ABSTRACT

Title of Thesis: EFFECT OF COMPOST ON THE MICROCLOVER ESTABLISHMENT AND USE OF COMPOST AND MICROCLOVER TO REDUCE LAWN NUTRIENT RUNOFF

Xiayun Xiao, Master of Science, 2016

Thesis Directed By: Dr. Mark Carroll, Associate Professor,
Department of Plant Science and Landscape Architecture

High volume compost incorporation can reduce runoff from compacted soils but its use is also associated with elevated N and P concentrations in runoff making it difficult to assess if this practice will reduce nutrient loading of surface waters. Additionally, little is known about how this practice will effect leguminous species establishment in lawns as a means to reduce long term fertilizer use. When 5 cm of compost was incorporated into soil a reduction in runoff of 36 and 53% was needed for N and P losses from a tall fescue + microclover lawn to be equivalent to a non-compost amended soil supporting a well fertilized tall fescue lawn. Use of compost as a soil amendment resulted in quicker lawn establishment and darker color, when compared to non-amended soil receiving a mineral fertilizer. Biosolid composts containing high amounts ammonium severely reduced the establishment of clover in a tall fescue + micrclover seed mixture.

EFFECT OF COMPOST
ON THE MICROCLOVER ESTABLISHMENT
AND USE OF COMPOST AND MICROCLOVER TO REDUCE
LAWN NUTRIENT RUNOFF

by

Xiayun Xiao

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Science
2016

Advisory Committee:
Dr. Mark Carroll, Chair
Dr. Thomas Turner
Dr. Gary Felton

Dedication

To my parents and friends for your endless support, encouragement and inspiration throughout my study.

Acknowledgements

I would like to thank all the people who have assisted me in the obtainment of educational goals.

This thesis would not have been completed without the contributions of Dr. Thomas Turner, Dr. Gary Felton and Mr. Stanley Paul Schlosnagle. Thank you all for your insights on the evaluation and analysis of the data, and the knowledge you imparted to me about your respective areas of expertise. Moreover, thank you Mr. David Funk, Mr. Matthew Katsuleres and Mr. Joseph DeRico, for your accessibility and assistance in helping me complete all field activities conducted at Paint Branch Turfgrass Facility.

Funding in support of this thesis research was received from the National Fish and Wildlife Foundation and is gratefully acknowledged. Above all, I would like to thank my advisor, Dr. Mark Carroll, for encouraging my interest and pursuit of knowledge concerning science and the research process.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

A recent assessment on the health of Chesapeake Bay revealed that the only source of nitrogen (N), phosphorous (P) and sediment pollution that is still growing within the Chesapeake Bay watershed (CBW) is urban/suburban storm water (Chesapeake Bay Program 2008). With nearly 9.4 % of the land area within Chesapeake Bay being comprised of turfgrass, this land use is considered to be a possible source of some of the N and P in stormwater. As the population within the CBW continues to increase, the conversion of forested and farmlands to residential developments will continue to occur. This in turn will raise the proportion of the watershed that is comprised of turfgrass.

Because of recent completed grading activity, the soil on new residential lots is often times compacted and may contain a high proportion of infertile subsoil. One of the concerns associated with new residential developments is that new homeowners, in an attempt to compensate for the poor soil conditions in their lot, may apply more fertilizer to their newly established lawns than the homeowners in more mature neighborhoods (Law et al., 2004; Loschinkohl and Boehm 2001). In attempt to limit the over application of fertilizers to lawns, several states have passed nutrient management and/or turfgrass fertilizer laws that restrict the timing, amount, and type of fertilizer than can be applied to lawns (New Jersey 2010; Minnesota Department of Agriculture 2007; Maryland Department of Agriculture 2011; Virginia’s Legislative Information System 2011). Additionally, in order to reduce the generation of stormwater in new residential developments, the principals of environmental site design and/or low impact development must be followed when creating a new development in many parts of the country (Kibert 2012). One of primary objectives underlying these two approaches is to restore the hydrologic function of the landscape.

The incorporation of high volume amounts of compost into the soil prior to turf establishment is a low impact development practice that is sometimes used to reduce runoff from turfgrass areas. The addition of high volume amounts of compost will also reduce the fertilizer needs of a newly established lawn, however the impact of this practice on the quality of stormwater lost from the lawn has not been well documented.

The inclusion of a legume such as clover in turfgrass seed mixtures is one potential way to reduce the long-term nitrogen fertilizer needs of a lawn (McCurdy et al., 2015). The recent introduction of microclover into the US seed market offers the potential to broaden the appeal of clover in lawns. The low growth habit of this variety of clover removes some of objections consumers have with heterogeneous appearance and patchiness of native white clover in lawns.

In most areas of the US a builder cannot proceed with the sale of new home until the soil on the lot has been stabilized. This has traditionally been done by seeding much of the lot with turfgrass and covering the seed with straw. A standard application rate of straw to cover a newly seeded turfgrass site is 4.5 Mg ha^{-1} , however, heavier rates are sometime used to provide a higher level of soil stabilization protection. Unlike grass plants, clover seedlings have a prostrate growth habit. The extent to which the growth of clover seedlings, and subsequent establishment of this species in the lawn, may be impacted by straw thickness is unknown. Additionally, little is known about how amending a soil with compost may potentially affect the establishment of microclover in lawn turf.

Before promoting the use of compost incorporation prior to turfgrass establishment and use of turfgrass seed containing microclover as ways to reduce stormwater runoff and fertilizer use, it is necessary to demonstrate that the use of these two practices will improve the quality of stormwater emanating from lawns when compared to the use of traditional turfgrass fertilizer use practices. Additionally, if such practices are to be endorsed the effect of factors that may affect the establishment of microclover would important to know.

1.1 Goals and Objectives

The objectives of this thesis are to: 1) compare runoff, total N, total P, and TSS losses from unfertilized plots amended with compost and seeded with tall microclover mixture with plots seeded with tall fescue and fertilized as typical lawn care operator would do in mid-Atlantic region of the US, 2) evaluate the shoot density of lawns established and maintained as listed in first objective to aid in the interpretation of runoff losses from the two treatments, 3) determine the effect of straw depth and compost type on the establishment and growth of 95% tall fescue + 5% microclover seed mixture, and 4) evaluate the effect of straw amount and compost type on soil moisture loss in a established tall fescue + microclover lawn.

Chapter 2: Literature Review

2.1 Types of Compost

Organic matter that has undergone substantial decomposition and is subsequently used as a soil amendment or fertilizer is referred to as compost. Compost, unlike manure, contains organic matter that is always in an advanced state of decomposition. Thus care must be exercised when attempting to extrapolate the findings of manure based research studies to soils receiving compost. For example, per unit additions of compost typically elevate soil carbon levels for a longer duration and to higher amount than do animal manures (Spargo et al., 2006). Composted materials also have lower nitrogen mineralization rates than manure (Hartz et al., 2000). Additionally, plant growth responses to manure additions are usually more pronounced than those from compost additions in nitrogen limiting environments (Hartz et al., 2000).

Compost produced by most private and municipal entities involves controlled microbial based decomposition of the organic matter. This results in the formation of a stable humus-like material devoid of weed, seed, insect, and pathogen problems. By controlling the rate of microbial based reactions compost production efficiency can be increased and the likelihood of environmental or nuisance problems (ie odor) reduced (Environment Protection Association. 1998).

