	0.7461	0.1816	0.8267	0.9696
						2013				
N	2	0.0072	0.0313	0.2503	0.2340	0.0811	0.1567	0.1425	0.0228	<.0001
C	2	0.0023	0.1291	0.8247	0.2340	0.2346	0.7279	0.3102	0.0089	0.1670
N×C	4	0.2140	0.0427	0.5541	0.7431	0.6897	0.2303	0.0080	0.2199	0.3707
T	1	0.2633	1.0000	0.7427	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
N×T	2	0.7209	1.0000	0.8954	1.0000	1.0000	0.4866	1.0000	1.0000	1.0000
C×T	2	0.1256	1.0000	0.6480	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
N×C×T	4	0.0552	1.0000	0.7750	1.0000	1.0000	0.1587	1.0000	1.0000	1.0000
						2014				
N	2	0.1291	0.0003	<.0001	0.1148	0.9717	0.5138	0.1470	0.2016	0.1513
C	2	0.0168	0.3145	0.4760	0.4282	0.8922	0.8955	0.3365	0.0932	0.5792
N×C	4	0.0705	0.4929	0.7748	0.7040	0.2960	0.8880	0.3003	0.8810	0.9120
T	1	1.0000	1.0000	0.3306	0.5917	0.8970	1.0000	0.7099	0.3306	0.0750
N×T	2	1.0000	0.6925	0.3874	0.9059	0.8014	0.6147	0.8679	0.3874	0.1848
C×T	2	1.0000	0.6925	0.3874	0.9059	0.3531	0.1643	0.8679	0.3874	0.8679
N×C×T	4	1.0000	0.1587	0.4332	0.6367	0.7122	0.4332	0.9639	0.4332	0.8357

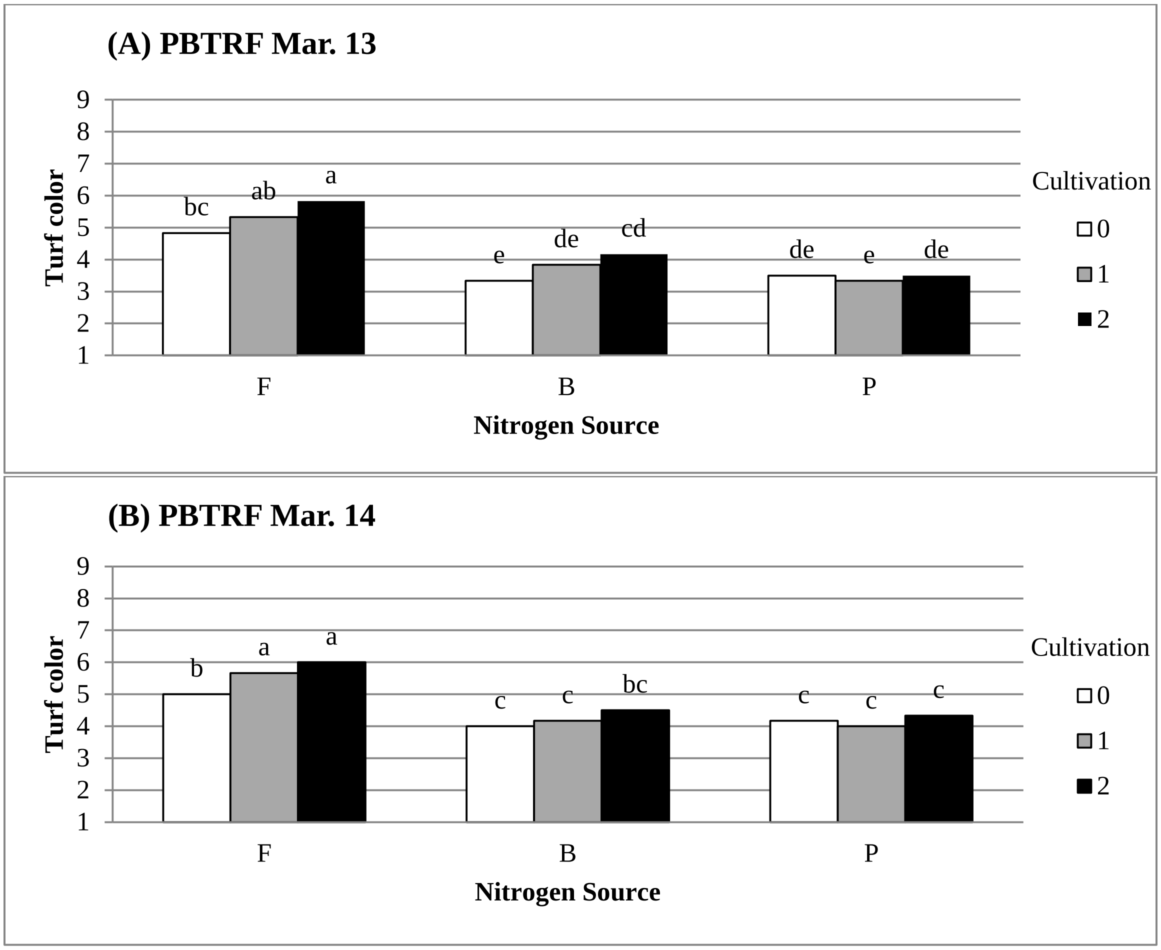


Figure 3.2. Effect of nitrogen source and cultivation treatment on tall fescue color at the Paint Branch Turfgrass Research Facility in (A) March 2013 and (B) March 2014.
Turf color on a scale of 1-9: 1 = brown turf, 9 = dark green turf.
F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro. 0, no cultivation; 1, one pass of cultivation; 2, two passes of cultivation.
Within a month rating, means labeled with the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

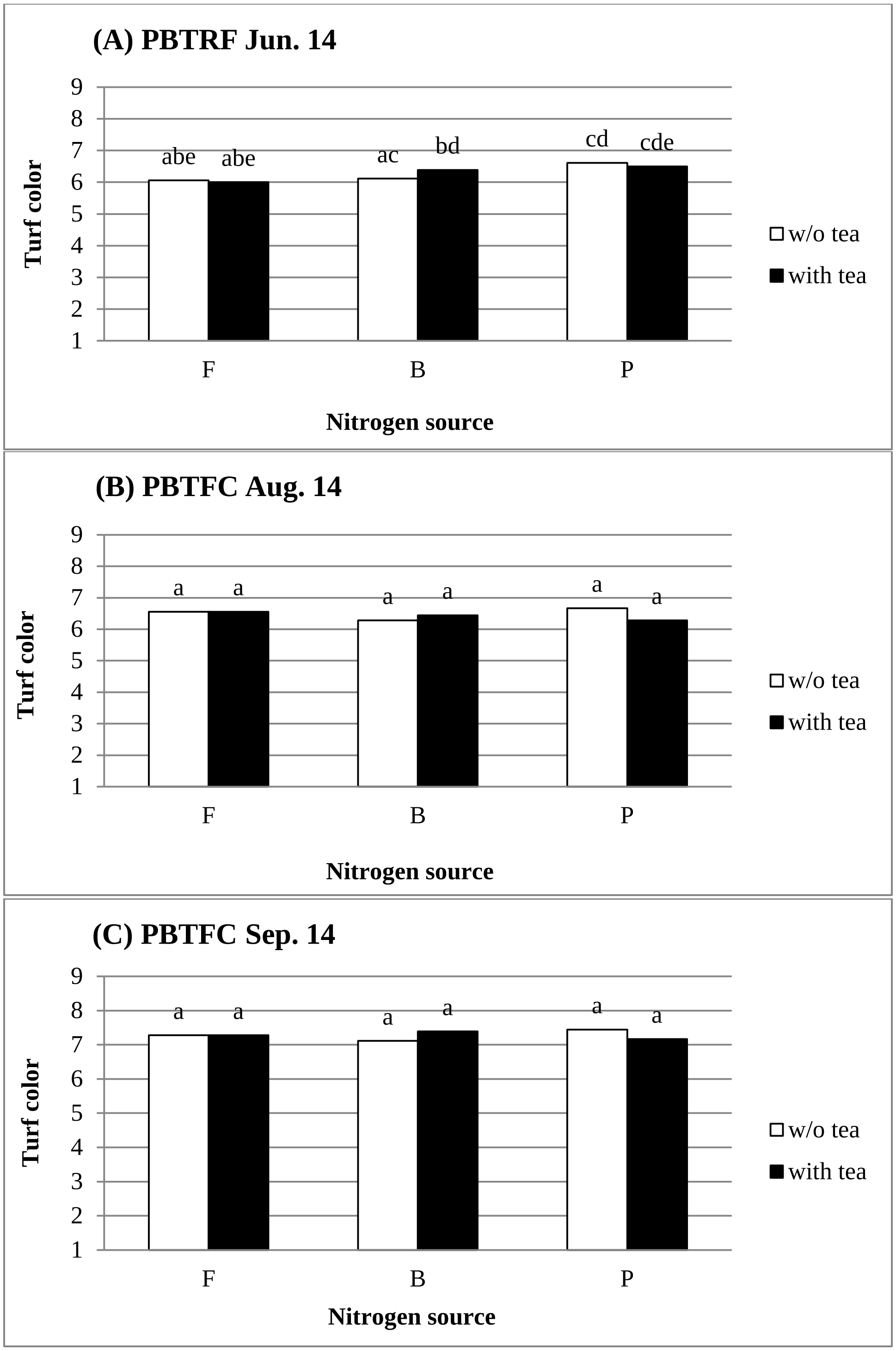


Figure 3.3. Effect of nitrogen source and compost tea treatment on tall fescue color at the Paint Branch Turfgrass Research Facility in (A) Jun., (B) Aug., and (C) Sep. 2014.
Turf color on a scale of 1-9: 1 = brown turf, 9 = dark green turf. F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro.
Within a month rating, means labeled with the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

Table 3.5. Comparison of non-cultivated nitrogen source with control on tall fescue color at the Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

Paint Branch Turfgrass Research Facility										
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Contrast	df					P				
						2012				
C† VS F	10	<.0001	0.0436	0.5439	0.1139	0.5765	0.0779	0.4543	<.0001	<.0001
C VS B	10	0.0961	0.0436	1.0000	0.1139	0.5765	0.0257	0.7053	0.0005	0.0045
C VS P	10	0.5540	0.2751	0.2375	0.4068	0.2751	0.2197	0.7053	0.0303	0.1757
C VS BE	10	<.0001	0.0436	0.0888	0.0015	0.1139	0.0084	0.1505	<.0001	<.0001
C VS PE	10	0.0120	0.1139	0.2375	0.4068	1.0000	1.0000	0.7053	0.0128	0.0045
						2013				
C VS F	10	<.0001	0.3362	1.0000	0.2009	0.0997	0.6867	0.7476	0.1801	<.0001
C VS B	10	0.0645	0.2184	0.5275	0.5091	0.5587	0.8714	0.3443	0.3593	0.0599
C VS P	10	0.0266	0.1607	0.2197	0.5091	0.5587	1.0000	0.5231	0.6413	0.4956
C VS BE	10	<.0001	1.0000	0.5275	0.0065	0.0361	0.0157	0.0244	0.6413	<.0001
C VS PE	10	0.0005	0.3362	0.2197	0.5091	0.2542	0.6867	0.3443	0.3593	0.0179
						2014				
C VS F	10	0.0180	0.0082	1.0000	0.0505	0.2605	0.7414	0.1988	0.4280	0.1045
C VS B	10	0.5846	0.5959	0.2903	0.2496	0.3140	0.2624	0.6171	0.4280	0.7891
C VS P	10	1.0000	0.2990	0.2903	0.5907	0.7963	0.5127	0.7380	0.3802	0.6890
C VS BE	10	<.0001	0.0082	0.2903	0.6662	0.0600	0.3326	0.0152	0.0326	0.1303
C VS PE	10	0.1210	0.2990	0.5012	0.8286	0.7963	0.6218	0.4099	0.5349	0.3590

Glenstone										
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Contrast	df					P				
						2012				
C VS F	10	0.0003	0.0836	0.0089	NA	0.0244	1.0000	0.2784	0.0002	0.1086
C VS B	10	0.1339	0.5362	0.1809	NA	0.0244	0.1011	0.0619	0.0179	0.3991
C VS P	10	0.4338	0.8352	0.4885	NA	0.0244	0.4866	0.7104	0.1877	0.5701
C VS BE	10	0.0009	0.1659	0.0563	NA	0.0079	0.7255	0.5792	0.0002	0.3991
C VS PE	10	0.3024	0.2291	0.4885	NA	0.7476	0.4866	0.8523	0.0179	0.2674
						2013				
C VS F	10	1.0000	0.0961	0.4135	0.4118	0.2009	0.5277	0.3250	0.1524	0.0133
C VS B	10	0.6730	1.0000	0.4135	0.6776	0.0021	0.0403	0.3250	0.4565	0.3409
C VS P	10	0.3214	0.5540	0.6198	1.0000	0.2009	0.7029	1.0000	0.4565	0.3409
C VS BE	10	0.0029	0.5540	0.1187	0.8674	0.0021	0.1198	0.0653	0.4565	0.0133
C VS PE	10	0.2215	0.2487	0.4135	0.6776	1.0000	1.0000	1.0000	0.4565	0.3409
						2014				
C VS F	10	0.0017	0.1297	0.0221	0.2563	0.2299	0.4512	1.0000	1.0000	1.0000
C VS B	10	0.1877	0.6310	0.5141	0.1988	0.1312	0.0405	0.8646	0.3750	0.1751
C VS P	10	0.4956	0.6310	0.5141	0.1162	0.2988	0.2981	0.1107	0.7181	0.3217
C VS BE	10	0.0002	0.0757	0.6616	0.7380	0.3529	0.3689	1.0000	0.3750	0.3217
C VS PE	10	0.0017	0.2159	0.6616	1.0000	0.1190	0.0893	0.7337	0.3750	1.0000

† C, control; F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro; BE, 1 cm biosolids compost Orgro; PE, 1 cm yard trimmings compost Leafgro.

3.2.1.2 Glenstone

Similar to observations at the PBTRF, turf receiving Signature at the Glenstone site had quicker spring green up than either of two compost treatments in 2012 and 2013 (Figure 3.1). Conversely, improved late fall color retention in the plots receiving Signature was only observed in one (2013) of the three years at Glenstone. As was observed at PBTRF, N source had no effect on turf color during summer in all three years of the study. Fall cultivation improved early spring green up in all three years, but unlike what was observed at PBTRF, the response to cultivation was independent of N source (Figure 3.4). The application of compost tea had no effect on turf color at Glenstone.

Comparison of the non-cultivated turf receiving N with the control treatment at Glenstone revealed that improved turf color, as indicated by a higher color rating, was most frequently associated with the use of Signature and to a lesser extent the use of either of the two biosolids compost treatments. Turfgrass receiving 1 cm biosolids compost was the only non-cultivated treatment to exhibit improved early spring color in all three years of study when compared to the untreated control. With the exception of two rating dates in 2012 and one date in 2014, when color was improved, the use of either rate of yard trimmings compost had little effect on turf color.

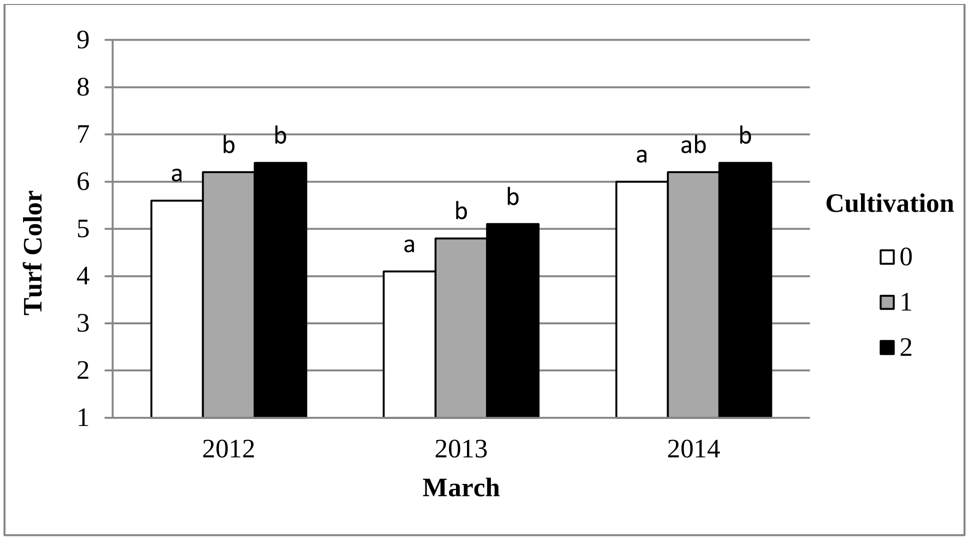


Figure 3.4. Effect of cultivation treatments on tall fescue color at Glenstone in Mar. 2012, Mar. 2013 and Mar. 2014.
Turf color on a scale of 1-9: 1 = brown turf, 9 = dark green turf.
0, no cultivation; 1, one pass of cultivation; 2, two passes of cultivation.
Within a month rating, means labeled with the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

3.2.2 Turf Quality

3.2.2.1 Paint Branch Turfgrass Research Facility

Nitrogen source affected turfgrass quality in all three years of the study at the PBTRF (Table 3.6). With the exception of the months of May and June in 2012, the use of Signature consistently resulted in higher turfgrass quality than the use of the yard trimmings compost (Figure 3.5). Similarly, plots receiving biosolids compost had lower turf quality than turf receiving Signature on most rating dates. Throughout the 3 year evaluation period turf receiving Signature had better late summer and fall (i.e., Aug. to Nov.) quality than turf receiving either compost material. Use of the biosolids compost resulted better turfgrass quality than use of the yard trimmings compost on 20 of 27 dates quality was evaluated. When compared to the yard trimmings compost, the use of biosolids compost improved quality in the early spring and late fall of 2012, but a similar response was not observed in the latter two years of the study. In contrast to color responses seen at this site hollow tine cultivation employed in the fall of 2011 caused turf quality to decline in spring 2012 (Figure 3.6). For the remainder of the study, cultivation had little to no effect on turf quality. Improved turfgrass quality with the use of compost tea at this site was detected on one of 18 evaluation dates. An increase in turf quality from 6.4 to 6.5 with the compost tea observed in May of 2013 (data shown in appendix) while statistically significant was not large enough to be considered meaningful.

When comparing the control treatment with the five non-cultivated N source treatments, only the biosolids compost, when applied to a depth of 1 cm, had turf quality that was higher on all rating dates than the control treatment. In contrast, little difference in turf quality was seen between turf receiving either of two rates of yard trimmings compost and control treatment on most evaluation dates. The use of Signature in non-cultivated plots resulted in higher turf quality than that seen control plots on all but three evaluation dates. Application of biosolids compost treatment at the 156 kg N ha^{-1} yr^{-1} rate resulted in improved turf quality compared to control treatment on 9 of 27 evaluation dates with a noticeable decline in the performance of this treatment relative to the control being observed in the third year of the study.

Table 3.6. Analysis of variance for the effect of nitrogen source, cultivation and compost tea on tall fescue quality at the Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

Paint Branch Turfgrass Research Facility										
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Treatment	df					P				
						2012				
N source (N)	2	<.0001	<.0001	0.0963	0.1194	0.0065	0.0029	0.0036	<.0001	<.0001
Cultivation (C)	2	0.0012	<.0001	0.2217	0.8310	0.0240	0.0034	0.3032	0.6839	0.6768
N×C	4	0.1383	0.0214	0.9737	0.8945	0.8444	0.3371	0.2814	0.3982	0.9054
						2013				
N	2	<.0001	<.0001	<.0001	<.0001	<.0001	0.0254	<.0001	<.0001	<.0001
C	2	0.9176	0.3498	0.1118	0.1801	0.8321	0.8739	0.6597	0.3360	0.4621
N×C	4	0.9719	0.5310	0.8462	0.7755	0.9165	0.7881	0.8337	0.7609	0.3456
T	1	0.5540	0.1004	0.0271	0.2457	0.3306	0.5995	0.3306	0.1440	0.3239
N×T	2	0.5407	0.0751	0.1742	0.2373	0.0096	0.9313	0.7815	0.5495	0.9182
C×T	2	0.2060	1.0000	0.2497	0.2373	0.9204	0.6147	0.7815	0.5495	0.7761
N×C×T	4	0.8313	1.0000	0.0822	0.3695	0.3583	0.4693	0.1830	0.8028	0.9858
						2014				
N	2	<.0001	<.0001	<.0001	0.0352	<.0001	<.0001	<.0001	0.0002	0.0051
C	2	0.5456	0.9704	0.2805	0.4639	0.4035	0.8165	0.2853	0.9041	0.4743
N×C	4	0.7693	0.5186	0.7010	0.9251	0.7950	0.7477	0.9155	0.1802	0.7488
T	1	1.0000	0.3306	0.8372	0.4331	0.1004	0.8595	0.1553	0.5891	0.3942
N×T	2	1.0000	0.3874	0.8418	0.8091	0.0751	0.5527	0.3514	0.5978	0.2884
C×T	2	1.0000	0.3874	0.9576	0.1742	0.7209	0.6637	0.4276	0.4726	0.7209
N×C×T	4	1.0000	0.4332	0.4549	0.7113	0.8519	0.7926	0.9300	0.4872	0.2310
Glenstone										
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Treatment	df					P				
						2012				
N source (N)	2	0.2186	0.0002	<.0001	NA	0.1748	0.0755	0.2259	<.0001	0.0005
Cultivation (C)	2	0.0283	0.0142	0.0620	NA	0.1860	0.3609	0.6202	0.1418	0.0472
N×C	4	0.6269	0.5215	0.0545	NA	0.5456	0.4970	0.0676	0.4511	0.2608
						2013				
N	2	0.0010	0.0019	0.0106	0.0252	0.3653	0.3288	0.3771	0.6316	0.4067
C	2	0.7547	0.3602	0.6044	0.6837	0.0837	0.3538	0.2533	0.7142	0.7771
N×C	4	0.4041	0.2910	0.4758	0.4685	0.7469	0.2710	0.1698	0.6325	0.7418
T	1	0.6879	0.1129	0.2547	0.3583	0.4746	0.7392	0.5709	0.0480	0.6430
N×T	2	0.9593	0.4743	0.4614	0.4284	0.4507	0.0893	0.2884	0.0260	0.2068
C×T	2	0.1952	0.2619	0.1170	0.0927	0.4115	0.6402	0.1256	0.2497	0.9461
N×C×T	4	0.5837	0.3471	0.5364	0.4469	0.1185	0.5408	0.8519	0.2440	0.3054
						2014				
N	2	0.3009	0.4993	0.2992	0.7441	0.4756	0.4084	0.1815	0.6254	0.1396
C	2	0.0733	0.4911	0.7194	0.9758	0.9738	0.6098	0.8053	0.5274	0.7928
N×C	4	0.0313	0.4277	0.3517	0.5726	0.3630	0.3964	0.4698	0.5794	0.4029
T	1	1.0000	0.8657	0.6879	0.5778	0.3709	0.2963	0.8970	1.0000	0.6231
N×T	2	1.0000	0.0440	0.6834	0.4866	0.1036	0.8802	0.6248	0.5785	0.5682
C×T	2	1.0000	0.0440	0.2497	0.3007	0.8121	0.5824	0.3698	0.4638	0.1535
N×C×T	4	1.0000	0.1574	0.6415	0.2762	0.4332	0.8308	0.6252	0.3871	0.8795

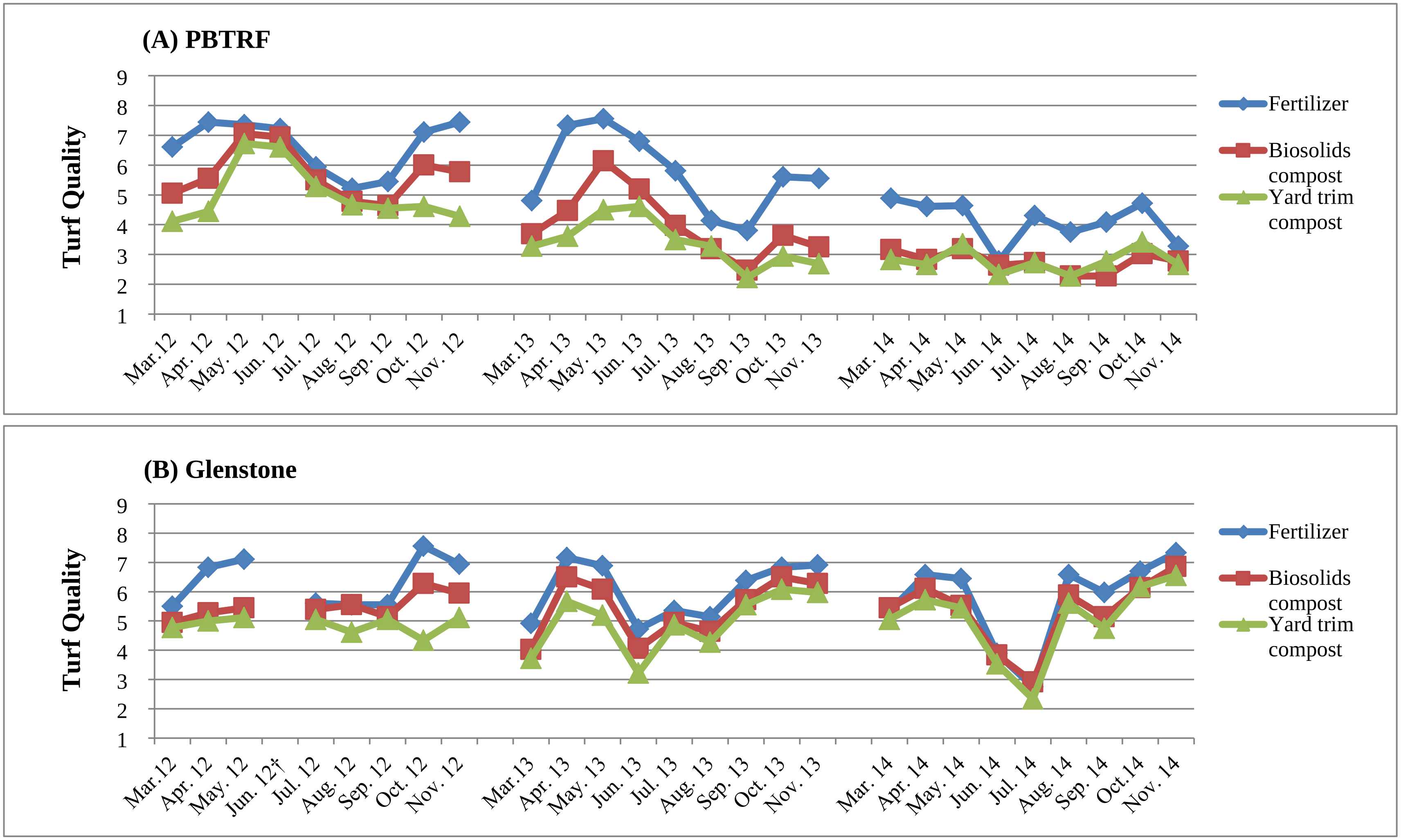


Figure 3.5. The effect of nitrogen source on turf type tall fescue quality at (A) the Paint Branch Turfgrass Research Facility and (B) Glenstone. Values are averaged across cultivation treatments. † No data was collected in this month. Turf quality on a scale of 1-9: 6 = a commercial acceptance.

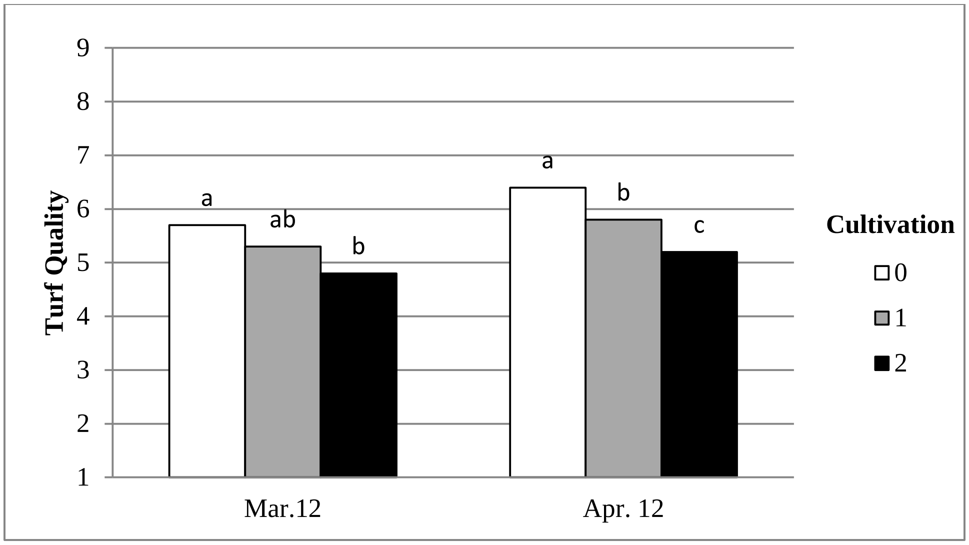


Figure 3.6. Effect of cultivation treatments on tall fescue quality at the Paint Branch Turfgrass Research Facility in spring 2012.
Turf quality on a scale of 1-9: 6 = a commercial acceptance.
0, no cultivation; 1, one pass of cultivation; 2, two passes of cultivation.
Within a month rating, means labeled with the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

3.2.2.2 Glenstone

Turf quality was less influenced by nitrogen source at Glenstone that at PBTRF (Figure 3.5). Differences in turf quality with the use of different N sources were observed in the first half of the 3 year evaluation period but not in the second (Table 3.6). In the first year of the study plots receiving Signature had higher late spring (i.e. May, June) and fall (i.e. Oct., Nov) quality than did plots that received either of the two compost materials. A similar response was seen in the spring (March, April, May) of the second year with the exception that plots receiving the biosolids compost had late spring quality that was closer in appearance to that receiving Signature. After the spring of 2013 there were no differences in turf quality among the three N-sources for the remainder of the study. As was seen at the PBTRF, hollow tine cultivation performed in the fall of 2011 resulted in lower early spring (March) quality the following year. The effect of cultivation on early spring turf quality was limited to the first year of the study as neither of the single or double pass cultivation treatment affected turf quality in the second or third years of the study. The use of compost tea effected turf quality on one date in 2013 and 2014. On the one date in 2013, the use of compost tea slightly improved the quality of turf that received the yard trimmings compost, but had no effect on the quality of turf that received Signature or the biosolids compost (Figure 3.7).

Comparison of the turf quality in non-cultivated turf receiving one of the five N source treatment with the control treatment at the Glenstone resulted in treatment response trends similar to those observed at the PBTRF (Table 3.7). With the exception of two evaluation dates, plots receiving the yard trimmings compost were of no better quality than turf that received no fertilizer at all. Applying 1 cm of biosolids compost resulted in higher spring quality in all three years of the study when compared plots not receiving fertilizer. Non-cultivated plots receiving Signature generally had higher turf quality than the non-cultivated control treatment however no consistent seasonal trends were apparent with use of this N source. Plots receiving 156 kg N ha^{-1} yr^{-1} of the biosolids compost had improved quality when compared to the control treatment on 5 of 27 evaluation dates. Similar to that seen in plots receiving Signature there was no consistent seasonal trend seen with use of this biosolids compost treatment over the three year period data was collected.

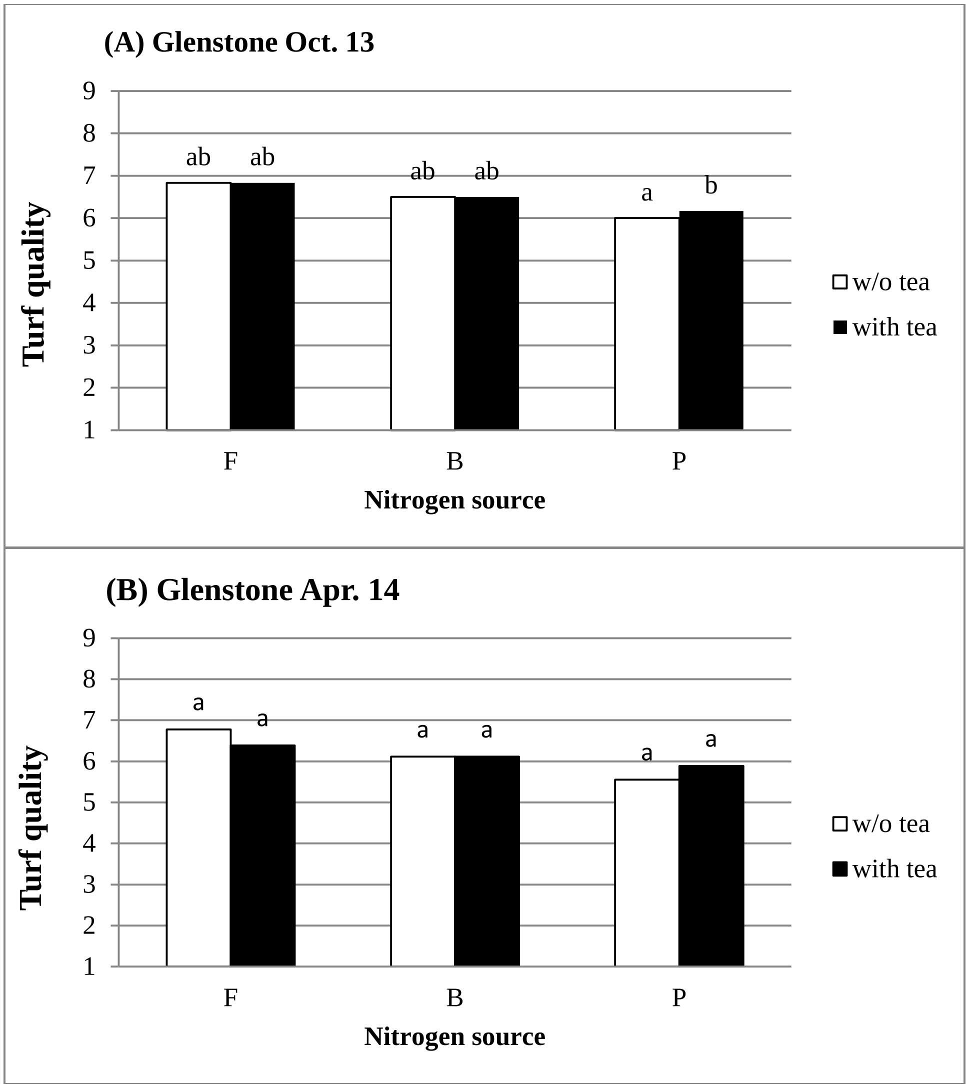


Figure 3.7. Effect of nitrogen source (F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro) and compost tea treatment on tall fescue quality at Glenstone in (A) Oct. 2013 and (B) April 2014.

Turf quality on a scale of 1-9: 6 = a commercial acceptance.

F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro.

Within a month rating, means labeled with the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

Table 3.7. Comparison of non-cultivated fertilizer source with control on tall fescue quality at the Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

Paint Branch Turfgrass Research Facility										
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Contrast	df	P								
2012										
C† VS F	10	0.0002	<.0001	0.0111	0.0128	0.0180	0.0359	0.0653	<.0001	<.0001
C VS B	10	0.0372	0.0011	0.0271	0.0881	0.2849	0.1374	0.8401	0.0009	0.0009
C VS P	10	0.6413	0.6279	0.1516	0.4671	0.5846	0.1374	0.1287	0.0305	0.0829
C VS BE	10	<.0001	<.0001	0.0047	0.0068	0.0027	0.0007	0.0055	<.0001	<.0001
C VS PE	10	1.0000	1.0000	0.3250	0.2833	0.2849	0.4381	0.5485	0.0165	0.0060
2013										
C VS F	10	0.0007	<.0001	0.0005	0.0017	0.0203	0.0024	0.0005	0.0006	<.0001
C VS B	10	0.0514	0.0009	0.0175	0.1023	0.3684	0.5570	0.0846	0.0854	0.0405
C VS P	10	0.4054	0.0225	0.6985	0.9154	0.9437	0.3467	0.6861	0.9220	0.5573
C VS BE	10	<.0001	<.0001	0.0003	0.0017	0.0039	0.0003	<.0001	0.0011	<.0001
C VS PE	10	0.0671	0.0225	0.0628	0.1220	0.2594	0.3467	0.1269	0.3388	0.0312
2014										
C VS F	10	0.0001	0.0008	0.0002	0.0918	0.0067	0.0056	0.0185	0.0046	0.7743
C VS B	10	0.1430	0.0871	0.0391	0.2779	0.7078	0.3603	0.8393	0.3919	0.2951
C VS P	10	0.6995	0.6335	0.0120	0.5788	0.4956	0.5883	0.5797	0.4730	0.3268
C VS BE	10	<.0001	<.0001	<.0001	0.0039	<.0001	0.0003	0.0045	0.0003	0.0402
C VS PE	10	0.4452	0.1533	0.0301	0.4897	0.2741	0.0564	0.1378	0.0322	0.4367
Glenstone										
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Contrast	df	P								
2012										
C VS F	10	0.0277	0.1486	0.0070	NA	0.1063	0.5306	0.7196	0.0004	0.0055
C VS B	10	1.0000	0.8276	0.1218	NA	0.1063	0.2231	0.8105	0.0008	0.0170
C VS P	10	0.3573	0.8276	0.1893	NA	0.1063	0.6742	0.7196	0.1685	0.0361
C VS BE	10	0.0481	0.2897	0.0182	NA	0.0175	0.0799	0.4772	0.0001	0.0170
C VS PE	10	1.0000	0.0719	0.4178	NA	0.4939	0.6742	0.9045	0.0501	0.1546
2013										
C VS F	10	0.0958	0.0604	0.0393	0.2841	0.0503	0.3060	0.3008	0.9279	0.1036
C VS B	10	0.3955	0.1837	0.0514	0.1088	0.5663	0.0305	0.0779	0.6106	0.1036
C VS P	10	0.8049	0.3149	0.2174	0.8382	0.1690	0.1809	0.0373	0.6527	0.1189
C VS BE	10	0.0111	0.0505	0.0065	0.0214	0.0207	0.0305	0.0373	0.2232	0.0246
C VS PE	10	0.3342	0.2715	0.1129	0.4923	0.1190	0.1809	0.5275	0.9519	0.1457
2014										
C VS F	10	0.5345	0.6733	0.3044	0.2346	0.4545	0.4534	0.2166	0.6855	0.1988
C VS B	10	0.0277	0.5074	0.4412	0.0225	0.0123	0.2183	0.3100	0.4910	0.4282
C VS P	10	0.2272	0.3187	0.1013	0.1418	0.5313	0.1813	0.3418	0.3925	0.4282
C VS BE	10	0.3573	0.3516	0.0322	0.0170	0.1667	0.1597	0.0935	0.1918	0.1610
C VS PE	10	1.0000	0.9157	0.2878	0.1089	0.1360	0.9044	0.3938	0.5646	0.3162

† C, control; F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro; BE, 1 cm biosolids compost Orgro; PE, 1 cm yard trimmings compost Leafgro.

3.2.3 Weed Encroachment

Visual assessment of weed cover (0 to 100%) was performed when annual grass or broadleaf weeds became apparent within the plots. The monthly ANOVA results for the effect of three nitrogen sources when applied at yearly rate of 156 kg N ha^{-1} yr^{-1}, cultivation and compost tea on weed encroachment is shown in Tables 3.8. Weed cover as function N source for these same data is presented in Figure 3.8.

At Glenstone in 2012, and in all three years at the PBTRF plots receiving Signature consistently had lower levels of weed encroachment that did at least one, but in most cases the use of either compost material when applied at 156 kg N ha^{-1} yr^{-1}. Weed pressure was much greater at the PBTRF that at Glenstone with no effect of cultivation or the use of compost tea, being observed at the latter site (Figure 3.8). Hollow tine cultivation performed in the fall of 2011 at the PBTRF resulted in a slight reduction in weed encroachment the following summer, however for the remainder of study cultivation had no impact on weed encroachment. The use of compost tea at the PBTRF reduced weed encroachment from 6.6 to 4.2% at the end of 2013 growing season (i.e., Nov, data not shown) and from 42.6 to 37.0% in September of 2014. On two additional dates (June and October, 2014) the effect of compost tea on weed encroachment at PBTRF was dependent on the N-source supplied to the turf (Figure 3.9). The slight beneficial effects of compost tea were only observed in plots receiving yard trimmings compost.

Mean contrasts comparing weed encroachment in the control plots verses the five N-source treatments in the absence of cultivation is shown in Table 3.9. On all evaluation dates at both sites the lowest level of weed encroachment was seen in plots that received

1 cm of the biosolids compost (data not shown). At PBTRF where weed encroachment pressure was high, the 1 cm biosolids treatment had significantly lower weed encroachment than the control treatment on 10 of the 11 evaluation dates. In contrast, at Glenstone where weed pressure was much lower, turf receiving 1 cm of the biosolids compost had significantly less weed encroachment than control on only 1 of the 11 evaluation dates. No other treatment at Glenstone had significantly less weed encroachment than the control treatment on any of the 11 evaluation dates. At PBTRF the overall effectiveness of the various N source treatments in suppressing weed encroachment was 1 cm biosolids compost > Signature > 1 cm yard trimmings compost > either the yard trimmings or biosolids compost when applied at 156 kg N ha^{-1} yr^{-1}.