Most municipal composters in the United States create compost from yard trimmings, municipal solid waste or biosolids. Yard trimming compost is comprised of leaves, herbaceous plants, grass clippings and ground woody plant material. Biosolid based compost is derived from treated sewage sludge that meets the United

States EPA's pollution and pathogen requirements for land application and surface disposal. Municipal solid waste compost is comprised of a myriad of materials but most frequently contains a combination of yard trimmings, food scraps, scrap paper products and other decomposable organic materials

The US Environment Protection Agency (2014) has reported that per capita compost production from municipal solid waste in 2012 was 0.37 lbs. per day. Composting of the yard trimmings component of municipal solid waste is projected to reduce CO_2 emissions, (when compared to combusting or landfilling the yard trimmings) by amount equivalent to taking 170,000 cars off the roads of USA each year. While no comparable data appears to be available for composts derived from biosolids or simple yard trimmings alone, the aforementioned report nevertheless highlights that compost production offers advantages to the environment beyond the agronomic value of the final end product to plants and soils.

2.2 Use of Compost as Soil Amendment

2.2.1 Historical Aspects of Compost Use

Compost use has been documented as far back as ancient Mesopotamia indicating that at least some of benefits associated with its use have been known for over 4000 years (Mehta et al., 2011). Knowledge of the effects of compost on specific soil properties has increased dramatically over the past 30 years as municipalities, state and federal regulatory agencies, and commercial composting operations have funded research to document the effect of compost use on crop production and environmental stewardship.

2.2.2 Effect on Soil Chemical Properties

Soil chemical properties likely be altered by the addition of compost include organic matter content, pH, nutrient and metal content, and cation exchange capacity. With the exception of metal and salt loading that occurs with the addition of some biosolid based composts, soil chemical properties changes that occur when amending a soil with compost generally improve plant growth and soil quality (Stratton et al., 1995, Tyler 1996).

i) Organic Matter Content

Incorporating composts into soil, especially infertile soil, can increase soil organic matter. Normally it takes years to replenish organic matter in soil by adding raw plant materials, green manures or farm manures (Barker, 1997). The addition of compost however results in a rapid increase in the amount soil organic carbon present in low organic matter containing soil. Typically soil matter is calculated from soil organic carbon by multiply soil organic carbon content by 2 (Nelson and Sommers, 1982). Cox et al., (2001) incorporated 100 ton ha^{-1} (2 cm surface application) of a primarily animal based compost into an eroded silt loam soil and reported than a year and half later the soil organic carbon level in the composted amended soil was over twice that of the non-amended soil (i.e., 2.9% verses 1.3%). Longer term responses have also been observed. Tester (1990) measured the surface soil organic carbon level of loamy sand soil (0 – 3.5 cm) five years after amending it to a depth of 15 cm with 240 Mg ha^{-1} of a biosolid compost and found that the compost amended soil organic carbon level was 4.7 times greater than an non-amended soil (38.1% verses 8.1%). A forage crop of tall fescue was maintained in the compost amended and non-compost amended soil over the 5 year period with the non-amended soil receiving a single 200 Mg ha^{-1} application of N, P and K fertilizer at establishment. The lack of subsequent fertilization of the tall fescue together with the fact the trial was conducted using sandy soil likely accentuated the measured differences in soil organic carbon between the two treatments. Grasses grown in fertile soils generate organic matter in the form decomposing leaf stem and root tissue (Landschoot and McNitt, 1994). The slow release of nitrogen from the added compost sustained greater biomass production compared to the soil that received the one time addition of fertilizer at establishment (Tester, 1990). This additional biomass production likely kept the organic carbon level high even as the decomposition of the added compost was occurring.

Studies on the long term contribution of compost based carbon to the total pool of soil organic carbon are few in number for one time applications of compost (Cogger, 2005). When examining the proportion soil organic matter than could be attributed to a one time addition of 155 Mg ha^{-1} compost made at the time of the establishment of a forage crop of tall fescue, Sullivan et al., (2003) reported that 18% of compost C remained seven years after the incorporation of the compost. Reports of the effect of repeated applications of compost on soil organic carbon are common in agricultural cropping systems and reflect the fact that yearly tillage in these systems is a common practice. A one time addition of compost is more common in perennial grass systems. Only with the fairly recent recommendation to amend soil with compost to reduce stormwater runoff, has there been an interest in characterizing the long term effect of one time additions of compost on soil chemical and physical properties of lawn areas that have been amended with this material (Cogger, 2005).

ii) pH

Soil pH affects the availability and absorption of nutrients by plants. Nutrients whose availability is highly dependent on soil pH include, phosphorus, zinc, manganese and iron. Compost induced soil pH changes are dependent on the source of the compost and the initial pH, and buffering capacity of the soil.

Most finished composts have a neutral to slightly alkaline pH (Barker 1997). Some biosolid based composts however are treated with hydrated lime during the dewatering stage of the compost process. This can result in this type of compost having a pH greater than 8 (Gouin, 1993). An often cited range for the increase in soil pH with compost addition is 0 to 1 pH unit (Cogger 2005). Thus when a sandy unbuffered soil is amended with large amount of the lime treated compost the change is soil pH would be likely be near the upper end of the range just cited.

Compost that undergoes anerobic decomposition often produce a large amount of acidic acid which causes the compost to have an acidic pH (Gouin, 1993). When applied at high rates of application such composts can depress the pH of neutral or alkaline soils. Near neutral pH composts can have a similar favorable effect on the pH of high pH soils. Moreno et al (1996) found that an aerobic compost having a pH of 7 to 7.2, when applied at a rate of 80 ton ha^{-1}, can reduce the pH of calcareous soil (pH =8.77) by as much 0.5 pH units.

Compost is sometimes used to remediate mine waste contaminated soils. The pH of a mine slurry soil undergoing acidification was raised by 0.39 pH units after adding an olive leaf based compost at a rate of 27 g air-dry compost kg^{-1} dry soil to the soil 83 days earlier (Walker et al., 2004). The presence basic cations in compost and the adsorption of H^+ ions by the compost were the two primary mechanisms thought to be responsible for the moderating the decline in pH caused by the oxidation of the mine slurry waste. Buffering of soil pH has also been reported for soils receiving high amounts sodium and soluble salts. In arid regions soil pH increases on the order of 0.5 to 1 pH unit are typical when continuously irrigated with saline water. Wright et al., (2008) found that amending a fine sandy loam soil with 80 to 160 Mg ha^{-1} of compost decreased soil pH by 0.2 units when compared to non-amended soil. Citing Wilkinson et al., (1997) and Kalbitz et al., (2000), Wright et al., (2008) hypothesize that the addition of the compost coated soil particles, which in turn, caused a decrease in the number of exchange sites that could react with basic cations in irrigation water.

iii) Macro and Micronutrients

The nutrient content of compost is depended on the waste stream from which the compost is created. Table 2.1 shows the reported ranges in N, P and K for three common types of compost. The reported N content of biosolids compost has ranged from at least 0.1 percent to 17.6 percent (Sommers et al., 1977), while the range in N content for yard trimmings and municipal solid waste composts are considerably narrower (Hartz, 2009; Hargreaves, 2008). Similarly, the reported range in P content is larger for biosolid based compost than for yard trimmings or MSW compost (Sommers et al., 1977). Yard trimmings and MSW compost typically have low to no P indicating the levels of these two nutrients in these two types of compost are unlikely to exceed 1 percent. The range in K content of biosolid compost is lower than that for N and P. In all three types of compost types the K content will likely be less than 2.6 %.

Table 2.1 Reported N P and K content, mineralization rates and dry bulk densities of biosolid, yard trimmings and municipal solid waste composts.