Table 3.8. Effect of nitrogen source, cultivation and compost tea on weed encroachment at the Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

		Paint Branch Turfgrass Research Facility													
		2012			2013			2014							
		Jul.	Sep.	Oct.	May	Oct.	Nov.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Treatments	df	P													
N source (N)	2	0.0113	N/A	N/A	N/A	<.0001	0.1900	0.0805	0.0028	0.0021	0.0003	<.0001	0.0007	0.0024	0.0237
Cultivation (C)	2	0.0265	N/A	N/A	N/A	0.8706	0.6312	0.8695	0.1913	0.7791	0.4981	0.9122	0.5908	0.5114	0.7224
N×C	4	0.6998	N/A	N/A	N/A	0.7628	0.5097	0.9502	0.2285	0.6510	0.7840	0.8842	0.9170	0.7427	0.5880
Tea (T)	1	N/A†	N/A	N/A	N/A	0.9211	0.0348	0.6601	0.2762	0.3743	0.0624	0.4389	0.0441	0.0698	0.0865
N×T	2	N/A	N/A	N/A	N/A	0.1424	0.0995	0.2722	0.0546	0.0148	0.1773	0.5465	0.1074	0.0231	0.2202
C×T	2	N/A	N/A	N/A	N/A	0.5173	0.5674	0.2722	0.5759	0.8434	0.9725	0.8197	0.1581	0.1758	0.5667
N×C×T	4	N/A	N/A	N/A	N/A	0.9431	0.8996	0.5409	0.9565	0.9902	0.7793	0.8694	0.4104	0.3586	0.6247
		Glenstone													
		2012			2013			2014							
		Jul.	Sep.	Oct.	May	Oct.	Nov.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Treatments	df	P													
N	2	N/A	0.3329	0.0073	0.0830	0.1547	0.3170	0.5941	0.2919	0.3037	0.2636	0.3847	0.3901	0.6879	0.2929
C	2	N/A	0.6378	0.4328	0.6235	0.8722	0.8600	0.2459	0.6661	0.5425	0.6377	0.5555	0.4801	0.8741	0.5643
N×C	4	N/A	0.2817	0.3581	0.4470	0.1672	0.5318	0.5822	0.3319	0.3420	0.4011	0.3766	0.4063	0.4697	0.6492
T	1	N/A	N/A	N/A	N/A	1.0000	0.2275	0.4625	0.8855	0.7206	0.1961	0.1673	0.5499	0.2104	0.2108
N×T	2	N/A	N/A	N/A	N/A	1.0000	0.5005	0.4985	0.5498	0.6311	0.5398	0.5136	0.4245	0.7413	0.9504
C×T	2	N/A	N/A	N/A	N/A	1.0000	0.5890	0.4954	0.2807	0.7501	0.5192	0.2217	0.4201	0.6558	0.1700
N×C×T	4	N/A	N/A	N/A	N/A	1.0000	0.3342	0.6482	0.9803	0.9488	0.5388	0.8924	0.8567	0.9362	0.8385

† N/A, not applicable

Table 3.9. Comparison of non-cultivated nitrogen source with control on weed encroachment at the Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

		Contrast													
	df	P													
		2012			2013			2014							
Contrast		Jul.	Sep.	Oct.	May	Oct.	Nov.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
		Paint Branch Turfgrass Research Facility													
C† VS F	10	0.0132	N/A‡	N/A	N/A	0.0068	0.0207	0.1299	0.0005	0.0018	<.0001	0.0117	0.0340	0.0006	0.0735
C VS B	10	0.2769	N/A	N/A	N/A	0.0827	0.0281	0.4286	0.0015	0.0106	0.0123	0.4165	0.6391	0.0212	0.9601
C VS P	10	1.0000	N/A	N/A	N/A	0.8231	0.0482	0.4749	0.0022	0.0081	0.0089	0.5098	0.5212	0.0088	0.5282
C VS BE	10	0.0062	N/A	N/A	N/A	0.0034	0.0170	0.0191	0.0003	0.0016	<.0001	0.0042	0.0100	0.0002	0.0751
C VS PE	10	0.2769	N/A	N/A	N/A	0.0117	0.4493	0.7889	0.0060	0.0640	0.0071	0.0512	0.1337	0.0008	0.2062
		Glenstone													
C VS F	10	N/A	0.3572	0.0530	0.2029	0.9189	0.2091	0.4347	0.8502	0.5464	0.4447	1.0000	0.3356	0.6363	0.2121
C VS B	10	N/A	0.4110	0.0653	0.2951	0.7604	0.4754	0.7169	0.9397	0.5075	0.7181	0.6679	0.3542	0.4803	0.3667
C VS P	10	N/A	0.1641	0.1462	0.2522	0.5125	0.1798	0.6926	0.3199	0.2062	0.6433	0.2981	0.1421	0.2258	0.2596
C VS BE	10	N/A	0.0824	0.0184	0.0661	0.2385	0.1011	0.6452	0.3032	0.1424	0.5725	0.3283	0.1062	0.1632	0.1276
C VS PE	10	N/A	1.0000	0.4073	0.4783	0.5125	0.1542	0.8429	0.5992	0.4736	0.6074	0.9971	0.4068	0.3053	0.2163

† C, control; F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro; BE, 1 cm biosolids compost Orgro; PE, 1 cm yard trimmings compost Leafgro.

‡N/A, not applicable

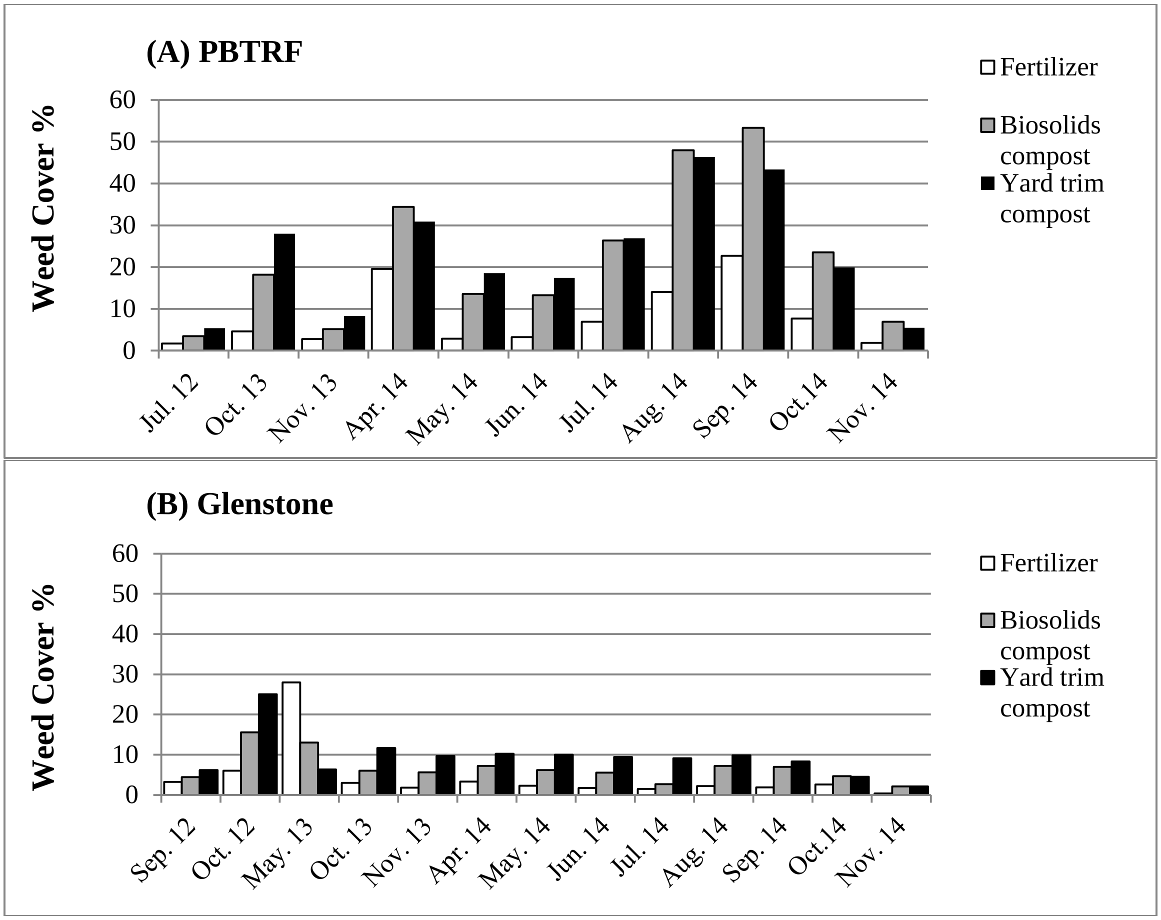


Figure 3.8. Plot weed cover (0-100%) in response to synthetic fertilizer (Signature), biosolids compost (Orgro) and yard trimmings compost (Leafgro) at rate of 156 kg N ha^{-1} yr^{-1} at (A) the Paint Branch Turfgrass Research Facility and (B) Glenstone.
Visual assessment of weed cover was made when grass or broadleaf weeds become apparent within the plots.

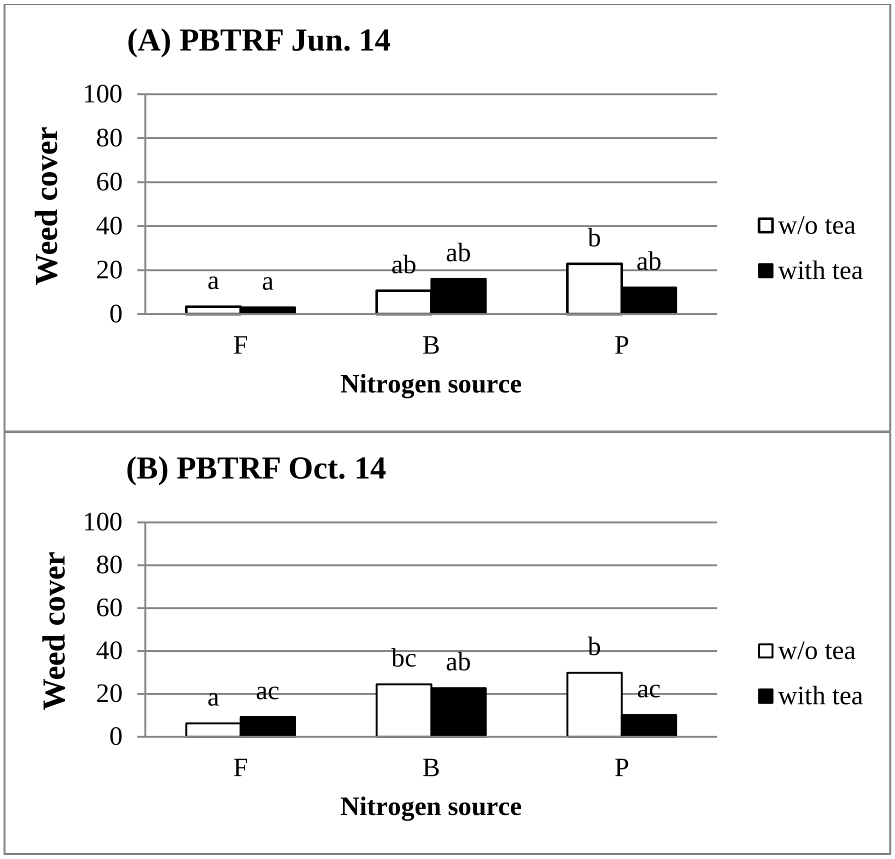


Figure 3.9. Effect of nitrogen source (F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro) and compost tea treatment on weed cover (0-100%) at the Paint Branch Turfgrass Research Facility in (A) Jun. 2014 and (B) Oct. 2014.
F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro.
Within a month rating, means labeled with the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

3.3 Discussion

Plots treated with synthetic nitrogen fertilizer (Signature) had faster green up in the spring and longer color duration in the fall at both sites, with the exceptions of Nov. 2012 and Mar. 2014 ratings at Glenstone, and the fall 2014 color ratings at both locations. Darker color reflects greater nitrogen use efficiency. The more ready available nitrogen present in the synthetic fertilizer probably accounts for the faster color response seen with this fertilizer. Slow initial N release from the two compost sources is a result of their greater reliance on microbial breakdown and the need for favorable soil conditions for the production of plant available nitrogen. These two factors may also explain the lack of differences in the turf color among the three N sources seen during the summer in this study. Increased biological activity and soil temperature in summer may have led to more efficient N mineralization. The observations seen in this study agree with Miller and Henderson (2012), who observed faster color response and darker mid- and late- fall color in plots treated with synthetic fertilizers than with organic treatments. The lack of color differences seen in the fall of 2014 was because no fertilizer and compost topdressing were applied in the fall of this year.

Based on our observations, high tall fescue quality was primarily the result of two factors: dense turf and less weed encroachment. The most desirable tall fescue quality responses were usually associated with the use of the synthetic nitrogen fertilizer at both sites (Figure 3.5). Although all nitrogen sources were applied at 156 kg N ha^{-1} yr^{-1}, the recovery or uptake of nitrogen (as surmised from color data) from biosolids compost and yard trimmings compost was less efficient than from the synthetic fertilizer Signature, especially shortly after the applications of the three N sources. This effect was likely due to the slow rate of N uptake by the turfgrass plants caused by the slow rate of N mineralization from the compost sources (Tester et al., 1982; Hartl and Erhart, 2005). The release rate of nitrogen from composts was not rapid enough to support sufficient turfgrass density, which led to greater weed encroachment. This is in agreement with results published by Geisel et al. (2001), who reported a single topdressing of a green and biosolids mixed compost at 0.3, 0.6 and 1.3 cm (1/8, 1/4 and 1/2 inch, respectively) were not sufficient to keep turf performance at a high standard. Landschoot and Waddington (1987) compared turfgrass color and growth responses of 25 nitrogen sources and concluded sludge compost at rate of 196 kg N ha^{-1} $year^{-1}$ was ineffective in meeting the fertility needs of turfgrass. Numerous studies have demonstrated that only 10 to 20% of the total N in compost is available in the first year and the remaining part of N is mineralized at rate of 3 to 8% in subsequent years (Iglesias-Jimenez and Alvarez, 1993; Diacono and Montemurro, 2010). Tester et al. (1982) observed about 76% of total fertilizer N and only 8% of total compost N were utilized by fescue during 167 days of growth in a greenhouse pot study. However, equivalent effects of compost topdressing and conventional fertilizer on turf quality have been found when the amount of compost was added based on the projected amount of actual nitrogen release (Geisel et al., 2001). Geisel et al. (2001) reported higher turfgrass quality and less weed coverage in plots receiving synthetic fertilizer at the rate of 195 kg actual N ha^{-1} yr^{-1} than when 0.6 cm (1/4 inch) compost topdressing (390 kg actual N ha^{-1} yr^{-1}) was applied quarterly.

Turf quality was influenced less by nitrogen source at Glenstone than at PBTRF. Tall fescue at Glenstone was generally of higher quality than that at PBTRF, except in July of 2014 when turf appearance was negatively affected by drought stress at Glenstone. The higher quality ratings seen at Glenstone can most likely be explained by differences in soil organic matter content and turfgrass mowing height. The soil at PBTRF originally had a soil organic matter content of 3.4%, while Glenstone had a soil organic content of 4.3%. The higher organic matter content at Glenstone may have resulted in the soil retaining higher amounts of soil moisture as well as supporting higher nitrogen mineralization rates, thus producing a higher quality turf. The turf at PBTRF was mowed at 6.4 to 7.6 cm (2.5 to 3 inch) while the turf at Glenstone was mowed at 10 cm (4 inch). Higher mowed turf can result in more extensive root systems and better turfgrass surface coverage than low mowed turf (Madison and Hagan, 1962; Salaiz et al., 1995). The presence of more verdure at Glenstone compared to PBTRF was likely responsible for the lower level of weed encroachment seen at Glenstone during the three-year study (Figure 3.8).

For the three years of this study, the sewage sludge based biosolids composts Orgro frequently showed darker green and better turf responses than plant based compost Leafgro. The differences between these two composts may due to the differences in C/N ratio (Table 3.1, Table 3.2 and Table 3.3). Orgro had a lower C/N ratio. Materials with lower C/N ratio, compared to higher C/N ratio materials, would be mineralized more quickly by microorganisms and thus more nitrogen would be available for turfgrass uptake. These results were comparable to that reported by other researchers. Stratton and Rechcigl (1998) observed ryegrass in MSW compost treatment had better vigor and coverage than that in yard trimmings compost treatment with higher C/N ratios.

Under the condition of no cultivation, increasing the amount of compost topdressing generally increased turf quality and color, with plots receiving 1 cm biosolids compost exhibiting darker color and better quality compared to the control on more rating dates than other treatments. The improvements brought about by the higher rates of each compost were largely due to higher amounts of organic matter and nutrients supplied to the soil with 1 cm treatments. Differences in tall fescue responses caused by 1 cm biosolids and yard trimmings compost materials most likely can be explained by differences in total nitrogen content of the compost. Biosolids compost Orgro contained a higher proportion of total nitrogen than yard trimmings compost Leafgro (Table 3.1, Table 3.2 and Table 3.3), thus supported more growth and darker turf. The biosolids compost generally contained more iron (Fe) as well, which typically darkens the color of turf (Yust et al., 1984).

Core cultivation had the potential to improve turf color responses, particularly in the spring. Core cultivation had little to slightly adverse effects on tall fescue quality. The adverse effect observed in a few months in 2012 could be due to the damage and stress posed by the verticutting that took place with treatment in the fall of 2011. Similar behavior to what was observed in 2013 and 2014 has been reported by some researchers. Garling and Boehm (2001) found core cultivation did not have significant effects on turfgrass color, growth and foliar N on low-cut fairway turfgrass with combination of fertilizer and compost treatment.

Compost tea generally had little effect on turf color, quality and weed control although some slight improvements in color, quality and weed control were seen with compost tea application in combination with certain nitrogen source at both sites. These differences were statistically significant, but they were not very meaningful, because our level of resolution in rating plots was only 0.5. The differences caused by compost tea application were substantially less than 0.5. Similar results have been reported by Miller and Henderson. (2012). They found compost tea applied at a rate of 408 L ha^{-1} provided no enhancement of Kentucky bluegrass color, quality and cover over the course of their two-year study (Miller and Henderson, 2012).

3.4 Conclusions

Organic compost materials have beneficial effects on turfgrass growth and are believed to be of agronomic and economic value. However, the results of this study suggest that compost topdressing at rate of 156kg N ha^{-1} yr^{-1} will not be as effective as an enhanced efficiency synthetic fertilizer in maintaining turf quality in the first few years of making this rate of N application in low organic matter-containing soils. In contrast, annual topdressing of 1 cm sewage sludge based biosolids compost can be used as an alternative N source to an enhanced efficiency synthetic fertilizer to maintain turf quality. However, the amount of nitrogen and phosphorus applied greatly exceeds current Maryland regulations for turfgrass fertilization when 1 cm of the two composts is applied as a topdressing material. Our results indicate if use restrictions similar to those in effect for bagged fertilizer products are placed on compost materials, a likely result will be a decline to turfgrass quality when compost is used as the sole nitrogen source to fertilizer tall fescue lawn.

Differences in the duration of color and turf quality brought about by different nitrogen sources and rates used in the present study can be largely explained by different amounts of nitrogen released from synthetic fertilizer, composts or soil. However, contributions from other plant nutrients, improved soil physical properties and microbiological process induced by treatments are also possible. Additional research involving such information is reported in subsequent chapters of this thesis. Also, longer term use of compost topdressing (past the 3 years of this study) beyond that examined here may eventually result in more beneficial results than those observed in this study.

Chapter 4: Effects of Cultivation, Compost Topdressing and Compost Tea on Lawn Soil Organic Matter Content and Soil Microbial Activity

Residential construction activity frequently involves the removal and redistribution of topsoil and the use of subsoil as fill material. These grading activities often result in compact infertile soils, which have the potential of accentuating the use of fertilizers on home lawns. Lawn fertilization typically results in the use of mineral and synthetic based fertilizers, however the use of composted organic materials often serve as a fertilizer source for organic lawn care programs. The passage of turfgrass fertilizer laws in several states has resulted in restrictions in amount of nitrogen (N) and phosphorus (P) that can be applied to turf as well as the form in which these nutrients can be applied (Maryland's Law Fertilizer Law, 2011; Weinberg et al., 2011). In the states of Maryland and New Jersey for example, no more than 34 kg ha^{-1} of a quickly available nitrogen source can be applied at one time. Higher single application N rates are permissible when slowly available sources of N are used, with Maryland permitting a single application up to 122 kg N ha^{-1} when an enhanced efficiency fertilizer is used to fertilize turf. An enhanced efficiency fertilizer is a slow release fertilizer that releases nitrogen at a rate of less than 34 kg ha^{-1} (0.7 lb 1000 ft^{-2}) monthly.

Frequent hollow tine cultivation alleviates soil compaction and aids in the incorporation of material into soil (Agresource, 2013). The use of hollow tine cultivation to incorporate compost is a desired practice as repeated application of compost can result in the formation of an organic matter layer that is harmful to the turfgrass root system (Landschoot, 1995). Hollow tine cultivation when performed without the incorporation of organic matter into the top soil has little effect on soil microbial activity (Mu and Carroll, 2013).

In recent years the use of a water extract from fermented compost (i.e., compost tea) on turf has become popular. Its use as a liquid spray has been promoted as a way to provide nutrient and biological benefits to plants and soil including the suppression of diseases (Ingham, 2005). The use of compost teas for controlling foliar diseases and soil-borne diseases mostly has been reported on agricultural crops such as corn, wheat, bean, tomato, lettuce, potato, cucumber, strawberry and grape etc. (Weltzien, 1992; Yohalem et al., 1994; Zhang et al., 1998; Scheuerell and Mahaffee, 2002; Al-Dahmani et al., 2003; Litterick et al., 2004; Koné et al., 2010). The suppression of disease through compost tea application has been extensive documented and summarized by Scheuerell and Mahaffee (2002), and Litterick et al. (2004). However, only a few studies involving the use of compost tea on turfgrass appear to exist in the literature. Rossi (2007) found that foliar compost tea (360 L ha^{-1}) applied to a mix annual bluegrass (*Poa annua* L.) and creeping bentgrass (*Agrostis stolonifera* L.) sand based putting green was able to suppress dollar spot in one of three years when compared to untreated plots. Miller and Henderson (2012) found that compost tea, when applied at 408 L ha^{-1} on 3 week intervals over a period of 4 months, had no effect on the color, quality or cover of Kentucky bluegrass (*Poa pratensis* L.).

In addition to increased levels of plant nutrients, the application compost materials has been shown to improve soil quality (Stratton et al., 1995, Ingham, 2005). The incorporation of compost into soil has been reported to increase soil organic matter, organic C content, and soil microbial activity (Godden et al., 1987; Jodice and Nappi, 1987; Rutili et al., 1987; García-Gil et al., 2000; Ros et al., 2006; Tian et al., 2008; Agresource, Inc. 2013). Less is known about the effect of compost topdressing on soil physical properties. Johnson et al. (2006a), added composted manure at surface application rates of 3.3, 6.6 and 9.9 mm three times over a year and found that topdressing with this material had no effect on the soil organic matter (SOM) content in the top 10 cm of soil. Interesting though, at the two highest rates of topdressing, SOM increased at the 10 to 20 cm depth when compare the no compost topdressing control treatment. Soil organic matter is an important parameter for maintaining healthy turf. The benefits associated with increased SOM with the use of compost usually include improved soil structure, water and nutrient holding capacity, and overall soil quality (Young and Onstad, 1978; Soane, 1990; He et al., 1992; Stratton 1995; Ros et al., 2006).

Microbiological and biochemical soil properties are very sensitive to changes in management. Microorganism plays a key role in nutrient cycling, residue degradation, organic matter formation and turnover, which makes the knowledge of soil microorganisms essential for determining soil quality. The methods for assessing soil microbiological presence can be classified into four groups: soil microbial number and biomass; soil microbial metabolic or enzymatic activity; soil microbial diversity and community structure; and plant-microbe interactions (Benedetti and Dilly, 2006).

Soil enzyme activity is one of the essential properties for assessing soil health and is commonly used for evaluating the effects of the application of different sources and amount of organic matter materials on soil (Giusquiani et al., 1995; Davis and Dernoeden, 2002). It is a crucial factor in the decomposition and cycling of plant nutrients, and is correlated with microbial biomass C (Perucci, 1992). In order to assess microbial activity the activity of several type of enzymes needs to be measured simultaneously. The fluorescein diacetate [3',6'-diacetylfluorescein (FDA)] hydrolysis assay is a rapid, sensitive, colorimetric method used for the measurement of total microbial activity without the isolation of specific microorganisms (Schnurer and Rosswall, 1982; Adam and Duncan, 2001; Green et al., 2006). This method allows for accurate assessment of microbial activity in a wide range of soil conditions at relatively low cost. Fluorescein diacetate is reactive to a number of free or membrane bound enzyme classes including proteases, lipases and esterases. Reactions with these enzymes result in the hydrolytic cleavage of FDA (colorless) into fluorescein (yellow-green), which can be quantified by spectrophotometry at 490 nm (Schnurer and Rosswall, 1982; Adam and Duncan, 2001; Green et al., 2006).

Most positive responses in soil microbial activity are associated with large compost applications (i.e. Mg ha^{-1}) or the use of compost as a soil amendment. For example, Perucci (1992) observed increases in soil biomass C and FDA hydrolysis activity when 30 and 90 Mg ha^{-1} yr^{-1} municipal refuse compost was incorporated to a depth of 10 to 15 cm in a loamy soil. However, little is known about the effect of a relatively small compost topdressing application on soil microbial activity. Davis and Dernoeden (2002), made four 50 kg N ha^{-1} applications per year of a composted biosolids compost to creeping bentgrass growing in a sandy loam soil and examined microbial activity three and four years after initiating the topdressing treatment. They observed similar responses in the two years soil microbial activity was measured. In the third year of making the topdressing applications there was no effect of topdressing on soil microbial activity on three of five dates when activity was measured. In the fourth year after initiating the topdressing treatment, soil microbial activity was higher in the compost topdressed plots than in untreated control plots on 2 of 4 dates soil microbial activity was measured.

Given that limitations may be placed on the application of compost to turf, there is a need to further examine potential changes in soil properties that may occur with light compost topdressings made to turf. Particularly when compost topdressing occurs only once per year which is a frequent practice in the management of lawn turf. Accordingly, the objectives of this research were to: 1) to compare the effect of biosolids and yard trimmings compost with the use of an enhanced efficiency fertilizer on the organic matter content and microbial activity of soil when all three materials are applied at equivalent nitrogen rates; 2) to compare soil organic matter and soil microbial activity of untreated control with those receiving an enhanced efficiency fertilizer or compost, with the compost applied at the same N loading rate as the enhanced efficiency or at a rate of 1 cm of compost per year; 3) to determine if hollow time cultivation affects the organic matter content and microbial activity of soil when performed in conjunction with the application of compost topdressing or the use of enhanced efficiency fertilizer; 4) to determine the effect of monthly applications of compost tea on soil microbial activity.

4.1 Materials and Methods

4.1.1 Site Location

Two field sites in Maryland were used to examine the effect of different nitrogen containing material, cultivation and compost tea on soil organic matter and microbial activity. The first site was a 4-year old stand of 'Titanium' tall fescue (*Festuca arundinacea* Schreb.) and 'Raven' Kentucky bluegrass located at the University of

Maryland Paint Branch Turfgrass Research Facility (PBTRF) in College Park, MD. The second site was 5-year old stand of 'Confederate' tall fescue seeded in 2006 and located at the Glenstone Art Museum in Potomac, MD.

The taxonomic classification of soil at the PBTRF site was a Russett (fine-loamy, mixed semiactive, mesic Aquic Hapludults) and Christiana (fine, kaolinitic, mesic Aquic Hapludults) complex soil, while that at the Glenstone site was a fine-loamy, mixed, mesic Typic Hapludults. The soil at the Glenstone site had been subjected to extensive grading activity prior to turfgrass establishment. The grading altered the natural pedology of soil profile at this site. The test site at Glenstone was located on a hillside having a 5.6 % slope while that at PBTRC was on land having a slope less than 1%.

The study took place over 3 years with the initial once a year fertilizer treatment being applied in October of 2011. The turf was mowed at least twice a month during the growing season PBTRF site with the clippings being returned. At Glenstone the turf was mowed weekly throughout the growing season with the clippings returned. At both sites the turf was irrigated only when needed to prevent the turf from entering water stress induced dormancy and no pest control measures were utilized throughout the course of the study at either location.

4.1.2 Treatments

Fertilizer treatments consisted of no fertilizer, a sewage sludge based biosolids compost (Orgro, Veolia Water North America Baltimore City Composting Facility, Baltimore, MD), a yard trimmings compost (Leafgro, Maryland Environmental Services/Dickerson, Dickerson, MD), and the application of an enhanced efficiency synthetic nitrogen fertilizer (Signature 35-0-10, Loveland Products, Inc. Greeley, CO).

Each material was applied by hand at the rate of 156 kg N $ha^{-1}yr^{-1}$ in late September or October. Two additional fertilizer treatments were also included in the study and consisted of a once a year application of 1 cm of the biosolids and yard trimmings compost. These compost applications were made on the same day as the previously described fertilizer treatments. The amount of compost that was applied for the 156 kg N $ha^{-1}yr^{-1}$ treatment was based on analysis of the two composts conducted in advance of each yearly application. Based on the results of the analyses, a surface application of 1 cm of the biosolids and yard trimmings compost applied ,on average, 1108 and 584 kg N ha^{-1} yr^{-1}, respectively. Cultivation treatments consisted of 0, 1 or 2 passes of a Ryan GA 30 aerator (Ryan, Div. of Schiller Grounds Care, Inc., Johnson Creek, WI) equipped with 1.9 cm by 12.7 cm tines. The tines penetrated to a depth of 10 cm. and the cultivation was imposed once per year immediately prior to spreading the compost or fertilizer. Plots receiving 156 kg N ha^{-1} yr^{-1} were subjected to one of the three cultivation treatments while plots receiving 1 cm of compost and the untreated control were not subjected to cultivation.

Compost tea was applied in the second and third year by splitting the main plots in half and making a monthly application of compost tea at rate of 1630 L ha^{-1} (4 gallons per 1000ft^2) to one of two sides during the growing season. Additional details on preparation of the compost tea, the soils at the two sites, and study treatments can be found in Chapter 3 of this thesis.

4.1.3 Soil Microbial Enzymatic Activities Analysis

Microbial activity within all subplots at both locations was assessed twice in 2013 and 2014 using the fluorescein diacetate (FDA) hydrolysis assay method. With the exception of one sampling period, sampling took place over three successive days each time microbial activity was evaluated at a site. Samples were collected from all plots within a given treatment block (one replication) on each day. The only exception to this was on 1 July 2013 when two replications were collected on a single day at PBTRF. Sample collection and analysis took place on 20, 21, 22 June, 6, 7, 8 September 2013, and on 6, 7, 8 June, and 25, 26, 27 August 2014 at the PBTRF. At the Glenstone site soil microbial activity was assessed on 1, 2 July, 13, 14, 15 September 2013 and on 17, 18, 19 June, and 20, 21, 22 August 2014.

Soil samples that were collected in June and July of 2013 were extracted from a depth of 2 to 6 cm using a 2-cm-diameter soil probe. Samples collected on all other dates consisted of extracting cores from a depth 1 to 5 cm using the same type of soil probe. On all dates three soil cores were collected from each subplot, the collected samples were placed in poly bags, mixed, and the bags (RD Plastics, Nashville, Tennessee) sealed until arrival at the laboratory. The samples were placed into a container that excluded light, after which they were transported to laboratory. Soil cores were always collected in the early morning with the collection being complete with 1 hour of arriving at the site.

Fluorescein diacetate hydrolysis assay of microbial activity closely followed the procedure described by Adam and Duncan (2001) and Green et al. (2006). Standard curves were constructed for each collection period that microbial activity was measured (i.e., a single standard curve was created and utilized for the 3 day period samples were collected from a site). Standard curves were produced from 0, 2.5, 5, 7.5, 10, 12.5 $\mu g\ ml^{-1}$ fluorescein standards that were prepared from mixture of a 2 mg/ml fluorescein solution, and 30 ml of a buffer solution that contained acetone (1:1 V/V). Absorbance as function of fluorescein concentration was measured at 490 nm using a spectrophotometer (BioMate 3, Thermo Spectronic, Thermo Fisher Scientific Inc., Waltham, Massachusetts) and a regression fit was generated automatically for future reference. A 60mM sodium phosphate buffer solution (pH=7.6) was made by dissolving Sodium phosphate tribasic ($Na_3PO_4 \cdot 12H_2O$, Fisher Chemical, Thermo Fisher Scientific Inc., Waltham, Massachusetts) in deionized water. The pH of the resulting solution was adjusted to 7.6 using 1 M hydrochloric acid (HCl). The FDA substrate solution was prepared by dissolving FDA ($C_{24}H_{16}O_7$, Alfa Aesar, Ward Hill, Massachusetts) in certified ACS reagent grade acetone (C_3H_6O, Fisher Chemical, Thermo Fisher Scientific Inc., Waltham, Massachusetts) for a final concentration of 0.3 mg ml^{-1}.

Two gram hand ground soil samples were placed into a 125 ml Erlenmeyer flask to react with FDA or to serve as an absorbance blank. Fifteen milliliter of 60mM sodium phosphate buffer solution was added to each flask, after which 0.1 ml of 3 mg ml^{-1} FDA was added to make the final FDA concentration 20 μg ml^{-1} at the start of the reaction. In the case of the paired absorbance blank, the addition of 0.1 ml FDA was replaced with 0.1 ml acetone. All flasks were placed on an orbit shaker (model 3590, Labline Instruments, India) operated at 90 rpm for 60 min. After shaking, 15 ml of acetone was added to each flask with the flasks being shaken by hand to terminate FDA hydrolysis. Filtrate was generated by passing the suspension through Whatman No. 2 filter paper and then transferring 3 ml of the filtrate to a 3 ml cuvette (BrandTech™ UV-Cuvets, BrandTech Scientific, Essex, Connecticut). The absorbance of the solution was then determined using the spectrophotometer set at 490 nm. The fluorescein concentration was calculated by the spectrophotometer using a standard curve generated at the beginning of sampling period. Because final microbial activity was expressed on a dry soil basis, the moisture content of individual sample was determined at taking a 5 gram subsample of the soil sample that was placed into a flask and drying it at 105 °C overnight. The moisture content of the sample was calculated as the weight of moisture lost divided by soil dry weight. The microbial enzymatic activity was expressed in units of μg fluorescein released g^{-1} dry soil min^{-1}.

4.1.4 Soil Organic Content Analysis

Soil organic content was measured at the end of third year of the study by the weight loss on ignition method (Storer, 1984; Schulte et al., 1991; Schulte, 1995). A 2-cm-diameter soil probe was inserted to a depth slightly in excess of 10 cm. The extracted core was trimmed to remove all plant material above the soil surface as well as any soil present beyond a depth of 10 cm below the soil surface. After trimming the core it was placed in a sealable plastic bag along with two other soil cores collected from same plot in an identical manner. In the laboratory, the cores were air-dried, ground and then passed a 2 mm mesh sieve. A sub sample of the resulting material was weighted after placing it in beaker having a known weight. The sample was heated at 125 °C for 1 hour and then combusted at 360 °C for 2 hours (Blue M mechanical convection oven, model CFD-10E-7, Blue Island, Illinois.). Soil organic matter content was determined as:

$$\%\, SOM = \%\, Loss\ on\ Ignition = \frac{(\mathrm{W1} - \mathrm{W2})}{\mathrm{W1}} \times 100$$

where SOM is soil organic matter content, W1 is weight of the soil after being dried at 125 °C for 1 hour, W2 is final weight of soil after 2 hours at 360 °C. W1 and W2 were determined by subtracting the weight of the glass beaker in which sample combustion took place.

4.1.5 Statistical Analysis

Nitrogen source and cultivation treatments were replicated 3 times and arranged in randomized complete block design, with compost tea being an additional spilt plot factor within the design. Analysis of variance (ANOVA) procedures were used to evaluate factorial treatment effects that constituted a 3 (nitrogen type) × 3 (cultivation) × 2 (compost tea) randomized complete block split plot design for microbial activity, and a 3 × 3 randomized complete block design for soil organic matter content. Planned contrasts that compared the untreated control with all other non-cultivated N source treatments were also performed. The analysis was conducted by evaluating each site location and sampling time as independent events. Data were analyzed using SAS Proc Mixed statistical software version 9.3 (SAS Institute, 2012). All reported differences were significant at $P \leq 0.05$ unless otherwise indicated and mean separations were conducted using Tukey's honestly significantly different test where appropriate.

4.2 Results

4.2.1 Soil Organic Matter Content

The effects of cultivation and the use of three different N source treatments, when applied at the rate of 156 kg N ha^{-1} yr^{-1} for 3 successive years, on soil organic matter content (SOM) are shown in Table 4.1. Cultivation had no effect on SOM while fertilizer N source only affected on SOM at PBTRF. At this site the use of yard clippings compost increased SOM by 17% when compared to synthetic fertilizer and by 11% when compared to the use of biosolids compost.

Table 4.1. Effect of nitrogen source and cultivation on soil organic matter content at the Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

		Organic matter content	
		PBTRF	Glenstone
N source (N) †		-----------------%----------------	
Synthetic fertilizer		3.5a‡	4.2
Biosolids compost		3.7a	4.6
Yard trimmings compost		4.1b	4.7
Cultivation (C) §			
0		3.8	4.6
1		3.9	4.5
2		3.7	4.4
	ANOVA		
Source of variation	df	P	
N	2	0.0002	0.0765
C	2	0.2128	0.6936
N×C	4	0.7729	0.5605

† Nitrogen sources were applied once per year at rate of 156 kg N ha^{-1}.
‡Within columns, means followed by the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).
§ Number of hollow tine cultivation passes made over the plot in advance of applying the nitrogen source treatment.

Contrasts comparing the effect of all non-cultivated treatments receiving N (data averaged across compost tea treatment) with the control treatment (i.e., no N, no tea, no cultivation) on SOM content are shown in Table 4.2. Plots receiving 1 cm of biosolids compost or yard trimmings compost had significantly higher SOM contents than untreated control at both sites. At PBTRF, topdressing of yard trimmings compost at rate of 156 kg N ha^{-1} yr^{-1} without cultivation also increased the SOM when compared to the control treatment.

Table 4.2. Comparison of non-cultivated nitrogen source with control on soil organic matter content at Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

		Organic matter content	
		PBTRF	Glenstone
N Treatment		-------------------%-----------------	
Control (C)		3.0	4.5
Synthetic fertilizer (F)		3.6	4.5
Biosolids compost (B)		3.7	4.8
Yard trimmings compost (P)		4.2	4.5
1 cm Biosolids compost (BE)		4.6	6.2
1cm Yard trimmings compost (PE)		5.1	5.8
	ANOVA		
Contrast	df	P	
C VS F	10	0.0986	0.8698
C VS B	10	0.0658	0.5360
C VS P	10	0.0038	0.9938
C VS BE	10	0.0005	0.0023
C VS PE	10	<0.0001	0.0146

4.2.2 Soil Overall Enzyme Activity

Fertilizer N source and cultivation and had no influence on soil microbial activity when the fertilizers were applied at the rate of 156 kg N ha^{-1} yr^{-1} (Table 4.3). A significant positive effect on soil microbial enzyme activity was seen with the use of compost tea but only during one evaluation interval. The use of compost tea increased microbial activity from 3.9 to 4.2 μg fluorescein g^{-1} dry soil min^{-1} when microbial activity measurements were collected in June of 2014 at the Glenstone site.

When the non-cultivated, non-fertilized control treatment was compared with the five non-cultivated N source treatments, only the 1 cm depth yard trimmings compost treatment had higher soil microbial enzyme activity than the control treatment (Table 4.4). This positive response was limited to a single evaluation period (June 2014) at the Glenstone site only.

Table 4.3. Effect of nitrogen source, compost tea and cultivation on soil microbial enzyme activity at the Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

		FDA†							
		PBTRF				Glenstone			
		2013		2014		2013		2014	
N source (N)‡		Jun.	Sep.	Jun.	Aug.	Jul.	Sep.	Jun.	Aug.
Synthetic fertilizer		2.8	3.5	3.8	3.2	2.9	3.3	3.9	3.5
Biosolids compost		2.8	3.3	3.7	3.2	2.8	3.6	4.0	3.6
Yard trim compost		2.9	3.3	3.9	3.3	3.0	3.4	4.2	3.5
Cultivation (C) §									
0		3.0	3.4	3.7	3.3	2.8	3.6	4.1	3.5
1		2.8	3.3	3.8	3.3	3.0	3.4	4.0	3.5
2		2.7	3.3	3.9	3.2	2.9	3.4	4.1	3.6
Compost tea (T)									
Yes		2.9	3.4	3.8	3.3	2.9	3.5	4.2a¶	3.5
No		2.8	3.3	3.9	3.2	3.0	3.4	3.9b	3.5
		ANOVA							
Source of variation	df	P							
N	2	0.3723	0.3478	0.1722	0.3971	0.3283	0.2209	0.2033	0.2530
C	2	0.0757	0.5504	0.5496	0.7083	0.3726	0.5293	0.4936	0.1251
N×C	4	0.9803	0.4975	0.9776	0.8538	0.1421	0.4226	0.0564	0.5959
T	1	0.1648	0.7871	0.1111	0.2366	0.2921	0.2096	0.0045	0.9906
N×T	2	0.9442	0.5997	0.2440	0.4530	0.3461	0.5045	0.9445	0.9692
C×T	2	0.2620	0.8124	0.5441	0.3034	0.4270	0.6285	0.5044	0.8698
N×C×T	4	0.4636	0.4522	0.1196	0.3931	0.6575	0.2132	0.1826	0.3728

† Fluorescein diacetate hydrolysis activity (μg fluorescein g^{-1} dry soil min^{-1}) .

‡ Nitrogen sources were applied once per year at rate of 156 kg N ha^{-1}.

§ Number of hollow tine cultivation passes made over the plot in advance of applying the nitrogen source treatment.