Compost type	Nutrients	Biosoild	Yard Trimming	Municipal Solid Waste
Range in Compost %	N	0.1-17.6	1-1.5	0.25-1
	P	0.1-14.3	0.2-0.5	0-1
	K	0.02-2.64	0.5-1.5	0-1
	Reference	Sommers et al., 1977	Harts 2009	Hargreaves 2008
Release Rate %	N	6-9.3	8-11	10-21
	P	NA	NA	10-50
	K	NA	NA	36-48
	Reference	Tester 1977, Epstein 1978	Amlinger et al.,2003	deHaan 1981, Iglesias-Jimenez and Alvarez 1993
Bulk Density	kg/m^3	720-800	215-330	475-594
	Reference	Spellman 1997	Reinhart et al.,1993, Day et al.,1998	Dickerson 2004

Past studies on the release of N and P from compost indicate that yearly N and P mineralization will likely range from 6 to 21 percent for N and 10 to 50 percent for the P (deHaan 1981). In a review of the chemical, physical and biological properties of composted municipal solid waste (MSW) Hargreaves et al. (2008) reported that 10% of nitrogen is typically available during the first year, although they did cited one study (Iglesias-Jimenez and Alvarez 1993) that reported 16 to 21% of the nitrogen in MSW was available within 6 months the making the compost application.

Berner et al., (1995) reported that one yard trimming compost had an annual N mineralization rate of 8 to 11 percent, while Zhang et al., (2006) found that most of the N in a mixed biosolids-MSW compost was released in the first two years following application of the compost.

Rowaan (1949), as cited by deHann (1981), reported that 10 to 15 of the P in MSW compost is available in the first and second years following application. Potassium availability from compost is similar to that of mineral salt K fertilizer (deHann 1981).

Nitrogen release from compost is highly dependent on the carbon to nitrogen (C: N) ratio of the finished product with nitrogen immobilization typically taking place when the C: N ratio exceeds 35 (Barker 1997). The presence of wood chips often results in a high C: N ratio in otherwise mature compost. Supplemental fertilizer applications are usually needed to maintain turf establishment vigor in soils amended with high C: N ratio composts.

Nitrogen and P added to soil by amending it with compost tends to remain the soil for extended periods of time. Tester (1990) found that amending a sandy loam soil with 240 Mg ha^{-1} of a wood chip containing high lime undigested sewage sludge compost elevated the total N and P in the soil by 5 and 8 times the amount of N and P present in soil that received a onetime application of N, P, and K fertilizer in place of the compost. The N and P levels in the soil were determined 5 years after amending the soil with compost.

Compost additions made on the basis of plant N and P needs may, in some instances, result in excessive amount of micronutrients being added to the soil. Of most concern is the addition of excessive amounts of heavy metals which can be phytotoxic to plant growth (McBride 1995; Sloan et al., 1997) and may increase the potential movement of these metals into water and air.

2.2.3 Effect on Physical Properties

Changes in soil physical properties that usually occur when amending a soil with compost include soil bulk density, water holding capacity, infiltration and aggregate stability. The change in soil physical properties that occurs when amending a soil with compost typically enhances plant growth and improve soil quality (Gentilucci et al., 2001 Cheng et al., 2006).

i) Bulk Density

Soil bulk density is the mass per unit volume of soil. It is a single measurement that reflects the porosity of media and the potential productivity of soil through its effect on root growth (Courtney and Mullen 2008). Bulk density is largely influenced by soil structure and the amount of organic carbon present in the soil (Barzegar et al., 2002, Aggelides and Londra 2000, Celik et al., 2004, Spargo et al., 2006). The addition of large amounts of organic matter as a soil amendment lowers soil density (Khaleel et al., 1981). The reduction in soil bulk density is mostly the result of dilution of the mineral fraction of the soil by lower density organic material. (Barzegar et al., 2002).

Barzegar et al., (2002) examined the effect of amending the top 20 cm of a fine loamy soil with 0, 5, 10 and 15 Mg ha^{-1} of compost and found that the respective rates of compost resulted soil bulk densities of 1.54 mg m^{-3}, 1.51 mg m^{-3}, 1.50 mg m^{-3} and 1.45 mg m^{-3} one year after incorporation. Higher rates of compost will likely result in larger reductions in bulk density. Aggelides and Londra (2000) for example, amended a sand and clay soil with 156 Mg ha^{-1} to a depth of 15 cm and found the bulk density in the amended layer declined by 19.7% and 16.7% respectively, for the two soils. Tester (1990) observed a 45% decrease in bulk density when the top 15 cm of soil was amended with 240 Mg ha^{-1} compost.

ii) Aggregate Stability

A soil aggregate is a group of primary (ie., mineral and organic matter) particles that cohere to each other more strongly than to other surrounding soil particles. Aggregates range in size from 0.25 to 10 mm in diameter. Aggregates stability is a measure of the ability of the cohesive forces between particles to withstand an applied disruptive force. (Kemper and Rosenau al., 1986). It is typically measured by subjecting aggregates to a disruptive force such as sieving, grinding or repeated agitation in distilled water after which the mass of aggregates of given particle size is determined (Nimmo and Perkins 2002). Aggregate stability is an important component of soil quality because the presence of aggregates increases the amount and size of pores, which in turn increases gravitational water movement in soil (Cogger 2005). Inconsistent responses to compost addition on aggregate stability have been observed. Guidi (et al., 1988) applied up to 300 kg ha^{-1} of available nitrogen as manure or municipal waste compost and failed to detect any effect of either material on aggregate stability. They concluded that natural seasonal changes have a more pronounced effect on aggregate stability than does the addition of compost. Aggelides and Londra, (2000) applied municipal compost created from a waste stream consisting of 62% town wastes, 21% sewage sludge and 17% sawdust by volume to loamy and clay soils at the rates of 0 (control), 75, 150 and 300 m^{3} ha$^{-1.}$ They used the concept of a instability index to determine aggregate stability where a decrease in the index was indicative of increased aggregate stability. Index changes of 0.46 to 0.32 and 0.29 to 0.24 were observed in the loamy and clay soils respectively at the highest rate of compost addition leading them to conclude that the addition of compost improved aggregate stability. Albiach (et al., 2001) reported that yearly incorporation of 24 ton ha^{-1} of a municipal wastes compost improved aggregate stability four and five years of after application of the compost. They also observed that soil aggregate stability was well correlated with soil organic matter and carbohydrate content, with simple correlations coefficients for the two soil components ranging from 0.78 to 0.84 over the two year evaluation period. Albiach el al., (2001) noticed a decline in aggregate stability in the fifth year of their study compared to the results obtained in the fourth year. They attributed the observed temporal variation in stability to the influence of normal seasonal change on aggregate stability. More specifically, the presence of warm soil temperatures, by increasing the decomposition of organic matter, increased aggregate stability. This is consistent with earlier reports by Guidi (1988) and Lax and Garc_õa-Orenes (1993).

iii) Infiltration

Soil water infiltration rate is defined as “the volume of water entering a specified cross-sectional area of soil per unit time [l t^{-1}]” (Soil Sience Society of America 2015). It is frequently measured by using the double ring infiltration test. A double ring infiltrometer has an inner ring and outer ring with purpose of the outer ring being to promote-one dimensional vertical flow beneath the inner cylinder. When the double ring test is performed by maintaining a constant head within the two cylinders, the measured infiltration rate is close to the saturated hydraulic conductivity (Ksat) of the soil (Matula and Dirksen 1989).