¶ Within columns, means followed by the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

Table 4.4. Comparison of non-cultivated nitrogen source with control on soil microbial enzyme activity at the Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

		FDA†							
		PBTRF				Glenstone			
		2013		2014		2013		2014	
N Treatment		Jun.	Sep.	Jun.	Aug.	Jul.	Sep.	Jun.	Aug.
Control (C)		2.9	3.4	3.7	3.1	2.8	3.3	3.7	3.3
Synthetic fertilizer (F)		2.9	3.7	3.7	3.2	2.8	3.4	3.9	3.4
Biosolids compost (B)		2.9	3.4	3.5	3.3	2.7	4.0	4.2	3.6
Yard trimmings compost (P)		3.1	3.2	3.9	3.3	3.0	3.3	4.2	3.5
1 cm Biosolids compost (BE)		2.7	3.3	4.2	3.1	3.1	3.7	4.3	3.5
1cmYardtrimmings compost (PE)		3.1	3.5	4.2	3.4	3.2	3.7	4.5	3.4
		ANOVA							
Contrast	df	P							
C VS F	10	0.8494	0.2567	0.9855	0.4703	0.8611	0.7355	0.5051	0.6701
C VS B	10	0.8177	0.9296	0.6019	0.2951	0.8044	0.0658	0.1386	0.1174
C VS P	10	0.4231	0.4341	0.6588	0.2395	0.3983	0.8730	0.1214	0.3115
C VS BE	10	0.4459	0.5734	0.2078	0.8232	0.1858	0.2283	0.0530	0.1687
C VS PE	10	0.5106	0.8109	0.1911	0.1182	0.0933	0.2187	0.0216	0.4936

† Fluorescein diacetate hydrolysis activity (µg fluorescein g^{-1} dry soil min^{-1})

4.4 Discussion

The increase in SOM content seen in the compost treatments was most likely the result of the contribution of organic matter to the soil from the compost itself rather than organic matter that may have been produced by enhanced turf growth turf in response to addition of compost to the soil. Compared to biosolids compost, yard trimmings compost contains more organic matter per unit mass of applied N (Table 3.1, Table 3.2 and Table 3.3). As an illustrated point of comparison, if all of the organic matter present in the two composts had been incorporated in the top 10 cm of soil without any subsequent decomposition, the SOM would increase by 0.8% for the biosolids compost and 2.1% for the yard trimmings compost (i.e. 8 g kg^{-1} and 21 g kg^{-1}) when the two composts are applied to the PBTRF site at the 156 kg N ha^{-1} yr^{-1} rate. This illustration assumes the bulk densities reported in Chapter 4 for the soil at this site would remain unchanged with the addition of the organic matter. Using the same assumption, the incorporation 1 cm of each compost to the same site for three successive years would raise the SOM by 5.7 and 6.9% for the biosolids and yard trimmings compost, respectively. The results presented in Table 4.2 indicate that the addition of either compost source at topdressing rate of 1.0 cm yr^{-1} will raise SOM in the top 10 cm of most mineral soils. The increase in SOM, however, will likely be small relative to the amount of organic matter that is initially incorporated to the soil.

The decomposition of compost in soil releases essential nutrients which simulates microbial growth and enzymes activity (Martens et al., 1992; Garcia-Gil et al., 2000; He et al., 2001; Zaman et al., 2004; Ingham, 2005; Ros et al., 2006). This effect is usually transitory and depends on soil conditions, compost maturity and the amount of compost applied (He et al., 1992). The two compost materials examined in this study had little effect on soil microbial enzymatic activity even though 1 cm of biosolids compost or yard trimmings compost treated plots had higher SOM content than the untreated control. Some researchers have reported that the presence of trace elements and heavy metals in fresh or composted organic wastes can be inhibitory to microbial activity (Jodice and Nappi, 1987; Rutili et al., 1987; Garcia-Gil et al., 2000). Alternatively, failure to see an increase in soil enzyme activity in the treatments having higher SOM in this current study is consistent with the promotion and suppression balancing mechanism hypothesized by Martens et al. (1992). Martens et al. (1992) observed an increase in the activity of 10 enzymes involved in cycling of carbon, nitrogen, phosphorus and sulfur when four 25 Mg ha^{-1} applications of either poultry manure, sewage sludge, barley straw or fresh alfalfa were made to coarse-loamy soil over 3 years. They found out the addition of all four organic amendments greatly enhanced the enzyme activity during the first year; but subsequent additions of the same amendments in the second and third year failed to maintain the high levels of enzyme activities seen in the first year of the study. They suggested that a trigger molecule or a promoter released with the initial addition of the organic amendment stimulated high levels of enzyme activities, but when the energy sources were sufficient due to constant or regular organic material additions, a feedback mechanism in soil existed to terminate enzyme production. This feedback mechanism may have been responsible for the lack of response seen in the second and third years of their study, and potentially in this study as well. The results presented in this current study are also supported by the findings of Debosz's et al. (2002). Debosz (et al., 2002) observed that FDA hydrolysis activity in a sandy loam soil increased immediately with the additions of 17 Mg (dry matter) ha^{-1} $year^{-1}$ of a sewage sludge or household compost under both laboratory and field conditions. Within two months however, FDA hydrolysis activity dropped to the level seen in the unamended soil (Debosz et al., 2002). Microbial activity in our study was measured at least 8 months after the addition of compost with the rate of compost application being much lower than Debosz's compost treatments. A significant effect of compost topdressing on microbial enzyme activity might have been observed if microbial activity had been determined immediately after the addition of compost, or perhaps at a higher compost topdressing rate.

The nutrients and beneficial organisms provided by correctly made and applied compost tea can improve plant health and soil quality (Ingham, 2005). Monthly foliar application of compost tea at a rate of 1630 L ha^{-1} (4 gallons per $1000ft^2$) had a significantly positive effect on soil microbial enzyme activity on one of four FDA evaluation periods over two summers. This one time increase may have been a result of a healthy turfgrass and root system existing under favorable climatic conditions.

4.5 Conclusions

Biosolids and yard trimmings compost when topdressed at a nitrogen rate comparable to annual application of synthetic enhanced efficiency fertilizer (156 kg N ha^{-1} yr^{-1}) had little effect on SOM content and microbial enzyme activities over a three-year period. Similarly neither response variable was influenced by the once a year hollow tine cultivation that was performed at the time fertilizer and compost topdressing applications were made. Additional applications of three nitrogen source materials over a period of several more years may be needed to observe a noticeable increase in SOM and/or microbial activity when compost is applied at annual nitrogen rates that are commensurate with those recommended for mineral and synthetic based fertilizers. When compost topdressing is applied in amounts used by practitioners (e.g. 1 cm of compost), our data suggest that an increase soil organic content, but not microbial activity will occur in soils initially having SOM content of less than 4.5%. Monthly foliar application of compost tea at rate of 1630 L ha^{-1} (4 gallons per 1000ft^2) had the potential to simulate higher FDA hydrolysis activity in soil, but certain favorable climatic and soil conditions appear to be necessary to observe such a response. In this study the alignment of favorable conditions that would induce an elevated level of soil microbial activity with the foliar application of compost tea was both an infrequent and non-reproducible occurrence. Additional examination of soil microbial activities immediately after compost topdressing and tea applications, and assessment of the biology in the compost tea is needed to gain a greater understanding of the effect of the two practices on soil microbial properties.

Chapter 5: The Effect of Compost Materials and Cultivation on Soil Bulk Density and Infiltration

In response to the USEPA's directive placing total daily maximum nutrient and sediment load limits on watersheds throughout the country, several states have recently passed legislation restricting the amount nitrogen and phosphorus that can applied to turfgrass (Weinberg et al., 2011). The limits are based in part on turfgrass needs for N obtained from mineral and synthetic fertilizer sources. Compost is often used in place of synthetic and inorganic fertilizer to provide all, or a portion of the supplemental N needs of turfgrass. When incorporated into the soil, compost can improve soil aggregate stability, decrease soil bulk density, and increase soil porosity, soil water holding capacity and soil hydraulic conductivity (Mays et al., 1973; Epstein et al., 1976; Pagliai et al, 1981; Tester 1990; Pagliai and Antisari 1993; Giusquiani et al., 1995; Aggelides and Londra 2000; Cheng et al., 2007; Nektarios et al., 2011). Improvements in the physical properties of soil with the addition of compost are most dramatic in soils with poor physical structure and a low level of soil organic matter such as soils reclaimed from mining and disturbed urban soil (Hortenstein and Rothwell, 1972; Scanlon et al., 1973; Landschoot and McNitt, 1994; Loschinkohl and Boehm, 2001; Cogger, 2005; Mandal et al., 2013). The growth and quality of turfgrass have also been improved with the addition of compost to soils possessing good physical properties and moderate amounts of organic matter (Hornick et al., 1984; Geisel et al., 2001; Linde and Hepner, 2005; Johnson et al., 2006b).

Stormwater runoff containing excessive concentrations of harmful pollutants is a contributor to nutrient impairment of surface waters in many urban areas (USEPA, 2006).

In a 2007 study on the health of Chesapeake Bay (Chesapeake Bay Program, 2008), stormwater was listed as the only pollution source sector that was growing within the watershed. Core cultivation is often cited as a management practice to reduce runoff from turfgrass areas (Rice and Horgan, 2011). It is also a recommended practice for the incorporating materials such and sand and compost into existing lawns to improve the physical properties of the soil. Johnson et al. (2006a) made three topdressing applications of composted manure at surface applications of 0, 0.33, 0.66 and 0.99 cm over a one year period, with core aeration taking place the day before each compost application. An incremental increase in soil water retention was seen with each rate of compost addition, however the amount of available soil water remained unchanged. Incremental declines in bulk density were also seen with the addition of compost, however only the 0.99 cm application rate had a bulk density that was significantly lower than soil not receiving compost. There was a trend suggesting that the saturated conductivity of the soil increased with the compost topdressing, however the trend was not statistically significant.

Compost topdressing and hollow tine cultivation are practices that are often performed once a year on home lawns. The potential benefits of these two practice to soil properties needs to be documented further before promoting the use of these two practices as way to reduce runoff from home lawns. Accordingly, the objective of this study is to determine the effect of once a year hollow tine cultivation, and of compost topdressing, on soil bulk density and soil infiltration. Compost applications consistent with recent restrictions placed on the use of compost as topdressing material are examined along with rates of application that have traditional been used by turfgrass practitioners.

5.1 Materials and Methods

5.1.1 Site Locations

Two field sites in Maryland were used to examine the effect of different nitrogen containing fertilizer materials and cultivation on soil bulk density. One of the two sites was also used to evaluate the effect of the various treatments on soil infiltration. The first site was a 4-year old stand of ‘Titanium’ tall fescue (*Festuca arundinacea* Schreb.) and ‘Raven’ Kentucky bluegrass (*Poa pratensis* L.) located at the University of Maryland Paint Branch Turfgrass Research Facility (PBTRF) in College Park, MD. The second site was 5-year old stand of ‘Confederate’ tall fescue located at the Glenstone Art Museum in Potomac, MD.

The taxonomic classification of soil at the PBTRF site was a Russett (fine-loamy, mixed semiactive, mesic Aquic Hapludults) and Christiana (fine, kaolinitic, mesic Aquic Hapludults) complex soil, while that at the Glenstone site was a fine-loamy, mixed, mesic Typic Hapludults. The soil at the Glenstone site had been subjected to extensive grading activity prior to turfgrass establishment. The grading altered the natural pedology of soil profile at this site. The test site at Glenstone was located on a hillside having a 5.6 % slope while that at the PBTRC was on land having a slope of less than 1% .

The study took place over three years, with the initial once a year fertilizer treatment being applied in October of 2011. The turf was mowed at least twice a month during the growing season at the PBTRF site with the clippings being returned. At Glenstone, the turf was mowed weekly throughout the growing season with the clippings returned. At both sites the turf was irrigated only when needed to prevent the turf from entering water stress induced dormancy and no pest control measures were utilized throughout the course of the study at either location.

5.1.2 Treatments

Fertilizer treatments consisted of no fertilizer, a sewage sludge based biosolids compost (Orgro, Veolia Water North America Baltimore City Composting Facility, Baltimore, MD), a yard trimmings compost (Leafgro, Maryland Environmental Services/Dickerson, Dickerson, MD), and the application of an enhanced efficiency synthetic nitrogen fertilizer (Signature 35-0-10, Loveland Products, Inc. Greeley, CO). Each material was applied by hand at the rate of 156 kg N ha^{-1} $year^{-1}$ in either late September or in October. Two additional fertilizer treatments were also included in the study and consisted of a once a year application of 1 cm of the biosolids and yard trimmings compost. These compost applications were made on the same day as the previously described fertilizer treatments. The amount of compost that was applied for the 156 kg N ha^{-1} $year^{-1}$ treatment was based on the analyses of the two composts conducted in advance of each yearly application. The results of the analyses revealed a surface application of 1 cm of the biosolids and yard trimmings compost applied, on average, 1108 and 584 kg N ha^{-1} yr^{-1}, respectively. Cultivation treatments consisted of 0, 1 or 2 passes of a Ryan GA 30 aerator (Ryan, Div. of Schiller Grounds Care, Inc., Johnson Creek, WI) equipped with 1.9 cm by 12.7 cm tines. The tines penetrated to a depth of 10 cm. The cultivation was imposed once per year immediately prior to spreading the compost or fertilizer. Plots receiving 156 kg N ha^{-1} yr^{-1} were subjected to one of the three cultivation treatments while plots receiving 1 cm of compost and the untreated control were not subjected to cultivation. Additional details on the soils at the two sites, and the study treatments can be found in Chapter 3 of this thesis.

5.1.3 Soil Bulk Density Measurement

Soil bulk density was measured at the end of third year of the study at both locations. Cores were extracted from the PBTRC site on 12, 14 and 15 Nov. 2014 and from Glenstone on 20 and 22 Nov. 2014. The cores were extracted from a depth of 0 to 6 cm after removing the top 1 cm of soil using a sod cutter. It was necessary to remove the sod prior to extracting the core because attempting to do this using a shovel caused the underlying root system of the turf to adversely affect the integrity of most of the cores that were extracted using this approach. In preliminary trials the bulk density of the cores extracted by removing the sod using a sod cutter were no different than the limited number of cores that were extracted without altering the surface of the core using a shovel. Brass cylinders 6.0 cm long and 5.4 cm in diameter were used to extract soil from beneath the cut sod. The cores were driven into the soil using a soil core sampler containing a cylindrical driving hammer (Model# 0200, Soilmoisture Corp. Santa Barbara, CA 93130). The cores were trimmed upon extraction to conform to the dimensions of brass core after which the base of the sample was covered with cheese cloth to prevent slippage of core simple within the brass core. After all samples had been extracted they were transported to lab and placed into an oven maintained at 105 °C for 24 hours. After drying the sample, the weight of the brass cylinder with dried soil inside (W_t) and the weight of clean brass cylinder (W_b) were recorded. The mass of dried soil sample was determined by subtracting W_b from W_t. Soil bulk density was calculated as the dry mass of soil in the core divided by volume of core.

5.1.4 Soil Infiltration

Assessment of the effect of compost and cultivation on soil infiltration was limited to the PBTRC site because the plot area at the Glenstone site has a 5.6 % slope. Preliminary infiltration measurements from select plots were collected in the fall of 2012 and measurements from all of plots at the PBTRC site were obtained in the summer of 2013 and 2014. Soil infiltration within the main plots at PBTRC was assessed by the constant head double ring method. This method is a proven and practical way to obtain representative infiltration rates for soils that have infiltration rates ranging from 22 to 225 mm h^{-1} (Gregory et al., 2005). Three measurements were collected from each plot using 152 mm diameter inner and 305 mm diameter outer rings (Turf-Tec, Tallahassee, Florida). Marriotte tubes attached to the inner and outer rings were used to maintain a constant head within each ring. Prior to initiating the collection of the infiltration data, each of the double rings was carefully filled with water and refilled as needed to maintain a ponded state for about 1.5 to 2 hours. This was done to reduce the time needed for infiltration within the ring to achieve steady state once data collection for the ring was initiated. Water entry into the soil was recorded at 30 minute intervals unless a shorter time interval was required due to the rapid entry of water into the soil. Water entry amounts were recorded until three consecutive readings had the same values. At that point in time it was assumed that steady state infiltration had been achieved. The infiltration rate was calculated using the following equation as recommended by Turf-Tec International:

$$\text{Infiltration Rate} = \frac{\Delta \mathrm{V1R}}{(\Delta \mathrm{A1R} \times \Delta\ \mathrm{t})}$$

where ΔV1R is volume of water used to maintain constant head in the inner ring during time interval, cm^3, ΔA1R is internal area of inner ring, cm^2, Δ t is time interval between successive readings, h.

Most infiltration measurements required several hours to reach steady state. As a result, soil infiltration was usually characterized at a rate of two plots per day. Infiltration rates were determined for all plots within one specific block of the experimental design before moving on to collect data from the next block within the experimental design. In 2013 and 2014 a total of 37 and 32 days elapsed between the time the first and last infiltration measurements were collected, respectively.

5.1.5 Statistical Analysis

Analysis of variance (ANOVA) procedures were used to evaluate the factorial arrangement of treatments within the randomized complete block design. Planned contrasts that compared the untreated control with all other non-cultivated nitrogen source treatments were also performed. The analysis was conducted by evaluating each site location and year of sampling as independent events. Data were analyzed using SAS Proc Mixed statistical software version 9.3 (SAS Institute, 2012). Treatment means for sources effects found to be different were separated at the $P \leq 0.05$ level using Tukey's honestly significantly different test. All infiltration data were log transformed to meet the assumption of normality of variance prior to conducting the ANOVA.

5.2 Results

5.2.1 Soil Bulk Density

Table 5.1 presents the soil bulk density within the plots at the end of third year. Plots topdressed with 156 kg N ha^{-1} yr^{-1} of the yard trimmings compost had a slightly lower bulk density at the PBTRF than the other two N source treatments, however there was no difference in the bulk density of the three 156 kg N ha^{-1} yr^{-1} N treatments at Glenstone. Cultivation performed once a year in the fall had no effect on soil bulk density at either site.

When the five non-cultivated treatments were compared with the control treatment, similar results were obtained at both sites with the application of 1 cm of the yard trimmings compost (Table 5.2). The use of this compost at the 1 cm rate, when compared to the control treatment, reduced the bulk density from 1.25 to 1.17 and from 1.37 to 1.21 at the PBTRF and Glenstone sites, respectively. The application of 1 cm of the biosolids compost significantly lowered soil bulk density compared with the control treatment, at Glenstone but not at PBTRF (Figure 5.1). None of three uncultivated 156 kg N ha^{-1} yr^{-1} N treatments had bulk densities that differed from the control treatment at either location.

Table 5.1. Effect of nitrogen fertilizer source and cultivation on soil bulk density at the Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

		Bulk density(g/cm^3)	
		PBTRF	Glenstone
N source (N) †			
Synthetic fertilizer		1.28a‡	1.36
Biosolids compost		1.26a	1.32
Yard trimmings compost		1.22b	1.30
Cultivation (C)§			
0		1.25	1.32
1		1.25	1.33
2		1.26	1.32
	ANOVA		
Source of variation	df	P	
N	2	0.0020	0.0935
C	2	0.7788	0.9057
N×C	4	0.2340	0.4043

† Nitrogen sources were applied once per year at rate of 156 kg N ha^{-1}.

‡ Within columns, means followed by the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

§ Number of hollow tine cultivation passes made over the plot in advance of applying the nitrogen source treatment.

Table 5.2. Comparison soil bulk density in the five non-cultivated nitrogen source treatments with that of non-cultivated control treatment at the Paint Branch Turfgrass Research Facility (PBTRF) and Glenstone.

		Bulk density(g/cm^3)	
		PBTRF	Glenstone
N Treatment			
Control (C)		1.25	1.37
Synthetic fertilizer (F)		1.27	1.35
Biosolids compost (B)		1.26	1.30
Yard trimmings compost (P)		1.23	1.31
1 cm Biosolids compost (BE)		1.23	1.18
1cm Yard trimmings compost (PE)		1.17	1.21
	ANOVA		
Contrast	df	P	
C VS F	10	0.4577	0.7657
C VS B	10	0.9001	0.2716
C VS P	10	0.3887	0.3503
C VS BE	10	0.3887	0.0071
C VS PE	10	0.0074	0.0183

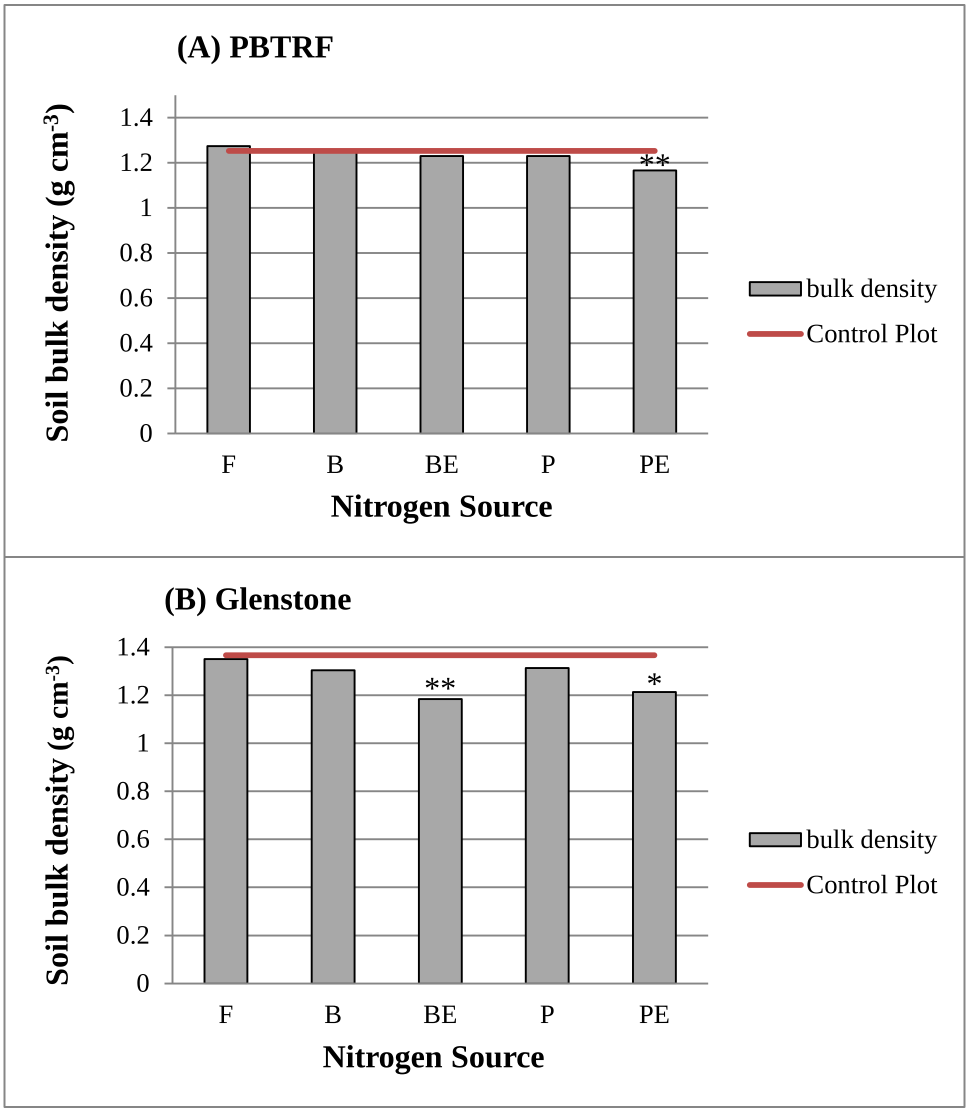


Figure 5.1. Comparison of non-cultivated nitrogen source treatments with the control treatment on soil bulk density at (A) the Paint Branch Turfgrass Research Facility and (B) Glenstone. Values are averaged across compost tea treatment.

C, control; F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro; BE, 1 cm biosolids compost Orgro; PE, 1 cm yard trimmings compost Leafgro.

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

5.2.2 Soil Infiltration at PBTRF

Application of 156 kg N ha^{-1} yr^{-1} of any of the three N sources had no statistically significant effect on soil infiltration rate in 2013 (Table 5.3). In 2014, soil infiltration was affected by nitrogen source with the effect being dependent on the number of hollow tine cultivation passes made over the plots (Figure 5.2). There were no differences among 156 kg N ha^{-1} yr^{-1} nitrogen source treatments without cultivation. Biosolids compost treated plots that received one pass of cultivation had a higher ($P \leq 0.05$) infiltration rate than one pass cultivated plots treated with yard trimmings compost. Similarly, the 156 kg N ha^{-1} yr^{-1} biosolids compost treated plots that received two passes of cultivation had a significantly higher soil infiltration rate than plots that were cultivated twice and received the synthetic fertilizer.

Table 5.3. Effect of nitrogen source and cultivation on soil infiltration at the Paint Branch Turfgrass Research Facility (PBTRF).

		Infiltration rate†	
		-----------cm/h-----------	
N source (N) ‡		2013	2014
Synthetic fertilizer		9.04	6.42
Biosolids compost		14.52	22.91
Yard trim compost		19.58	10.60
Cultivation (C)§			
0		10.34	8.28
1		15.95	16.59
2		16.85	15.07
		ANOVA	
Source of variation	df	P¶	
N	2	0.2453	0.0152
C	2	0.6569	0.2043
N×C	4	0.1385	0.0041

† Data shown are non-transformed treatment means.
‡ Nitrogen sources were applied once per year at rate of 156 kg N ha^{-1}.
§ Number of hollow tine cultivation passes made over the plot in advance of applying the nitrogen source treatment.
¶ P value after log_{10} transformation of soil infiltration data.

Comparisons of the soil infiltration in the non-cultivated control plots with non-cultivated plots of the five N source treatment are shown in Table 5.4. While there was a strong trend suggesting the application of 1 cm of compost improved soil infiltration, the only treatment found to be significantly different that non-cultivated control treatment was the application 156 kg N ha^{-1} yr^{-1} of yard trimmings compost in 2013.

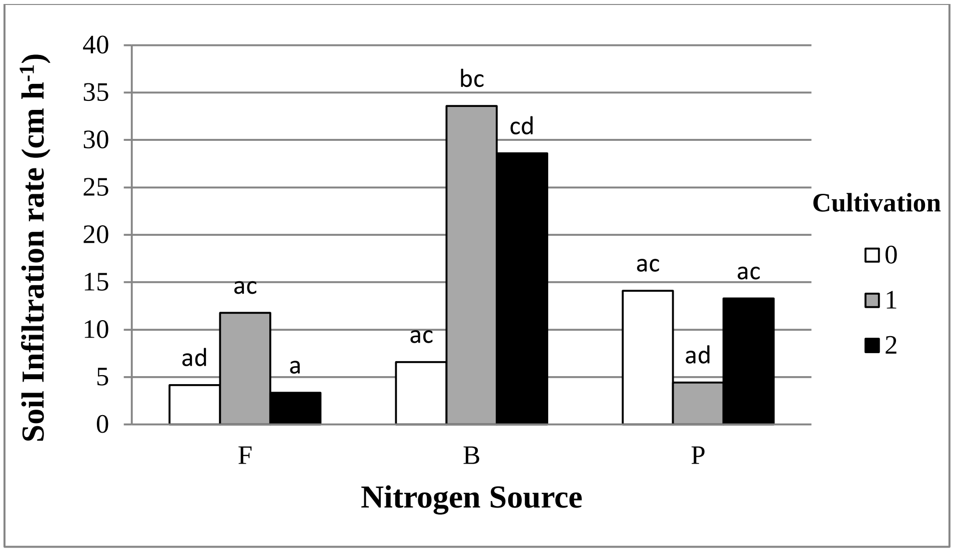


Figure 5.2 Effect of nitrogen source and cultivation treatments on soil infiltration at the Paint Branch Turfgrass Research Facility in summer, 2014.
Nitrogen source treatment designation are as follows: F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro. 0, no cultivation; 1, one pass of cultivation; 2, two passes of cultivation.
Histograms possessing different letter labels are significantly different from one another using Tukey's honestly significantly different test ($P \leq 0.05$).

Table 5.4. Comparison of non-cultivated nitrogen source treatments with control treatment for soil infiltration for plots located at the Paint Branch Turfgrass Research Facility (PBTRF).

		Infiltration rate†	
		----------------cm/h---------------	
N Treatment‡		2013	2014
Control (C)		1.29	4.81
Synthetic fertilizer (F)		7.77	4.14
Biosolids compost (B)		4.09	6.58
Yard trim compost (P)		19.17	14.11
1 cm Biosolids compost (BE)		10.45	13.10
1cm Yard trimmings compost (PE)		20.05	12.13
		ANOVA	
Contrast	df	P§	
C VS F	10	0.1488	0.9757
C VS B	10	0.3891	0.9288
C VS P	10	0.0379	0.1110
C VS BE	10	0.1108	0.4950
C VS PE	10	0.1257	0.2709

† Data shown are non-transformed treatment means.
‡ Nitrogen sources were applied once per year at rate of 156 kg N ha^{-1}.
§ P value after $\log_{10}$ transformation of soil infiltration data.

5.3 Discussion

Hollow tine cultivation is often performed when topdressing turfgrass with compost to aid in incorporating the compost into the soil (Agresource, 2013). A reduction in soil bulk density occurs when the volume of void space (i.e., porosity) increases and/or the mineral fraction of soil is diluted by the presence of organic matter (Hill and James, 1995; Cogger, 2005). Cultivation typically alters soil bulk density by increasing soil void space while the addition of organic matter lowers bulk density by reducing the portion of mineral particles present in the soil. An additional consequence of adding organic matter to soil is that it usually also increases the proportion void spaces present within the soil (Pagliai et al., 1981; Giusquiani et al., 1995). In general, the results presented in this study indicate that plots receiving higher amounts of organic matter had lower soil bulk densities. In the process of removing the dried cores from the brass cylinders, it was noticed that in the cores of both the cultivated and non-cultivated compost treated plots that there were channels present in the cores as well as evidence of compost derived organic matter throughout the cores. This suggests that earthworms and perhaps smaller macrofauna are of equal or perhaps greater importance than once a year cultivation in lowering the bulk density of soils receiving topdressing applications of compost. Additional support in this line of thinking can be found in Chapter 4 of this thesis where it was reported that cultivation had no effect on the amount of organic matter present in the top 10 cm of soil.

When organic matter additions alter soil properties that favorably effect soil bulk density, such as soil aggregation and porosity, the infiltration properties of the soil should be improved as well (Hill and James, 1995). There were some significant increases in soil infiltration rate caused by the compost treatments in this study, however the increases, with the exception of yard trimmings compost treatment, were inconsistent by treatment and year of measurement. The trend of increasing soil infiltration with the amount of compost topdressing material added to the turf observed in this study is similar to the results reported by Koadivko and Nelson (1979). In their study all compost treatments and cultivation regimes increased soil infiltration compared with untreated control, even though the differences were not statistically significant. Koadivko and Nelson (1979) applied digested sewage sludge to two silt loam soils at rates of 0, 22.4, 56 and 89.6 Mg ha^{-1} with or without incorporation by rototilling or disking, and found an increasing trend in infiltration rate as a result of sludge applications, but no statistical significance of infiltration data were seen 2 and 12 months after the application of compost. Their results were attributed to the inherent spatial heterogeneity that exists when measuring soil infiltration. But they pointed out the increasing trend in infiltration would be a result of a protection against soil surface sealing provided by sludge treatment and channels opened by earthworms in the soil. The effect of compost topdressing on soil infiltration rate may not be apparent over a short time period as many relevant effects like possible soil stabilization of aggregates, nutrient and organic matter enrichment change slowly. It should be noted that data analyses were performed by using logarithmic transformation via log10 (raw data) due to the lack normality of the non-transformed data. Plots topdressed with yard trimmings compost at 1 cm thickness had a higher average value of infiltration rate over three replications than a rate of 156 kg N ha^{-1} yr^{-1}, but logarithmic transformation gave one negative value for one replication of 1 cm yard trimmings compost (i.e. Log10(0.82) = -0.086), which resulted in an insignificant result.

5.4 Conclusions

Hollow tine cultivation is believed to be capable of reducing bulk density and enhancing hydraulic conductivity, but in this study cultivation performed once a year at the time of compost topdressing had no effect on soil bulk density and on soil infiltration, when measurements for the latter were collected from 9 to 10 months after incorporating compost into the soil.

The amount of compost required to favorably and consistently alter soil bulk density and soil infiltration rate, is more than a topdressing application of 156 kg N ha^{-1} yr^{-1}. Thus, when compost topdressing applications need to conform to the same annual N load restrictions as bagged fertilizers, the annual amount of compost applied to turf will be insufficient to increase the infiltration properties of the underlying soil. Conversely, the data presented herein suggest that applying 1 cm of compost to turf per year for three successive years will likely improve the infiltration properties of a soil not subjected to hollow tine cultivation. Use of enhanced efficiency nitrogenous fertilizer had no effect on soil infiltration or bulk density.

To better understand the implications of placing restrictions on the use of compost in turfgrass, longer term compost topdressing studies are needed. Given the need to identify best management practices that reduce stormwater losses from turf, future investigations should focus on evaluating soil properties that affect runoff as well as directly measuring runoff from turf area that have received compost topdressing applications for a number of years.

Appendix A

Table 1. Effect of nitrogen source, cultivation on tall fescue color at the Paint Branch Turfgrass Research Facility in 2012.

		Color (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)										
Synthetic fertilizer		7.1a†	7.2a	7.1	7.1	5.7	5.8	5.9	8.0a	7.6a
Biosolids compost		5.4b	7.2a	7.1	7.0	5.5	5.9	5.9	7.5b	5.9b
Yard trim compost		4.8c	6.8b	7.5	6.8	5.4	5.6	5.8	6.5c	4.6c
Cultivation (C)										
0		5.4a	6.9	7.2	6.9	5.4	5.7	5.7	7.3	6.0
1		5.9b	7.1	7.3	6.9	5.6	5.8	5.9	7.2	5.9
2		6.1b	7.2	7.2	7.1	5.6	5.8	6.0	7.5	6.2
		ANOVA								
Source of variation	df	P								
N	2	***	*	*	NS	NS	NS	NS	***	***
C	2	**	NS	NS	NS	NS	NS	*	NS	NS
N×C	4	NS‡	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).
‡ NS, nonsignificant.

Table 2. Effect of nitrogen source, cultivation and compost tea on tall fescue color at the Paint Branch Turfgrass Research Facility in 2013.

		Color (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)										
Synthetic fertilizer		5.3a	7.6	6.4	6.2	6.3a†	6.4	5.9a	7.4a	8.3a
Biosolids compost		3.8b	7.8	6.7	6.0	6.0b	6.4	5.8a	6.8b	7.3b
Yard trim compost		3.4c	7.7	6.7	6.1	5.8b	6.2	5.3b	6.6b	6.9c
Cultivation (C)										
0		3.9a	7.8	6.7	6.2	6.1	6.3	5.6	7.0	7.4a
1		4.2a	7.6	6.7	6.1	6.0	6.4	5.7	6.9	7.4a
2		4.5b	7.8	6.6	6.0	6.1	6.4	5.7	6.9	7.7b
Compost tea										
No		4.2	7.7	6.6	6.1	6.1	6.3	5.7	6.9	7.5
Yes		4.2	7.7	6.6	6.1	6.1	6.3	5.7	6.9	7.5
		ANOVA								
Source of variation	df	P								
N	2	***	NS	*	NS	***	NS	***	***	***
C	2	***	NS	NS	NS	NS	NS	NS	NS	**
N×C	4	*§	NS	NS	*¶	NS	NS	NS	NS	NS
T	1	NS‡	NS	NS	NS	NS	NS	NS	NS	NS
N×T	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
C×T	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C×T	4	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).
‡ NS, nonsignificant.
§ Nitrogen source by cultivation interaction is shown in Figure 3.2.
¶ Nitrogen source by cultivation interaction is shown in Figure 1. (Appendix B).

Table 3. Effect of nitrogen source, cultivation and compost tea on tall fescue color at the Paint Branch Turfgrass Research Facility in 2014.

		Color (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)										
Synthetic fertilizer		5.6a†	7.5a	6.8	6.0a	7.1	6.6	7.3	6.7	4.3a
Biosolids compost		4.2b	7.1b	6.9	6.3ab	7.2	6.4	7.3	6.5	4.7b
Yard trim compost		4.2b	7.0b	6.9	6.6b	7.1	6.5	7.3	6.3	4.8b
Cultivation (C)										
0		4.4a	7.2	6.8	6.2	7.1	6.3	7.2	6.4	4.5
1		4.6a	7.2	6.8	6.3	7.1	6.6	7.2	6.4	4.5
2		4.9b	7.2	6.9	6.4	7.2	6.4	7.4	6.6	4.8
Compost tea										
No		4.6	7.2	6.8	6.3	7.1	6.5	7.3	6.5	4.6
Yes		4.6	7.2	6.9	6.3	7.1	6.4	7.3	6.5	4.6
		ANOVA								
Source of variation	df	P								
N	2	***	**	NS	*	NS	NS	NS	NS	*
C	2	***	NS	NS	NS	NS	NS	NS	NS	NS
N×C	4	*§	NS	NS	NS	NS	NS	NS	NS	NS
T	1	NS‡	NS	NS	NS	NS	NS	NS	NS	NS
N×T	2	NS	NS	NS	**¶	NS	*¶	*¶	NS	NS
C×T	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C×T	4	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test (P ≤ 0.05).
‡ NS, nonsignificant.
§ Nitrogen source by cultivation interaction is shown in Figure 3.2.
¶ Nitrogen source by compost tea interactions for various dates are shown in Figure 3.3.

Table 4. Comparison of non-cultivated nitrogen source treatments with control on tall fescue color at the Paint Branch Turfgrass Research Facility in 2012.

		Color (1-9)								
		Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N Treatment										
Control (C)		4.3	6.3	7.0	6.7	5.5	5.2	5.6	5.7	4.0
Synthetic fertilizer (F)		6.8	7.0	7.2	7.0	5.7	5.7	5.8	8.0	7.7
Biosolids compost (B)		4.8	7.0	7.0	7.0	5.3	5.8	5.7	7.3	5.7
Yard trim compost (P)		4.5	6.7	7.3	6.8	5.2	5.5	5.7	6.5	4.7
1 cm Biosolids compost (BE)		8.3	7.0	7.5	7.5	6.0	6.0	5.9	8.0	8.0
1cm Yard trim compost (PE)		5.2	6.8	7.3	6.8	5.5	5.2	5.7	6.7	5.7
		Contrast								
Contrast	df					P				
C VS F	10	***	*	NS	NS	NS	NS	NS	***	***
C VS B	10	NS†	*	NS	NS	NS	*	NS	***	**
C VS P	10	NS	NS	NS	NS	NS	NS	NS	*	NS
C VS BE	10	***	*	NS	**	NS	**	NS	***	***
C VS PE	10	*	NS	NS	NS	NS	NS	NS	*	**

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† NS, nonsignificant.

Table 5. Comparison of non-cultivated nitrogen source treatments with control on tall fescue color at the Paint Branch Turfgrass Research Facility in 2013.

		Color (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N Treatment										
Control (C)		2.7	7.3	6.5	6.0	5.8	6.3	5.5	7.0	6.7
Synthetic fertilizer (F)		4.8	7.7	6.5	6.3	6.3	6.2	5.7	7.5	8.2
Biosolids compost (B)		3.3	7.8	6.7	6.2	6.0	6.3	6.0	6.7	7.2
Yard trim compost (P)		3.5	7.8	6.8	6.2	6.0	6.3	5.2	6.8	6.8
1 cm Biosolids compost (BE)		6.9	7.3	6.3	6.8	6.5	7.5	6.8	7.2	8.3
1cm Yard trim compost (PE)		4.3	7.7	6.8	6.2	6.2	6.5	6.0	6.7	7.3
		Contrast								
Contrast	df	P								
C VS F	10	***	NS	NS	NS	NS	NS	NS	NS	***
C VS B	10	NS†	NS	NS	NS	NS	NS	NS	NS	NS
C VS P	10	*	NS	NS	NS	NS	NS	NS	NS	NS
C VS BE	10	***	NS	NS	**	*	*	*	NS	***
C VS PE	10	***	NS	NS	NS	NS	NS	NS	NS	*

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† NS, nonsignificant.

Table 6. Comparison of non-cultivated nitrogen source treatments with control on tall fescue color at the Paint Branch Turfgrass Research Facility in 2014.

		Color (1-9)								
		Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N Treatment										
Control (C)		4.2	6.7	6.7	6.5	7.2	6.5	7.3	6.3	4.7
Synthetic fertilizer (F)		5.0	7.7	6.7	5.8	6.8	6.4	7.1	6.7	4.3
Biosolids compost (B)		4.0	6.8	6.9	6.1	7.4	6.3	7.3	6.7	4.8
Yard trim compost (P)		4.2	7.0	6.9	6.7	7.1	6.3	7.3	6.0	4.6
1 cm Biosolids compost (BE)		6.8	7.7	6.9	6.6	7.7	6.7	7.9	7.3	5.1
1cm Yard trim compost (PE)		4.7	7.0	6.8	6.4	7.1	6.6	7.5	6.6	4.9
		Contrast								
Contrast	df	P								
C VS F	10	*	**	NS	NS	NS	NS	NS	NS	NS
C VS B	10	NS†	NS	NS	NS	NS	NS	NS	NS	NS
C VS P	10	NS	NS	NS	NS	NS	NS	NS	NS	NS
C VS BE	10	***	**	NS	NS	NS	NS	*	*	NS
C VS PE	10	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† NS, nonsignificant.

Table 7. Effect of nitrogen source, cultivation on tall fescue color at Glenstone in 2012.

		Color (1-9)							
		Mar.	Apr.	May.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)									
Synthetic fertilizer		7.6a†	7.2a	7.3a	5.2	5.5	6.1	8.0a	7.3
Biosolids compost		5.4b	6.2b	6.6b	5.6	5.6	6.5	6.7b	6.9
Yard trim compost		5.2b	5.6b	6.1b	5.6	5.4	6.0	5.9b	6.7
Cultivation (C)									
0		5.6a	6.4	6.3	5.7	5.6	6.3	6.9	6.8
1		6.2b	6.2	6.8	5.3	5.4	6.1	6.9	7.1
2		6.4b	6.4	6.8	5.3	5.5	6.2	6.8	7.0
		ANOVA							
Source of variation	df	P							
N	2	***	**	***	NS	NS	NS	***	NS
C	2	**	NS	NS	NS	NS	NS	NS	NS
N×C	4	NS‡	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

‡ NS, nonsignificant.

Table 8. Effect of nitrogen source, cultivation and compost tea on tall fescue color at Glenstone in 2013.

		Color (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)										
Synthetic fertilizer		5.1a	7.4a	7.6	6.3	6.1	7.3	7.6	7.7a†	7.7a
Biosolids compost		4.4b	7.2ab	7.4	6.5	6.3	7.4	7.6	7.6b	7.2b
Yard trim compost		4.5b	7.1b	7.5	6.6	6.2	7.1	7.4	7.6b	7.2b
Cultivation (C)										
0		4.1a	7.4	7.5	6.3	6.3	7.3	7.5	7.7a	7.3
1		4.8b	7.2	7.5	6.5	6.2	7.3	7.6	7.5b	7.4
2		5.1b	7.1	7.5	6.6	6.1	7.2	7.5	7.6ab	7.4
Compost tea										
No		4.7	7.2	7.5	6.5	6.2	7.2	7.5	7.6	7.4
Yes		4.6	7.2	7.5	6.5	6.2	7.2	7.5	7.6	7.4
		ANOVA								
Source of variation	df	P								
N	2	**	*	NS	NS	NS	NS	NS	*	***
C	2	**	NS	NS	NS	NS	NS	NS	**	NS
N×C	4	NS‡	*§	NS	NS	NS	NS	**§	NS	NS
T	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×T	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
C×T	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C×T	4	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

‡ NS, nonsignificant.