Soil organic matter content along with other factors such as shoot density at the soil surface, and soil texture affect water entry into the soil (Barzegar et al., 2002; Easton and Petrovic 2004; Curtis et al., 2007). Compost when used as a soil amendment, can increase water entry into the soil by lowering bulk density and increasing the stability of aggregates present in the soil. Martens and Frankenberger (1992) found that amending a coarse loamy soil with 25 Mg ha^{-1} compost increased the cumulative infiltration rate of the soil by 18 to 25% when compared to the same soil that did not receive compost. Pit (et al. 1999) examined the effect of cedar grove compost on the infiltration of a glacial till soil at three locations, and found that when compost was incorporated at a ratio of 2 parts soil to 1 part compost, soil infiltration increased 10 fold compared to the same soils not receiving compost.

The positive effect of amending a soil with compost on plant biomass production can also be an important factor in enhancing water entry into the soil. Curtis and Claassen (2007) amended a decomposed granite-based loamy sand soil with 0, 6, 12 and 24% by volume of yard trimmings compost after which half of each plot was seeded with a stress-tolerant perennial grass (*Elymus multisetus*). They measured the saturated hydraulic conductivity of the surface soil and the above the ground biomass 1 and 2 years after amending the soil with compost. There was a trend suggesting Ksat increased with increasing amount of compost in the first year of study however there was no significant different among the 4 compost treatments. Two years after amending the soil with 12 and 24% compost Ksat increased by 34 and 74% respectively, when compared to the non-amended control. There was no different in the biomass levels among the four treatments in first year of the study, however by the second year the amount of biomass in the plots receiving 12 and 24% compost were 164 and 348% higher than the non-amended control plots. Curtis and Claassen concluded that vegetative establishment was necessary to maintain improvements in soil infiltration associated with the addition of compost. Moreover, their data revealed that long term compost induced enhancement in biomass production may be of greater importance in reducing runoff than improvements in soil physical property brought about by the addition of compost.

iv) Soil Moisture

Plant available water has traditionally been considered to be the amount of soil water present in the soil between field capacity and wilting point. It is typically determined as the difference in soil water held at surface tension of .01 to 1.5 Mpa in sandy soils and 0.33 to 1.5 Mpa in finer textured soils (Kar, et al., 2007)

The effect of compost addition on soil available water is dependent on soil texture as well as the amount of compost added to the soil. Giusquiani et al., (1995) examined the effect of amending a clay loam soil with yearly amounts of 0, 10 and 90 Mg ha^{-1} of an urban waste compost and reported that the three respective treatments had available soil water contents of 25, 27 and 35% five years after making the first compost application. In contrast, Turner et al. (1994) examined the moisture retention properties of a sandy soil amended with municipal solid waste compost at a rate of 0, 67, 134 Mg ha^{-1}, after one year amending the soil and reported that compost increased the water retention capacity of the soil but not the amount of plant available water held by the soil. A sandy soil has less adsorptive surface area to retain water than a does a clay soil. The incorporation of a large amount of organic matter into soil will increase the water held at the wilting point to a greater extent in a sandy soil than in a fine textured soil. Conversely, the effect of a large organic matter addition on increasing the amount of water held at field capacity in fine textured soils is greater than that in course textured soils (Khaleel et al., 1981). The net effect of the two changes is that there will likely be a larger change in the amount of water held between field capacity and the wilting point in a fine textured soil than in course textured soil when similar amounts of organic matter being added to both soil types.

Time after application of the compost can also influence the amount of plant available water that is held by the soil. Foley and Cooperband (2002) applied paper mill residues and composted paper mill residues with and without bark and peat and measured the amount of available water in loamy sand soils 1 and 2 years after incorporation the two organic materials into the soil. They observed that the plant available water increased with increasing soil organic matter with plant available water being higher in year 1 than year 2 of their study. The decline in plant available water seen in the second year of the study was presumably due to the degradation of the organic matter over time which lowered the amount of organic matter present in the soil.

2.2.4 Effect on Runoff and on Nutrient and Sediment Losses in Runoff

i) Runoff

Runoff is described as the discharged of water from soil when precipitation and irrigation exceed the infiltration capacity of the soil (Soil Sience Society of America 2015; Pit et al., 1999). The use of compost as a soil amendment can reduce runoff, especially in disturbed soils that have poor fertility and soil quality. Harrison (1997) incorporated compost at a ratio of 2 parts of soil with 1 part compost into the top 20 cm of glacial till soil and seeded the site with cool season turfgrass mixture. One year after seeding 1.47 mm hr^{-1} of simulated rainfall was applied for 30 hours. Runoff from the non-amended and compost amended plots was 34 mm and 14 mm respectively. Elevated soil organic matter levels resulting from the addition of compost reduce runoff by increasing soil porosity and enhancing plant shoot density. The latter creates a more tortuous path for water movement allowing more time for water to infiltrate (Spargo et al., 2006; Curtis and Claassen 2007; Linde et al., 1997).

The addition of compost to reduce runoff is most effective in soils that initially have bulk densities that are inhibitory to root growth (Pennsylvania Stormwater Manual, 2006). Pit et al (1999) incorporated either yard trimmings compost or a municipal sawdust waste at a ratio of 2 parts soil to 1 part compost or sawdust into a compacted glacial till soil at three different sites prior to seeding each with perennial ryegrass (*Lolium perenne*). Two of the sites were amended with compost and seeded in spring of year while the third site was amended with compost and seeded in fall three years later. Runoff was collected during seven naturally occurring rainfall events from December, 1997 to June, 1998 at all three sites. The total rainfall varied from 27 mm to 288 mm at the three sites during the time which runoff was evaluated. At the younger fall seeded site runoff from the compost amended soil was 5.6 times less than from the non-compost amended soil. There was no difference in runoff between the two treatments at the two sites seeded three year earlier. While rainfall amounts varied at the three sites Pit's et al (1999) findings suggests that there is a limited period of effectiveness in the ability of compost amended soil to reduce runoff.

The effectiveness of compost incorporation to reduce runoff is influenced by the presence of a compacted or impermeable layer beyond the reach of conventional tillage equipment (Pennsylvania Stormwater Manual, 2006). The presence of a compacted or impermeable layer within the top 60 cm of soil can be broken up using solid-shank ripper or other type of subsoil cultivation piece of equipment (Pennsylvania Stormwater Manual, 2006). The combined use of a ripper, followed by one pass of a chisel plow and the incorporation of 7.5 cm of compost into the top 15 cm of tilled soil has been shown to reduce runoff by 98% when compared same soil left in its compacted state (Balousek, 2003). Most of the reduction in runoff could be attributed to the use of the aforementioned cultivation practice however a significant further reduction in runoff was seen with the incorporation of the compost. The use of two cultivation treatments without adding compost to the soil reduced runoff by 71% when compared to the compact untreated soil.

ii) Nutrient and Sediment Losses in Runoff

Recent emphasis on the incorporation of high volume amounts of compost to reduce stormwater runoff from urban landscapes has raised questions about the impact of this practice on nutrient and sediment runoff (Wright et al., 2008; Provin et al., 2008). Compost amendment rates currently being recommended to reduce runoff supply nitrogen (and P in many instances) far in excess of turf and ornamental plant needs for at least the first two years following incorporation of the compost. The general assumption when using high rates of compost is that the reduction in runoff will be large enough to offset increase concentrations in N and P detected in the runoff. In other words actual load losses of nutrients in soils amended with compost and sediment in runoffs should be less than in non-amended soils because dramatic reductions runoff are generally anticipated when soils are heavily amended with compost.

There are few studies to support the just mentioned assumption. Pitt et al., (1999) examined both sub and surface flow losses from compost amended soils and reported that the compost amended soil they investigated had 69% less loss of total N and 50% less loss of total P in runoff when compared to the same soil not receiving compost over a 6 month evaluation period. Utilizing the same soil in an earlier study, Harrison et al., (1997) reported that incorporating compost at rates of 2 parts soil to 1 part compost reduced nitrate-N losses by 7% and total P losses 70% when compared to the same soil not amended with compost. The lower load losses reported in the latter study were attributed more to declines runoff resulting from the compost addition rather than lower measured concentrations of the two nutrients. Pit et al., (1999) reported that nutrient concentrations were consistently higher in compost amended soils than in the same soil not amended with compost. In contrast, Harrison et al., (1997) reported that total P, soluble reactive P and nitrate-N concentration were lower in the runoff from the compost amended soil than in the non-amended soil. Specifically, the mean concentration for total P was 2.05 mg L^{-1} in runoff from the compost amendment soil and 2.45 mg L^{-1} in the runoff from the non-amended soil. Soluble-reactive P was 1.09 mg L^{-1} in runoff from the compost-amended soil and 1.19 mg L^{-1} from the non-amended soil. Concentrations in excess of 0.1 mg phospate L^{-1} have been linked to phytoplankton blooms is surface waters (Mallin and Wheeler 2000).

Sediment is the primary pollutant of surface waters in the United States (Carpenter, S. R. et al. 1998). Sediment reductions in runoff have been observed from soils that have been amended with compost. Bresson et al., (2001) amended a soil with municipal solid waste compost at a rate of 50 Mg ha^{-1}. One week later bare soil sediment losses were then measured while applying 19 mm hr^{-1} of simulation rainfall for one hour. The mean sediment concentration in runoff were 36.4g L^{-1} and 11g L^{-1} from non-composted amended and compost amended soil respectively. Ojeda et al., (2003) applied three different forms of sewage sludge compost to a loam and a sandy soil respectively. Both sandy and loam soils were reestablished fired burned pasture fields. The composts examined included fresh compost; thermally-dried compost; and mature compost. The three compost were applied to the surface of the soils at a rate of 10 Mg ha^{-1} of sludge dry matter. Cumulative soil sediment loss from the control treatment was 1191g in loam soil and 118g in sand soil. An average reduction of 40 and 60 percent sediment loss was seen for the compost treatments in sand and loam soils respectively. The results of Ojeda's study suggest that the effectiveness of compost incorporation in reducing sediment loss is depended on surface soil texture. The incorporation of compost into fine textured soils will have greater impact on reducing sediment loss than into course of sandy textured soils.

2.2.5 Turfgrass Growth and Management

i) Establishment

Studies examining the effect of compost incorporation on turf establishment have reported that this practice can either delay or hasten establishment (Sikora et al. 1980, Chen 1997, Markham 1998, Loschinkohl and Boehm 2001). The beneficial effect of compost on turfgrass establishment is most dramatic when compost is incorporated into a compact or infertile soil. Loschinkohl and Boehm (2001) examined the establishment of Kentucky bluegrass, perennial ryegrass, and a Kentucky bluegrass and perennial ryegrass mixture in a nutrient-deficient subsoil with and without the soil being amended with compost. The amended soil received 130 m^3 ha^{-1} of a locally produced composted biosolids product, with the material being mixed with soil to a depth of 10-15 cm. After almost five weeks, the compost amended treatments all showed significantly better establishment and turfgrass growth rate as assessed by percent visual cover and clipping dry weight. In the case of the perennial ryegrass treatment, turf cover four weeks after seeding was twice as much (75%) in the compost amended soil as in the unamended soil (36%).

Landschoot and McNitt (1994) examined the effect 8 different compost sources on Kentucky bluegrass establishment. Compost was spread on surface of an infertile soil at a rate of 237 m^3 ha^{-1} (2.5 cm) and 474 m^3 ha^{-1} (5 cm) and was incorporated to depths 10 and 15 cm, respectively. One month after seeding plots receiving biosolid compost, at either rate of incorporation, had the quickest rates of establishment with some plots having as much as 80% turf cover at that time. The improved ability of this compost to enhance turf establishment was mostly attributed to greater N and P availability at the time of seedling emergence. Harrell and Miller (2005) applied 5 cm and 10 cm of yard trimmings compost to the surface of two hillside slopes after which they were seeded with either asiastic jasmine (*Trachelopermum asiaticum*), bahiagrass (*Paspalum notatum Flugge*) or bermudagrass (*Cynodon dactylon L.*). Neither rate of compost had a significant effect on the establishment of the three species.

Poor or delayed turfgrass establishment with the incorporation of compost prior to seeding is frequently associated with composts maturity. Well-matured composts usually have C: N ratio of 5:1 to 6:1 (Hirai et al., 1983). Immature composts having a high C: N ratio can cause immobilization of soil nitrogen which delays seed germination and establishment (Forester et al., 1993). Some immature composts may contain excessive amounts of ammonium nitrogen, or more generally a high salt level, which can also reduce seed germination and delay seedling growth (Barker 2001, Breslin, 1995). Breslin (1995) reported that when a high salt containing immature biosolid compost was incorporated into a loam clay soil almost two years was required for the turf to reach an acceptable shoot density. The impact of compost salinity on turf establishment can be much shorter than that reported by Breslin (1995). For example, Linde and Hepner (2005) incorporated a biosolid compost to depths of 5 and 7.5 cm and found that turf establishment was delayed for the first 6 weeks following seeding. After this time the condition reversed with the two depths of compost incorporation exhibiting significantly better color, cover and overall quality than non-amended control treatment.

ii) Growth Responses

Typical turfgrass grow responses seen in soils amended with compost include darker turf color, increased growth rate (biomass) and higher tissue nitrogen content. Zhang et al., (2010) amended a Black Chenozem soil with 50 Mg ha^{-1} of a biosolid compost for two years, 150 Mg ha^{-1} of the same compost in first year and 50 Mg ha^{-1} for second year, or a single one time application 150 Mg ha^{-1}. Significant improvements in turf color were seen with all three compost treatments when compared to the control in the first two years following seeding. In the third and fourth year after seeding there was no difference in turf color among any of the treatments. Tissue nitrogen level in turf receiving the single 150 Mg ha^{-1} compost application was 33% higher than turf growth in soil that did not receive any compost indicating N mineralization from compost was sufficient to meet turf needs for a period of 2 to 3 years but after this the rate of N mineralization from the compost was insufficient to meet the needs of the turfgrass.

2.3 Clover in Grass Swards

Prior to the 1940's cool season grass lawn seed typically included white clover (*Trifolium repens* L.) as a part of the seed mixture (Sincik, and Acikgoz, 2007; Legard and Steele, 1992; Frame and Newbould, 1986; Legard et al., 2001). Clover was included within the lawn seed mixture to provide nitrogen to the turf. However it was gradually removed from the seed mixtures with the development of 2, 4-dichlorophenoxyacetic acid (2, 4-D) and later, other broadleaf herbicides (Tukey 2007). These herbicides, which are still in use today, do not possess a level of selectivity that would remove undesirable broadleaf weeds without killing clover as well.

Shortly before the development of 2, 4-D the availability of low cost fertilizers containing a high portion of N increased dramatically with the discovery of the Haber process (Erisman et al., 2008). With the application of nitrogen fertilizers becoming a relatively cheap and simply task, the need to include clover in lawns seed mixtures no longer seemed to be necessary by the middle of 20th century, so it was removed from nearly all lawn seed mixtures in the United States.