§ Nitrogen source by cultivation interactions for various dates are shown in Figure 2.and Figure 3. (Appendix B).

Table 9. Effect of nitrogen source, cultivation and compost tea on tall fescue color at Glenstone in 2014.

		Color (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)										
Synthetic fertilizer		6.4	7.8a	7.4a	5.2	3.2	7.5	7.4	7.8	8.0
Biosolids compost		6.2	7.4b	7.0b	5.4	3.2	7.7	7.3	7.6	7.8
Yard trim compost		6.1	7.3b	7.0b	5.5	3.3	7.5	7.2	7.8	7.9
Cultivation (C)										
0		6.0a	7.4	7.2	5.4	3.1	7.6	7.2	7.6	7.9
1		6.2ab	7.6	7.1	5.3	3.3	7.6	7.3	7.8	7.9
2		6.4b	7.5	7.1	5.4	3.3	7.6	7.4	7.8	7.8
Compost tea										
No		6.2	7.5	7.1	5.4	3.2	7.6	7.3	7.7	7.8
Yes		6.2	7.5	7.1	5.3	3.2	7.6	7.3	7.7	7.9
		ANOVA								
Source of variation	df	P								
N	2	NS‡	***	***	NS	NS	NS	NS	NS	NS
C	2	*	NS	NS	NS	NS	NS	NS	NS	NS
N×C	4	NS	NS	NS	NS	NS	NS	NS	NS	NS
T	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×T	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
C×T	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C×T	4	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).
‡ NS, nonsignificant.

Table 10. Comparison of non-cultivated nitrogen source treatments with control on tall fescue color at Glenstone in 2012.

		Color (1-9)							
		Mar.	Apr.	May.	Jul.	Aug.	Sep.	Oct.	Nov.
N Treatment									
Control (C)		4.0	5.7	5.5	4.3	5.2	6.1	5.3	6.2
Synthetic fertilizer (F)		7.3	7.2	7.0	5.7	5.2	5.6	8.0	7.2
Biosolids compost (B)		5.0	6.2	6.2	5.7	6.0	7.0	6.7	6.7
Yard trim compost (P)		4.5	5.8	5.8	5.7	5.5	6.3	6.0	6.5
1 cm Biosolids compost (BE)		6.8	6.8	6.5	6.0	5.0	6.3	8.0	6.7
1cm Yard trim compost (PE)		4.7	4.7	5.2	4.5	5.5	6.0	6.7	6.8
		Contrast							
Contrast	df	P							
C VS F	10	***	NS	**	*	NS	NS	***	NS
C VS B	10	NS†	NS	NS	*	NS	NS	*	NS
C VS P	10	NS	NS	NS	*	NS	NS	NS	NS
C VS BE	10	***	NS	NS	**	NS	NS	***	NS
C VS PE	10	NS	NS	NS	NS	NS	NS	*	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† NS, nonsignificant.

Table 11. Comparison of non-cultivated nitrogen source treatments with control on tall fescue color at Glenstone in 2013.

		Color (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N Treatment										
Control (C)		4.3	7.2	7.3	6.5	6.0	7.0	7.5	7.5	7.0
Synthetic fertilizer (F)		4.3	7.7	7.5	6.2	6.2	7.2	7.3	7.8	7.5
Biosolids compost (B)		4.2	7.2	7.5	6.3	6.5	7.6	7.7	7.7	7.2
Yard trim compost (P)		3.9	7.3	7.4	6.5	6.2	7.1	7.5	7.7	7.2
1 cm Biosolids compost (BE)		5.8	7.0	7.7	6.4	6.5	7.4	7.8	7.7	7.5
1cm Yard trim compost (PE)		4.8	6.8	7.5	6.3	6.0	7.0	7.5	7.7	7.2
		Contrast								
Contrast	df	P								
C VS F	10	NS†	NS	NS	NS	NS	NS	NS	NS	*
C VS B	10	NS	NS	NS	NS	**	*	NS	NS	NS
C VS P	10	NS	NS	NS	NS	NS	NS	NS	NS	NS
C VS BE	10	**	NS	NS	NS	**	NS	NS	NS	*
C VS PE	10	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

†NS, nonsignificant.

Table 12. Comparison of non-cultivated nitrogen source treatments with control on tall fescue color at Glenstone in 2014.

		Color (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N Treatment										
Control (C)		5.5	7.3	7.1	5.2	2.4	7.3	7.3	7.7	8.0
Synthetic fertilizer (F)		6.5	7.6	7.5	5.4	3.1	7.4	7.3	7.7	8.0
Biosolids compost (B)		5.8	7.3	7.0	5.4	3.3	7.8	7.3	7.5	7.8
Yard trim compost (P)		5.7	7.3	7.0	5.5	3.0	7.5	7.0	7.6	7.8
1 cm Biosolids compost (BE)		6.8	7.7	7.2	5.3	2.9	7.4	7.3	7.8	7.8
1cm Yard trim compost (PE)		6.5	7.5	7.2	5.2	3.3	7.7	7.3	7.8	8.0
		Contrast								
Contrast	df	P								
C VS F	10	**	NS	*	NS	NS	NS	NS	NS	NS
C VS B	10	NS†	NS	NS	NS	NS	*	NS	NS	NS
C VS P	10	NS	NS	NS	NS	NS	NS	NS	NS	NS
C VS BE	10	***	NS	NS	NS	NS	NS	NS	NS	NS
C VS PE	10	**	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† NS, nonsignificant.

Table 13. Effect of nitrogen source, cultivation on tall fescue quality at the Paint Branch Turfgrass Research Facility in 2012.

		Quality (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)										
Synthetic fertilizer		6.6a†	7.4	7.4	7.2	5.9a	5.2a	5.4a	7.1a	7.4a
Biosolids compost		5.0b	5.6	7.1	6.9	5.5ab	4.8b	4.6b	6.0b	5.8b
Yard trim compost		4.1c	4.4	6.7	6.6	5.3b	4.7b	4.6b	4.6c	4.3c
Cultivation (C)										
0		5.7a	6.4	7.3	7.0	5.3a	4.6a	4.7	5.8	5.7
1		5.3ab	5.8	6.9	6.9	5.8b	5.1b	5.1	6.1	5.9
2		4.8b	5.2	6.9	6.8	5.6ab	5.1b	4.9	5.8	5.8
		ANOVA								
Source of variation	df	P								
N	2	***	***	NS	NS	**	**	**	***	***
C	2	**	***	NS	NS	*	**	NS	NS	NS
N×C	4	NS‡	*§	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test (P ≤ 0.05).

‡ NS, nonsignificant.

§ Nitrogen source by cultivation interaction is shown in Figure 4. (Appendix B).

Table 14. Effect of nitrogen source, cultivation and compost tea on tall fescue quality at the Paint Branch Turfgrass Research Facility in 2013.

		Quality (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)										
Synthetic fertilizer		4.8a†	7.3a	7.6a	6.8a	5.8	4.1a	3.8a	5.6a	5.6a
Biosolids compost		3.7b	4.5b	6.1b	5.2b	4.0	3.2b	2.5b	3.6b	3.3b
Yard trim compost		3.3b	3.6c	4.5c	4.6b	3.5	3.3ab	2.2b	2.9b	2.7b
Cultivation (C)										
0		3.9	5.3	5.9	5.7	4.4	3.5	3.0	4.3	4.1
1		4.0	5.2	6.4	5.8	4.6	3.6	2.8	4.2	3.8
2		3.9	4.9	5.8	5.1	4.3	3.5	2.8	3.7	3.6
Compost tea										
No		3.9	5.1	6.0a	5.5	4.4	3.5	2.8	4.0	3.8
Yes		3.9	5.2	6.1b	5.6	4.5	3.6	2.9	4.1	3.9
		ANOVA								
Source of variation	df	P								
N	2	***	***	***	***	***	*	***	***	***
C	2	NS‡	NS	NS	NS	NS	NS	NS	NS	NS
N×C	4	NS	NS	NS	NS	NS	NS	NS	NS	NS
T	1	NS	NS	*	NS	NS	NS	NS	NS	NS
N×T	2	NS	NS	NS	NS	**§	NS	NS	NS	NS
C×T	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C×T	4	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).
‡ NS, nonsignificant.
§ Nitrogen source by compost tea interaction is shown in Figure 5. (Appendix B).

Table 15. Effect of nitrogen source, cultivation and compost tea on tall fescue quality at the Paint Branch Turfgrass Research Facility in 2014.

		Quality (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)										
Synthetic fertilizer		4.9a†	4.6a	4.6a	2.8a	4.3a	3.8a	4.1a	4.7a	3.3a
Biosolids compost		3.2b	2.8b	3.2b	2.6ab	2.7b	2.3b	2.3b	3.0b	2.8b
Yard trim compost		2.8b	2.7b	3.4b	2.3b	2.7b	2.3b	2.8b	3.4b	2.7b
Cultivation (C)										
0		3.8	3.4	3.9	2.5	3.3	2.8	3.2	3.8	2.8
1		3.6	3.3	3.8	2.7	3.4	2.8	3.2	3.8	2.9
2		3.6	3.4	3.5	2.6	3.1	2.7	2.8	3.6	3.0
Compost tea										
No		3.6	3.4	3.7	2.6	3.2	2.8	2.9	3.7	2.9
Yes		3.6	3.4	3.7	2.6	3.3	2.8	3.1	3.8	2.9
		ANOVA								
Source of variation	df	P								
N	2	***	***	***	*	***	***	***	***	**
C	2	NS‡	NS	NS	NS	NS	NS	NS	NS	NS
N×C	4	NS	NS	NS	NS	NS	NS	NS	NS	NS
T	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×T	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
C×T	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C×T	4	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

‡ NS, nonsignificant.

Table 16. Comparison of non-cultivated nitrogen source treatments with control on tall fescue quality at the Paint Branch Turfgrass Research Facility in 2012.

		Quality (1-9)								
N Treatment		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Control (C)		4.7	5.0	6.5	6.2	4.8	4.2	4.2	3.5	3.5
Synthetic fertilizer (F)		6.7	7.7	7.5	7.5	5.7	4.7	5.0	7.2	7.3
Biosolids compost (B)		5.5	6.5	7.3	7.0	5.2	4.5	4.3	5.7	5.5
Yard trim compost (P)		4.8	5.2	7.0	6.5	5.0	4.5	4.8	4.7	4.3
1 cm Biosolids compost (BE)		7.0	7.2	7.7	7.7	6.0	5.2	5.6	6.8	7.2
1cm Yard trim compost (PE)		4.7	5.0	6.8	6.7	5.2	4.3	4.4	4.8	5.0
		Contrast								
Contrast	df	P								
C VS F	10	***	***	*	*	*	*	NS	***	***
C VS B	10	*	**	*	NS	NS	NS	NS	***	***
C VS P	10	NS†	NS	NS	NS	NS	NS	NS	*	NS
C VS BE	10	***	***	**	**	**	***	**	***	***
C VS PE	10	NS	NS	NS	NS	NS	NS	NS	*	**

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† NS, nonsignificant.

Table 17. Comparison of non-cultivated nitrogen source treatments with control on tall fescue quality at the Paint Branch Turfgrass Research Facility in 2013.

		Quality (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N Treatment										
Control (C)		2.8	3.0	4.1	4.5	3.3	2.7	2.0	2.8	2.3
Synthetic fertilizer (F)		4.8	7.7	7.5	7.1	5.8	4.4	4.0	6.1	6.3
Biosolids compost (B)		3.8	4.4	6.0	5.6	4.2	2.9	2.8	4.1	3.3
Yard trim compost (P)		3.2	3.8	4.3	4.4	3.3	3.1	2.2	2.8	2.6
1 cm Biosolids compost (BE)		6.2	7.3	7.7	7.1	6.8	5.0	5.4	5.8	6.2
1cm Yard trim compost (PE)		3.7	3.8	5.5	5.5	4.4	3.1	2.7	3.5	3.4
		Contrast								
Contrast	df	P								
C VS F	10	***	***	***	**	*	**	***	***	***
C VS B	10	NS†	***	*	NS	NS	NS	NS	NS	*
C VS P	10	NS	*	NS	NS	NS	NS	NS	NS	NS
C VS BE	10	***	***	***	**	**	***	***	**	***
C VS PE	10	NS	*	NS	NS	NS	NS	NS	NS	*

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† NS, nonsignificant.

Table 18. Comparison of non-cultivated nitrogen source treatments with control on tall fescue quality at the Paint Branch Turfgrass Research Facility in 2014.

		Quality (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N Treatment										
Control (C)		2.7	2.3	2.3	2.3	2.6	2.1	2.5	2.6	3.1
Synthetic fertilizer (F)		5.2	4.5	4.8	2.8	4.3	3.6	4.3	5.0	3.3
Biosolids compost (B)		3.3	3.2	3.3	2.6	2.8	2.5	2.6	3.2	2.6
Yard trim compost (P)		2.8	2.5	3.7	2.2	2.9	2.3	2.8	3.1	2.7
1 cm Biosolids compost (BE)		5.8	5.6	5.8	3.2	5.8	4.4	4.8	6.2	4.2
1cm Yard trim compost (PE)		3.0	3.0	3.4	2.5	3.2	3.0	3.5	4.3	3.5
		Contrast								
Contrast	df	P								
C VS F	10	***	***	***	NS	**	**	*	**	NS
C VS B	10	NS†	NS	*	NS	NS	NS	NS	NS	NS
C VS P	10	NS	NS	*	NS	NS	NS	NS	NS	NS
C VS BE	10	***	***	***	**	***	***	**	***	*
C VS PE	10	NS	NS	*	NS	NS	NS	NS	*	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† NS, nonsignificant.

Table 19. Effect of nitrogen source, cultivation on tall fescue quality at Glenstone in 2012.

		Quality (1-9)							
		Mar.	Apr.	May.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)									
Synthetic fertilizer		5.5	6.8a	7.1a	5.6	5.6	5.6	7.6a	6.9a
Biosolids compost		4.9	5.3b	5.4b	5.4	5.6	5.1	6.3b	5.9b
Yard trim compost		4.8	5.0b	5.1b	5.1	4.6	5.1	4.3c	5.1b
Cultivation (C)									
0		5.8a†	6.4a	6.3	5.7	5.6	5.4	6.6	6.6a
1		4.8ab	5.4b	5.7	5.2	5.0	5.3	6.0	5.8ab
2		4.6b	5.3b	5.7	5.2	5.1	5.1	5.6	5.6b
		ANOVA							
Source of variation	df	P							
N	2	NS‡	***	***	NS	NS	NS	***	***
C	2	*	*	NS	NS	NS	NS	NS	*
N×C	4	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test (P ≤ 0.05).

‡ NS, nonsignificant.

Table 20. Effect of nitrogen source, cultivation and compost tea on tall fescue quality at Glenstone in 2013.

		Quality (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)										
Synthetic fertilizer		4.9a†	7.2a	6.9a	4.7a	5.4	5.1	6.4	6.8	6.9
Biosolids compost		4.0b	6.5ab	6.1ab	4.1ab	4.9	4.6	5.7	6.5	6.3
Yard trim compost		3.7bc	5.7b	5.2b	3.2b	4.9	4.3	5.6	6.1	6.0
Cultivation (C)										
0		4.3	6.7	6.3	4.3	5.6	5.1	6.4	6.6	6.6
1		4.1	6.2	6.0	3.9	4.7	4.7	5.9	6.7	6.4
2		4.3	6.4	5.9	3.9	4.9	4.3	5.3	6.1	6.1
Compost tea										
No		4.2	6.5	6.1	4.0	5.0	4.7	5.9	6.4a	6.4
Yes		4.2	6.4	6.0	4.0	5.1	4.7	5.9	6.5b	6.4
		ANOVA								
Source of variation	df	P								
N	2	***	**	*	*	NS	NS	NS	NS	NS
C	2	NS‡	NS	NS	NS	NS	NS	NS	NS	NS
N×C	4	NS	NS	NS	NS	NS	NS	NS	NS	NS
T	1	NS	NS	NS	NS	NS	NS	NS	*	NS
N×T	2	NS	NS	NS	NS	NS	NS	NS	*§	NS
C×T	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C×T	4	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).
‡ NS, nonsignificant.
§ Nitrogen source by compost tea interaction is shown in Figure 3.7.

Table 21. Effect of nitrogen source, cultivation and compost tea on tall fescue quality at Glenstone in 2014.

		Quality (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)										
Synthetic fertilizer		5.3	6.6	6.4	3.9	2.8	6.6	6.0	6.7	7.3
Biosolids compost		5.4	6.1	5.5	3.8	2.9	5.9	5.1	6.1	6.9
Yard trim compost		5.1	5.7	5.4	3.5	2.3	5.6	4.8	6.2	6.6
Cultivation (C)										
0		5.6	6.5	6.1	3.8	2.6	6.3	5.5	6.6	6.9
1		5.2	6.2	5.8	3.7	2.7	6.2	5.3	6.5	7.1
2		5.0	5.7	5.6	3.8	2.7	5.6	5.1	5.9	6.8
Compost tea										
No		5.3	6.1	5.8	3.8	2.6	6.1	5.3	6.3	6.9
Yes		5.3	6.1	5.8	3.7	2.7	5.9	5.3	6.3	6.9
		ANOVA								
Source of variation	df	P								
N	2	NS‡	NS	NS	NS	NS	NS	NS	NS	NS
C	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C	4	*§	NS	NS	NS	NS	NS	NS	NS	NS
T	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×T	2	NS	*¶	NS	NS	NS	NS	NS	NS	NS
C×T	2	NS	*#	NS	NS	NS	NS	NS	NS	NS
N×C×T	4	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).
‡ NS, nonsignificant.
§ Nitrogen source by cultivation interaction is shown in Figure 6. (Appendix B).
¶ Nitrogen source by compost tea interaction is shown in Figure 3.7.
# Cultivation by compost tea interaction is shown in Figure 7. (Appendix B).

Table 22. Comparison of non-cultivated nitrogen source treatments with control on tall fescue quality at Glenstone in 2012.

		Quality (1-9)							
		Mar.	Apr.	May.	Jul.	Aug.	Sep.	Oct.	Nov.
N Treatment									
Control (C)		5.2	6.0	5.0	4.8	5.0	5.4	4.0	4.3
Synthetic fertilizer (F)		6.5	7.2	7.0	5.7	5.5	5.2	7.5	7.0
Biosolids compost (B)		5.2	6.2	6.0	5.7	6.0	5.3	7.2	6.5
Yard trim compost (P)		5.7	5.8	5.8	5.7	5.3	5.7	5.0	6.2
1 cm Biosolids compost (BE)		6.3	6.8	6.7	6.2	6.5	5.9	8.0	6.5
1cm Yard trim compost (PE)		5.2	4.5	5.5	5.2	5.3	5.3	5.5	5.5
		Contrast							
Contrast	df	P							
C VS F	10	*	NS	**	NS	NS	NS	***	**
C VS B	10	NS†	NS	NS	NS	NS	NS	***	*
C VS P	10	NS	NS	NS	NS	NS	NS	NS	*
C VS BE	10	*	NS	*	*	NS	NS	***	*
C VS PE	10	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† NS, nonsignificant.

Table 23. Comparison of non-cultivated nitrogen source treatments with control on tall fescue quality at Glenstone in 2013.

		Quality (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N Treatment										
Control (C)		3.8	5.8	5.1	3.4	4.9	4.3	5.0	6.3	5.3
Synthetic fertilizer (F)		4.8	7.1	6.6	4.3	5.9	4.8	5.8	6.2	6.7
Biosolids compost (B)		4.3	6.7	6.5	4.8	5.2	5.5	6.5	6.8	6.7
Yard trim compost (P)		3.9	6.4	5.9	3.6	5.6	5.0	6.8	6.8	6.6
1 cm Biosolids compost (BE)		5.4	7.2	7.3	5.6	6.2	5.5	6.8	7.7	7.3
1cm Yard trim compost (PE)		4.3	6.5	6.2	4.0	5.7	5.0	5.5	6.3	6.5
		Contrast								
Contrast	df	P								
C VS F	10	NS†	NS	*	NS	NS	NS	NS	NS	NS
C VS B	10	NS	NS	NS	NS	NS	*	NS	NS	NS
C VS P	10	NS	NS	NS	NS	NS	NS	*	NS	NS
C VS BE	10	*	NS	**	*	*	*	*	NS	*
C VS PE	10	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† NS, nonsignificant.

Table 24. Comparison of non-cultivated nitrogen source treatments with control on tall fescue quality at Glenstone in 2014.

		Quality (1-9)								
		Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N Treatment										
Control (C)		4.8	5.8	5.1	2.7	1.8	5.3	4.4	5.8	6.2
Synthetic fertilizer (F)		5.2	6.3	6.0	3.4	2.3	6.0	5.7	6.3	7.2
Biosolids compost (B)		6.2	6.5	5.8	4.3	3.4	6.4	5.4	6.7	6.8
Yard trim compost (P)		5.5	6.8	6.6	3.7	2.2	6.5	5.3	6.8	6.8
1 cm Biosolids compost (BE)		5.3	6.8	7.2	4.4	2.6	6.6	6.2	7.4	7.3
1cm Yard trim compost (PE)		4.8	5.8	6.0	3.8	2.7	5.3	5.3	6.5	6.9
		Contrast								
Contrast	df	P								
C VS F	10	NS†	NS	NS	NS	NS	NS	NS	NS	NS
C VS B	10	*	NS	NS	*	*	NS	NS	NS	NS
C VS P	10	NS	NS	NS	NS	NS	NS	NS	NS	NS
C VS BE	10	NS	NS	*	*	NS	NS	NS	NS	NS
C VS PE	10	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† NS, nonsignificant.

Table 25. Effect of nitrogen source, cultivation and compost tea on weed encroachment at the Paint Branch Turfgrass Research Facility.

		Weed Encroachment (0-100%)										
		2012	2013		2014							
		Jul.	Oct.	Nov.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)												
Synthetic fertilizer		1.7a†	4.6a	2.8	19.6	2.8a	3.2	6.9a	14.1a	22.7a	7.7	1.9a
Biosolids compost		3.5ab	18.2b	5.2	34.4	13.6b	13.3	26.4b	47.9b	53.3b	23.6	6.9b
Yard trim compost		5.4b	28.0c	8.3	30.9	18.6b	17.4	26.9b	46.4b	43.3b	19.9	5.5ab
Cultivation (C)												
0		5.4a	16.7	3.8	28.7	7.4	10.1	17.3	35.4	35.9	14.4	4.6
1		2.6b	16.2	5.9	26.4	13.8	11.3	20.4	35.4	41.2	18.8	4.2
2		2.6b	17.9	6.5	29.8	13.8	12.6	22.5	37.5	42.2	18.0	5.5
Compost tea												
No		N/A§	16.8	6.6a	28.5	13.0	12.2	22.4	37.2	42.6a	20.1	5.8
Yes		N/A	17.0	4.2b	28.1	10.3	10.4	17.7	35.0	37.0b	14.0	3.8
		ANOVA										
Source of variation	df	P										
N	2	*	***	NS	NS	**	**	***	***	***	**	*
C	2	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C	4	NS‡	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
T	1	N/A	NS	*	NS	NS	NS	NS	NS	*	NS	NS
N×T	2	N/A	NS	NS	NS	NS	*¶	NS	NS	NS	*¶	NS
C×T	2	N/A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C×T	4	N/A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).
‡ NS, nonsignificant.
§ N/A, not applicable
¶ Nitrogen source by compost tea interactions for various dates are shown in Figure 3.9.

Table 26. Effect of nitrogen source, cultivation and compost tea on weed encroachment at Glenstone.

	Weed Encroachment (0-100%)												
	2012		2013			2014							
	Sep.	Oct.	May.	Oct.	Nov.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)													
Synthetic fertilizer	3.2	6.0a†	28.0	3.0	1.8	3.3	2.3	1.7	1.5	2.2	1.9	2.6	0.4
Biosolids compost	4.4	15.6ab	13.0	6.0	5.6	7.2	6.2	5.5	2.7	7.2	7.0	4.7	2.1
Yard trim compost	6.2	25.0b	6.3	11.7	9.7	10.2	10.0	9.4	9.1	9.8	8.3	4.5	2.1
Cultivation (C)													
0	3.6	11.7	10.6	5.7	4.2	4.8	4.0	2.4	1.8	3.2	2.9	3.4	1.3
1	5.0	18.2	18.1	7.9	6.9	2.4	6.1	7.2	5.8	7.0	5.6	3.8	1.0
2	5.3	16.7	18.7	7.1	6.1	13.6	8.3	7.0	5.8	9.1	8.8	4.7	2.2
Compost tea													
No	N/A§	N/A	N/A	6.9	5.3	6.2	6.0	5.3	4.0	5.5	5.4	3.2	1.2
Yes	N/A	N/A	N/A	6.9	6.1	7.6	6.2	5.7	4.9	7.3	6.1	4.7	1.8

ANOVA

Source of variation	df	P												
N	2	NS‡	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
T	1	N/A	N/A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×T	2	N/A	N/A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C×T	2	N/A	N/A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N×C×T	4	N/A	N/A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† Within columns, means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).
‡ NS, nonsignificant.
§ N/A, not applicable

Table 27. Comparison of non-cultivated nitrogen source treatments with control on weed encroachment at the Paint Branch Turfgrass Research Facility.

	Weed Encroachment (0-100%)										
	2012	2013		2014							
N Treatment	Jul.	Oct.	Nov.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Control (C)	8.0	29.0	22.5	41.7	36.7	43.3	39.2	54.2	52.5	35.8	6.9
Synthetic fertilizer (F)	2.3	4.3	2.2	21.7	3.5	3.9	6.2	16.7	18.7	6.7	1.7
Biosolids compost (B)	5.8	15.0	3.5	31.7	8.5	14.0	23.3	43.8	45.8	19.8	7.0
Yard trim compost (P)	8.0	30.7	5.8	32.7	10.2	12.5	22.3	45.8	43.3	16.8	5.2
1 cm Biosolids compost (BE)	1.5	1.3	1.3	7.8	1.3	3.2	2.7	9.2	8.8	2.7	1.7
1cm Yard trim compost (PE)	5.8	6.7	16.7	38.3	14.2	23.8	21.7	27.2	30.0	8.3	3.4

		Contrast										
Contrast	df	P										
C VS F	10	*	**	*	NS	***	**	***	*	*	***	NS
C VS B	10	NS†	NS	*	NS	**	*	*	NS	NS	*	NS
C VS P	10	NS	NS	*	NS	**	**	**	NS	NS	**	NS
C VS BE	10	**	**	*	*	***	**	***	**	*	***	NS
	10	NS	*	NS	NS	**	NS	**	NS	NS	***	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† NS, nonsignificant.

Table 28. Comparison of non-cultivated nitrogen source treatments with control on weed encroachment at Glenstone.

	Weed Encroachment (0-100%)												
	2012		2013			2014							
	Sep.	Oct.	May.	Oct.	Nov.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
N source (N)													
Control (C)	7.0	32.7	21.7	8.0	10.0	3.5	5.7	5.0	1.8	5.5	8.3	7.3	4.2
Synthetic fertilizer (F)	4.0	9.0	9.3	7.3	3.3	7.5	4.8	3.2	4.3	5.5	3.7	5.0	0.9
Biosolids compost (B)	4.3	10.3	11.7	6.0	6.3	5.3	6.0	3.0	0.7	3.5	3.9	3.9	1.8
Yard trim compost (P)	2.3	15.7	10.7	3.7	2.8	1.5	1.2	1.1	0.3	0.5	1.0	1.2	1.2
1 cm Biosolids compost (BE)	1.0	2.3	3.0	0.0	1.0	1.2	1.0	0.4	0.0	0.9	0.2	0.2	0.0
1cm Yard trim compost (PE)	7.0	23.3	15.0	3.7	2.3	2.5	3.3	2.8	3.5	5.5	4.4	2.2	0.9

		Contrast												
Contrast	df	P												
C VS F	10	NS†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C VS B	10	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C VS P	10	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C VS BE	10	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C VS PE	10	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
† NS, nonsignificant.

Appendix B

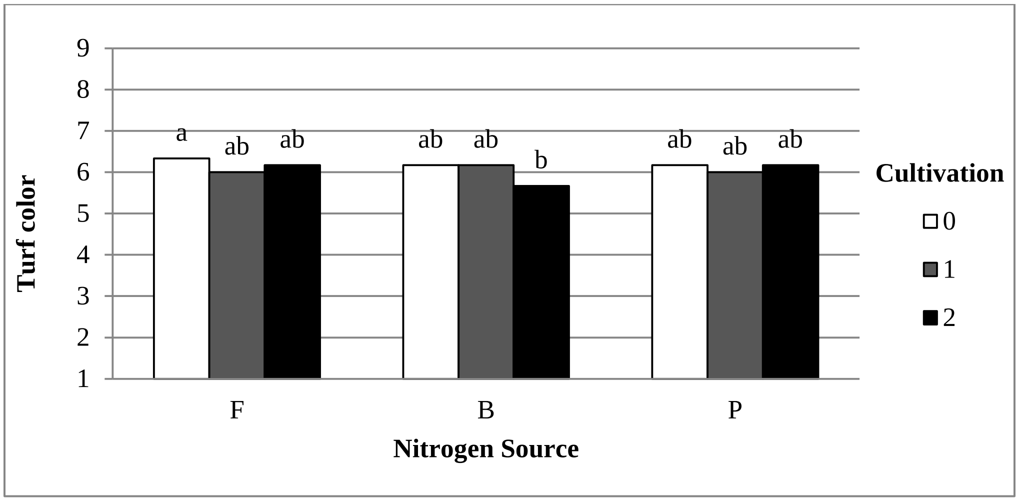


Figure 1. Effect of nitrogen source and cultivation treatment on tall fescue color at the Paint Branch Turfgrass Research Facility in Jun. 2013.
Turf color on a scale of 1-9: 1 = brown turf, 9 = dark green turf.
F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro. 0, no cultivation; 1, one pass of cultivation; 2, two passes of cultivation.
Means labeled with the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

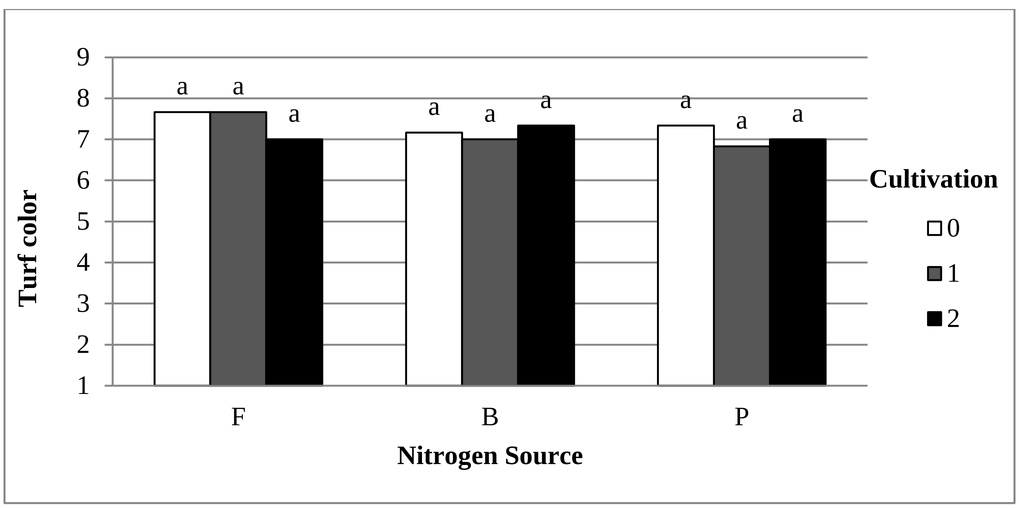


Figure 2. Effect of nitrogen source and cultivation treatment on tall fescue color at Glenstone in Apr.2013.
Turf color on a scale of 1-9: 1 = brown turf, 9 = dark green turf.
F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro. 0, no cultivation; 1, one pass of cultivation; 2, two passes of cultivation.
Means labeled with the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

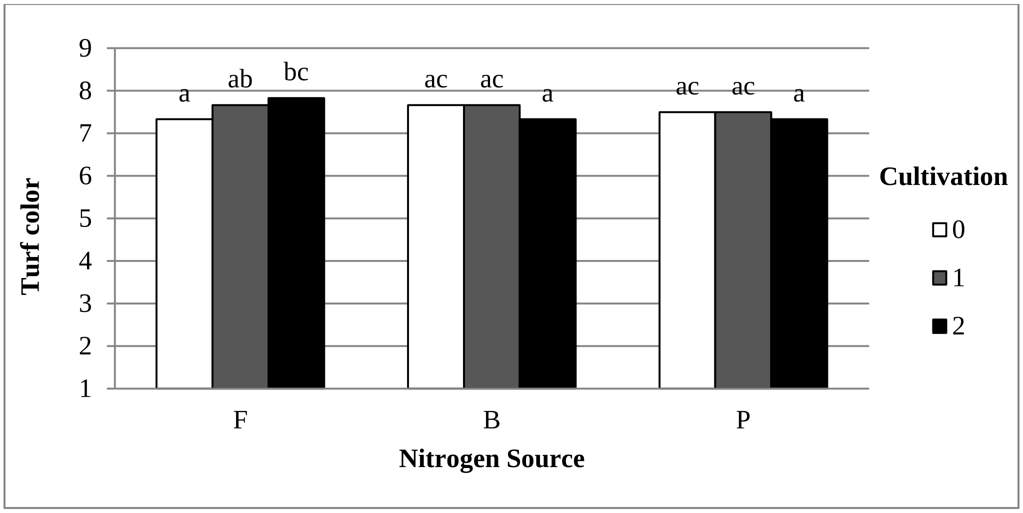


Figure 3. Effect of nitrogen source and cultivation treatment on tall fescue color at Glenstone in Sep. 2013.
Turf color on a scale of 1-9: 1 = brown turf, 9 = dark green turf.
F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro. 0, no cultivation; 1, one pass of cultivation; 2, two passes of cultivation.
Means labeled with the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

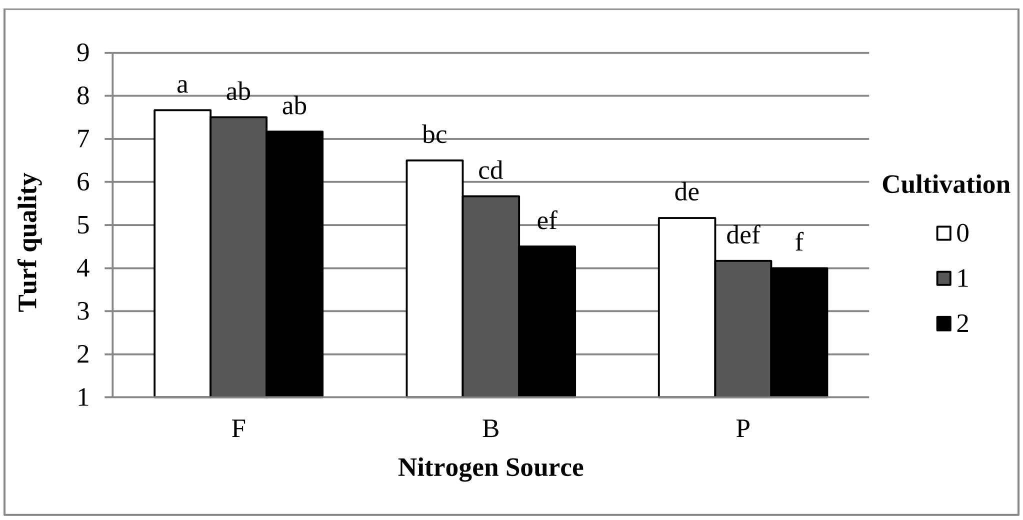


Figure 4. Effect of nitrogen source and cultivation treatment on tall fescue quality at the Paint Branch Turfgrass Research Facility in Apr. 2012.
Turf quality on a scale of 1-9: 6 = a commercial acceptance.
F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro. 0, no cultivation; 1, one pass of cultivation; 2, two passes of cultivation.
Means labeled with the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

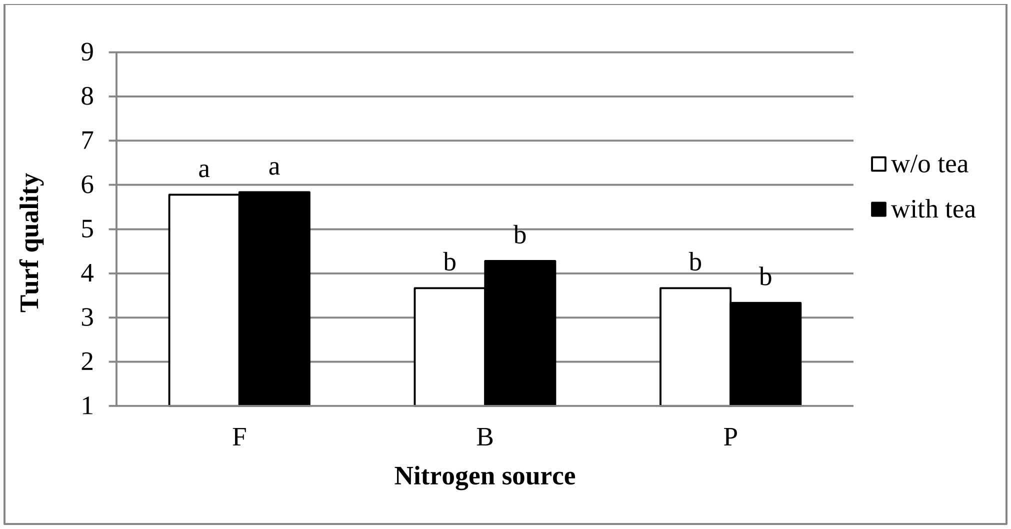


Figure 5. Effect of nitrogen source and compost tea treatment on tall fescue quality at Paint Branch Turfgrass Research Facility in Jul. 2013.

Turf quality on a scale of 1-9: 6 = a commercial acceptance.

F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro.

Means labeled with the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

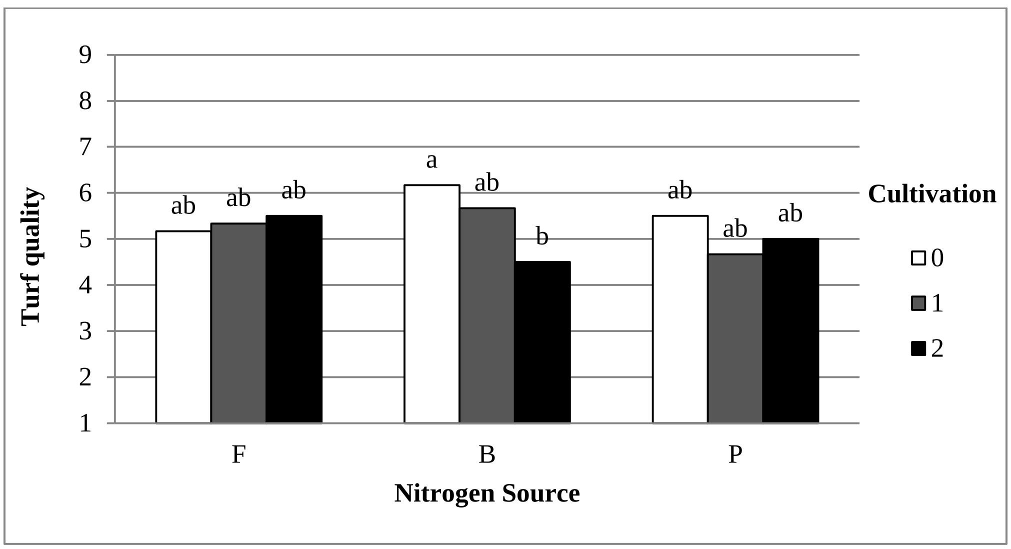


Figure 6. Effect of nitrogen source and cultivation treatment on tall fescue quality at Glenstone in Mar. 2014.

Turf quality on a scale of 1-9: 6 = a commercial acceptance.

F, synthetic fertilizer Signature; B, biosolids compost Orgro; P, yard trimmings compost Leafgro. 0, no cultivation; 1, one pass of cultivation; 2, two passes of cultivation.

Means labeled with the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

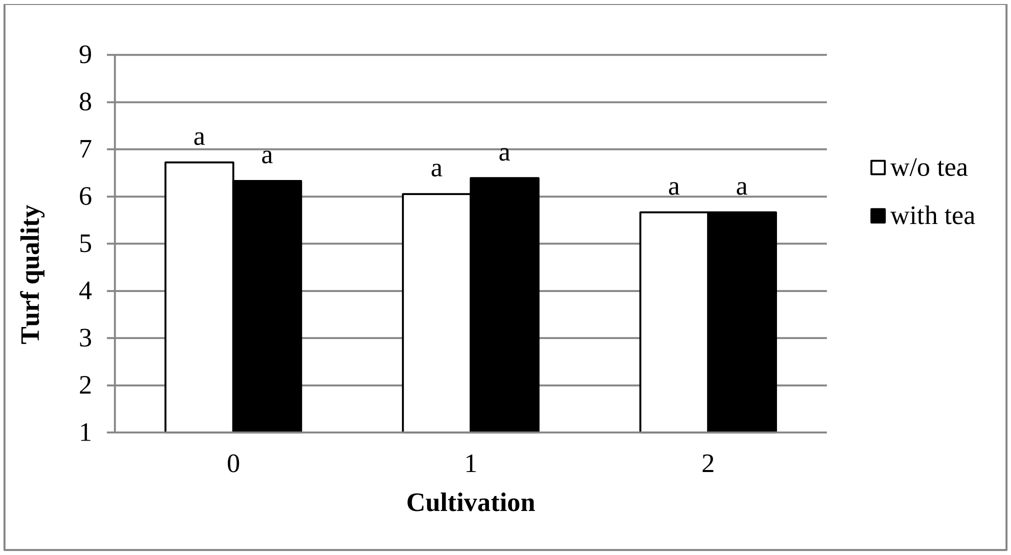


Figure 7. Effect of cultivation and compost tea treatment on tall fescue quality at Glenstone in April 2014.

Turf quality on a scale of 1-9: 6 = a commercial acceptance.

0, no cultivation; 1, one pass of cultivation; 2, two passes of cultivation.

Means labeled with the different letters are significantly different according to Tukey's honestly significantly different test ($P \leq 0.05$).

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