Recent concerns about nutrient runoff from lawns has led some jurisdictions in the US to place restrictions on the timing and amount of nitrogen that can be applied to lawns (O'Malley et al., 2011). Intentionally reintroducing clover into lawns has been proposed as a way to maintain turf color and density in lawn areas that receive little fertilizer (McCurdy et al., 2015). The degree to which this can be accomplished will depend on ability of clover to uniformly persist in lawns subjected to various cultural practices and environmental conditions, as well as the amount N clover provides the grass portion of the lawn.

2.3.1 Nitrogen Fixation in Clover

Nodule formation and the activity of bacteria within this structure ultimately determine the extent of nitrogen fixation by leguminous plants. Lantinga (2000) reported that 160 kg N ha^{-1} $year^{-1}$ was fixed by white clover when a pasture was managed to maintain a white clover to perennial ryegrass dry mass ratio of 1:2. According to Legard and Steele (1992), the amount of nitrogen that clover may fix can reach as high as 680 kg N $ha^{-1}year^{-1}$ in a grass clover pasture, however a more typical nitrogen fixation range for clover is 50 to 250 kg N ha^{-1} $year^{-1}$.

The factors known to have a substantial effect on the nitrogen fixing capability of clover include soil moisture and oxygen, temperature, light intensity, soil acidity, soil biotic effects, and nutritional status and toxic chemicals in soil as well as mixture ratio of clover and grasses (Rice et al., 1977; Bordeleau and Prevost 1994; Vincent 1965). Among all the factors listed above soil moisture, temperature and nutrient status have the most substantive role in white clover's ability to fix nitrogen (Wu and McGechan, 1998; Vincent 1965)

i) Effect of Soil Moisture

Nitrogen in the root nodules of leguminous plants decline in the presence excessive or deficit water conditions (Sprent 1971; Wu and McGechan, 1999). Sprent (1971) examined the effect of water deficits on soybean N fixation and found that nodule activity declined when the plant wilted in a sandy soil. According to Sprent

(1971), the N fixation ability of water stress soybeans recovers when the stress is alleviated, however the rate and extent of recovery in the N fixation ability of soybean is dependent on the extent of water deficient the plant is subjected to. Insufficient exchange of oxygen in the nodules of legume roots including white clover is the primary reason N fixation in legumes declines saturated soils (Sprent 1971).

ii) Effect of Soil Temperature

The optimum temperature range for nodules to fix nitrogen is 20 to 30 °C. According to Bordeleau and Prevost (1994), temperatures outside this range delay or reduce nodule formation. Frings (1976) examined the effect of high temperatures on legume nodulation by placing 5 cm pea plants (*Pisum sativum L*.,) seedlings into nutrient solutions. The seedlings were inoculated with *Rhizobium leguminosarum* after which they were placed into water baths maintained at temperatures ranging from 22 ^{o}C to 30 ^{o}C. They found at temperatures of 30 ^{o}C depressed root hair formation which reduced the root area on which nodules could form.

iii) Effect of Soil Nitrogen Content

Multiple researchers have reported that increasing availability of inorganic N will reduce nodule development and the subsequent fixation of N by clovers (Macduff et al., 1996; McAuliffe et al., 1958). Macduff et al., (1996) grew white clover in solutions containing of 0, 10,100 or 1000 mmol NO_3 m^{-3} for 60 days. The N fixation rates one week after placing the plants in the four solutions were 7.9, 5.4, 3.2, and 2.0 mmol N d^{-1} g^{-1} nodule dry weight respectively. McAauliffe et al., (1958) examined N fixation of clover in a sward of turfgrass receiving different amounts of N. They found 65 percent of N in clover was fixed from the atmosphere when 28 kg ha^{-1} of the inorganic N was applied to the sward while only 10 percent of N in clover was fixed from the atmosphere at an inorganic N application rate of 224 kg ha^{-1}.

2.3.2 Nitrogen Transfer in Clover

Murray and Clements (1998) and Mallarino et al., (1990) have summarized the primary modes N is transferred from clover to other plants. Some leakage of soluble N into soil from viable clover roots occurs permitting the roots of other plants located in close proximity to clover roots to absorb and use this N for its own growth. Most N fixed by clover however becomes available to other plants when the nodule containing roots of a clover decompose (Murray and Clements 1998; Mallarino et al 1990).

Nitrogen transfer from clover to cool season grass species has been reported to range from 29 to 73 kg N, ha^{-1}, yr^{-1} (Cowling 1982). In a pasture of mature tall fescue and clover Mallarino et al., (1990) reported that 29 to 49 kg N ha^{-1}, yr^{-1} fixed by clover was transferred to tall fescue. Similarly, McNeil and Wood (1990) measured N transfer at three harvest times during the first year of growth in a white clover, perennial ryegrass pasture and found that 43 kg ha^{-1} year^{-1} of N was transferred from white clover to perennial ryegrass. More recently, Sincik and Acikgoz (2007) reported that 10 to 34 kg N ha^{-1}, yr^{-1} was transferred from white clover to three cool season grass species three years after establishing the grass plus clover mixtures. McCurdy et al., (2015) examined N transfer from white clover to hybrid Bermudagrass (*Cynodon dactylon* (L.) x C transvaalensis*)* in a Alabama lawn from April to August for two successive years. Plots within the lawn received monthly supplement N at rates ranging from 0 to 8 g N m^{-2} as part of the study. Nitrogen transfer to bermudagrass was modeled as a quadratic response with maximum transfer of N occurring at an N fertilization rate of 10 g N m^{-2} in one year and 2.5 g N m^{-2} in the other. During the two year period N transfer was evaluated, N transfer averaged 23 kg N, ha^{-1}, $yr.^{-1}$ regardless of supplemental N rate. This amounted to 24% of N fixed during the two years. McCurdy et al., (2015) concluded that the inclusion of white clover into bermudagrass is a viable option to reduce the amount of supplemental N that is needed to maintain the growth of this grass.

Chapter 3: Use of Compost and Microclover to Reduce Lawn Nutrient Runoff

3.1 Introduction

A recent assessment on the health of Chesapeake Bay revealed that the only source of nitrogen (N), phosphorous (P) and sediment pollution that is growing within the Chesapeake Bay watershed (CBW) is urban/suburban storm water (Chesapeake Bay program 2008). Nearly 9.4 % of the land area within Chesapeake Bay is turfgrass, with this amount expected to increase as the conversion of forested and farm lands to residential land uses is likely continue for the foreseeable future (Schueler 2000). Land grading and the allied construction activities that take place in the lots of newly constructed homes often lead to compact, infertile soil conditions around the house. Compacting soil around the foundation of the house is desirable because it stabilizes the foundation of the structure, however when compact soil conditions extend into areas that are to be landscaped, the result is an increased potential for runoff and poor growth of the plants that are subsequently planted into this soil (Woltemade C. 2010). In the case of lawn areas, one potential consequence of poor soil conditions is that homeowners may apply more than recommended amounts of fertilizer in attempt to improve turf density and color and to minimize weed encroachment. A recent expert panel having the goal of reducing nutrient and sediment losses from lawn areas within the Chesapeake Bay watershed, concluded that new lawns having low vegetative densities should receive some fertilizer to reduce the potential for sediment entrained P loads, however there is still a need to educate consumers in limiting lawn fertilizer use to amounts recommended by turfgrass experts within in the various states of the watershed (Chesapeake Bay Program 2013).

Compost, when used as soil amendment, can increase water entry into the soil by lowering bulk density and increasing the stability of aggregates present in the soil (Martens and Frankenberger 1992, Cogger 2005, Khaleel et al., 1981). More specifically, the increased soil organic matter levels associated with large additions of compost reduce runoff from turfgrass by increasing soil porosity and enhancing plant shoot density. The latter creates a more tortuous path for water movement allowing more time for water to infiltrate which increases the time to the initiation of runoff (Spargo et al., 2006; Curtis and Claassen 2007; Linde et al., 1997). Dramatic reductions in runoff have been observed from turf areas amended with compost prior to turfgrass establishment. Harrison (1997) incorporated compost at a ratio of 2 parts of soil with 1 part compost into the top 20 cm of glacial till soil. One year after seeding the plots with a cool season turfgrass mixture 1.47 mm hr^{-1} of simulated rainfall was applied for 30 hours. Runoff from the non-amended and compost amended plots were 34 mm and 14 mm respectively. There appears to be little information on runoff and nutrient losses from compost amended soils beyond the initial year of turfgrass establishment. In addition, data obtained by Hansen et al., (2007) suggests that shallow incorporation of compost immediately before establishment of turfgrass will not reduce runoff when compared to a mature turf present on the same native soil. In the Hansen et al., (2007) study, they created 12.5 and 25 % by volume composted biosolids soil mixes by removing 5 cm of sandy-clay loam soil and mixing it with one of two municipal biosolids composts. The compost-soil mixtures were then placed back into the areas from which native soil had originally been removed, with the site being sprigged with bermudagrass (*Cynodon dactylon L.*) on the same day. Over the course of the next eight months runoff from eight storm events was measured. There was no difference in runoff from the sprigged compost-amended soil areas when compared to the mature turf areas that were left undisturbed throughout the study. Similarly, there were no differences in N losses as measured by total N, and in the three forms of P that were measured between the compost amended and mature turf areas. The study was conducted on hillside having an 8% slope.

Compost incorporation into soils reduces the need for fertilizer by slowly mineralizing nutrients needed for plant growth. Past studies on the release of N and P from compost indicate that N and P mineralization will likely range from 6 to 21 percent for N and 10 to 50 percent for P (deHaan 1981). Hargreaves et al. (2008) reported that 10% of the N in municipal solid waste compost becomes available for plant update during the first year following incorporation, although they did cited one study (Iglesias-Jimenez and Alvarez 1993) that reported 16 to 21% of the N in a MSW compost was available within 6 months of the compost application. Berner et al., (1995) reported that one yard trimming compost had an annual N mineralization rate of 8 to 11 percent, while Zhang et al., (2006) found that most of N in a mixed biosolids-MSW compost was released in the first two years following application of the compost. According to Landschoot and McNitt (1994) 2.5 to 5 cm of the compost incorporated into the soil can meet the N requirement of turfgrass for at least two growing seasons.

In an attempt to comply with total daily maximum load limits now being placed on waters within the US, several state have placed restrictions on the timing and amount of fertilizer that can be applied to lawns (New Jersey 2010; Minnesota Department of Agriculture 2007; Maryland Department of Agriculture 2011; Virginia’s Legislative Information System. 2011; Maryland Department of Environment 2007). While the incorporation of high volume amounts of compost, such as a surface application 2.5 to 5.0 cm, will supply most if all of N needs of cool season turfgrass for first few years following establishment, at some point supplement N will be needed to maintain a turf density. Mixing clover into lawns has been proposed as a way to maintain turf color and density in lawn areas that receive little fertilizer (McCurdy et al., 2015). Lantinga (2000) reported that 160 kg N ha^{-1} year^{-1} was fixed by white clover when a pasture was managed to maintain a white clover to perennial ryegrass dry mass ratio of 1:2. According to Legard and Steele (1992), the amount of nitrogen that clover may fix can reach as high as 680 kg N ha^{-1}year^{-1} in a grass clover pasture, however a more typical nitrogen fixation range for clover is 50 to 250 kg N ha^{-1} year^{-1}.

Nitrogen transfer from clover to perennial grass species has been reported to range from 29 to 73 kg N, ha^{-1}, yr^{-1} (Cowling 1982; Mallarino et al., 1990; McNeil and Wood, 1990; Sincik, and Acikgoz, 2007) for cool season grasses and as high as 102 kg ha^{-1} yr^{-1} for warm season bermudagrass (*Cydonon dactylon*) (Mc Curdy et al., 2012). Sincik, and Acikgoz, (2007) have reported that unfertilized cool season turgrasses containing a small leaf white clover (*Trifolium repens* L. cv. Nanouk) have color and biomass densities comparable to grass-only lawns that receive 22 lb N A^{-1}, per month. The aforementioned nitrogen transfer rates, color and biomass data suggest that the inclusion of clover into lawns could reduce the N fertilizer needs of mature cool season turfgrass by about one third. Microclover is a relatively new N-fixing white clover variety that has only recently entered the lawn market in the United States. The small leaf size of microclover, allows it to blend better with turfgrasses than native white clover. The small leaf size and low growth habit of this variety diminishes the appearance of individual clover patches within lawns which most homeowners find objectionable. Additionally the nitrogen fixation ability and transfer of N to turfgrass for this variety of clover appears to be similar to that reported for larger leaf varieties of white clover (Heijden and Roulund, 2010).

Amending a soil with large amounts of compost and utilizing a turfgrass mixture containing microclover as means to reduce runoff and lawn fertilizer use are two potential turfgrass establishment best management practices (BMPs) for reducing urban stormwater pollutants. To further consider the two practices as turfgrass stormwater BMPs actual reductions in stormwater pollutant load must demonstrated with the use of such practices when compared to traditional practitioner turfgrass establishment and fertilization practices, Therefore the objectives of this study are to: 1) compare runoff, and total N, total P, and TSS losses in runoff from unfertilized plots amended with compost and seeded with a tall fescue microclover mixture with plots seeded with tall fescue and fertilized as typical lawn care operator would do in the mid-Atlantic region of US and, 2) to determine the shoot density and biomass of the two treatments described in objective one to aid in the interpretation of runoff losses from these two treatments. Runoff was monitored over a twenty-seven month period to permit characterization of temporal changes in runoff that may exist for the two treatments.

3.2 Materials and Methods

Four 12.2 m by 18.3 m plots located at the University of Maryland Paint Branch Turfgrass Research and Education Center (PBTREC) in College Park, MD were utilized for this study. The plots were located on a 3.5 % hillside slope that had previously been laser graded to establish a uniform grade down the length of the plot with cross slope of no more 0.6% within any plot. Metal sheeting was inserted to depth of 10 cm along the cross slopes sides of the plots to prevent runoff from moving into or out of the plot along the borders. Runoff at the base of the plot was intercepted by a 25 cm cut PVC pipe which directed flow to large 60 degree trapezoidal flume (Plasti Fab, Tualatin, OR) equipped with bubbler and sampling tubes. The tubes were connected to an ISCO 4230 flow meter and ISCO 3200 series autosampler, respectively (ISCO, Lincoln, NE), when storm event monitoring was actively taking place.

The soil at the site was classified as a Russett-Christiana complex fine-loamy, mixed semiactive, mesic Aquic Hapludults. The hydrologic group designation for this soil type is C or D, however the presence of tile drainage system at this site is improves the drainage properties of soil so that the actual potential for runoff for these plots is low to moderate. The physical and chemical properties of the soil within each of plots after implementing the treatments, as discussed below are provided in Table 3.1.

Table 3.1 Surface soil (0 – 12.5 cm) chemical and physical properties of the runoff plots located at the University of Maryland Turfgrass Paint Branch Turfgrass Facilityǂ.

Treatment	Unit	Compost amended TF+MC		Fertilized tall fescue	
Plot rep.		1	2	1	2
Sand	(g kg^{-1})	264	204	294	280
Silt		496	516	466	486
Clay		240	280	240	232
Organic Matter£		24	28	21.5	17
Soil type		Loam	Clay Loam	Loam	Loam
P€	(mg kg^{-1})	43	43	26.5	26
K		167	158	70	55
Mg		171	251	105	89
Ca		1091	1481	743	558
pH		6.8	6.7	5.8	5.7
CEC	Ɨ	7.5	10.4	5.9	4.7

ǂ Samples were collected from all plots 8 months after the incorporation of compost into the compost amended TF+MC plots.

Ɨ units for CEC are milliequvailents per 100 g.

£ Organic matter was determined by the lost on ignition method

€ Nutrients were determined using the Mehlich III extractant.

3.2.1 Study Treatments

Two turf establishment and management protocols were examined in this study. The protocols that were followed were considered to be treatments with each treatment being replicated twice in the study. The establishment phase of the first treatment consisted of incorporating 5 cm of yard trimmings compost to a depth of 13 cm after which the two plots receiving the compost were seeded with a mixture of tall fescue and microclover. For the duration of the study this treatment received no fertilizer or herbicides. The establishment phase of the second treatment consisted of tilling the soil to 13 cm prior to establishment, applying a starter fertilizer at seeding, and seeding the plots with monostand of tall fescue. The maintenance phase of this treatment was designed to simulate a typical treatment schedule followed a lawn care company in the mid-Atlantic region of the USA. This consisted of five yearly applications of nitrogen, a single yearly application of a pre-emergence herbicide to control annual grasses, and a once a year application of a post emergence broadleaf herbicide. The two treatments just described are hereinafter referred to as the: 1) compost amended tall fescue plus microclover treatment (Compost Amended TF+MC) and the fertilized tall fescue (Fertilized TF) treatment.

The two plots receiving the compost amended TF+MC treatment were individually amended with 100 Mg ha^{-1} of Leafgro® compost on 31 July and 2 Aug, 2012, respectively. Leafgro® is derived from the leaves, herbaceous plants, grass clippings, and ground woody plant material of properties located in Montgomery and Prince Georges County MD. The chemical properties of this compost, as determined by the University of Massachusetts soil testing laboratory, are shown in Table 3.2. The plots were smoothed to finished grade on the day they were tilled and were then covered with a plastic tarp until the plots were prepared for seeding in the fall. The two plots receiving the Fertilized TF treatments were rototilled to depth of 13 cm and smoothed to a finished grade on 6 and 8 August 2012. A tarp was not placed over these plots in the interval being smoothing the plots and seeding them.

Table 3.2 Chemical properties of compost incorporated into compost amended TF+MC plots at the University of Maryland Turfgrass Paint Branch Turfgrass Facility.

Compost	Unit	Leafgro®
Soluble salts	(ds M^{-1})	1.7
Total N	(%)	2.12
Organic Matter		58.3
Organic Carbon		31.5
NO_3-N	(mg kg^{-1})	219
NH_4-N		6
P		25
K		509
Ca		40192
Mg		351
C/N ratio		14.9
pH		7.6

Between 21 and 24 September, all plots were verticut to a depth of 0.5 cm in two directions and then seeded. The compost amended TF+MC plots were seeded with mixture containing 95% 'Faith' tall fescue, and 5% rhizobium (*Rhizobium leguminosarum biovar*) coated microclover at a rate 342 kg ha^{-1}. The Fertilized TF plots were seeded at the same rate with 100% 'Faith' tall fescue, after which 217 kg ha^{-1} of 18-24-12 was broadcast into the seedbed. All four plots were covered with tobacco blankets on the day of seeding to prevent seed and seedling washout until the seedlings were firmly rooted into the soil.

The Fertilized TF plots received 26 kg ha^{-1} of urea fertilizer on 1 April 2013, 9 April, 2014 and 5 June 2015. The same rate of sulfur coated urea was applied to these same plots on 4 June, 5 Sept., 16 Oct., 15 Nov. 2013; 5 June, 7 Sept., 6 Oct., 10

Nov. 2014; and 2 April and 15 June 2015 . Preemergence annual grass herbicide products were applied to the Fertilized TF plots as follows: 1.06 kg ha^{-1} of Dimension (dithiopyr) 40 WP on 2 May 2013 and 28 April, 2015 and 3.7 kg ha^{-1} PreM (pendimethaline) product on 22 April, 2014. Broadleaf post emergence herbicide applications made to the Fertilized TF treatment plots consisted of 2 kg ha^{-1} of Confront (triclopyr + clopyralid) applied on 12 Sept. 2013, and 30 May 2014. Throughout the growing season the turf in all plots was mowed weekly at 50 mm using a walk behind rotary mower with the clippings being returned. Supplemental irrigation was applied only when drought stress symptoms were observed within the plots.

3.2.2 Monitoring and Sampling of Runoff

Monitoring of natural runoff events took place from 1 April 2012 to 30 June 2015. Due to equipment limitations monitoring activities were suspended throughout much of the winter months and whenever persistent below freezing temperatures were anticipated. Thus snowmelt generated runoff and storms that may have produced runoff at temperatures close to, or below freezing, were not examined in this study. Discrete sampling of runoff occurred on a flow weighted basis with the first sample being collected when flow exceeded 0.02 L s^{-1}. Initially, a flow weighted collection interval of 2.5 mm (557 L) of runoff was used. However this was adjusted downward as the study progressed when it became apparent that runoff losses for many events were less than the initial sampling interval. In the last year of study the flow weighted collection interval was dependent on projected storm rainfall amounts, with the programmed collection interval typically being set at 0.3 or 0.6 mm of runoff. Storm event flow losses were calculated from one minute flow rate averages that were stored in flow meter every five minutes. Sample collection times stored in the autosampler were used along with the flow rate data to calculate storm water losses that occurred between the collection of successive samples. Daily precipitation was retrieved from a weather station located 1 km from the study site location.

3.2.3 Sample Analysis

Samples were retrieved from the field within 33 hours of the end of a storm event, with the sample being placed in a refrigerator maintained at 4 °C within 1 hour of being retrieved from the field. A 50 mL aliquot of the sample was acidified to pH of 1.6 to 1.9 within 34 hours of being collected from field. Analysis of the total-N and total-P concentration in the acidified sample occurred within 30 days of retrieval from the field. Total-N and total-P were determined using the alkaline per sulfate digestion method described by Patton and Kryskalla (2003) for simultaneous determination of dissolved total-N and total-P in filtered whole water samples. Duplicate and N and P spiked samples were also prepared from the first and second field collected samples to document precision and accuracy of the method. Storm events having samples with a relative percent difference of greater than 25% for precision and 20% for accuracy were not included in the final data based used to calculate N and P load losses.

Non- acidified portions of the collected samples were used to determine the amount of total suspended solids (TSS) present in the sample. The TSS of a sample was determined using the American Public Health Standard Method 2540-D (American Public Health Association, 2005) with analysis occurring within one week of retrieval from the field. Precision of the method was evaluated on first sample collected from the field for all events generating runoff in 2014 and 2015. Samples collected in 2013 and analyzed without the inclusion of a precision measurement were not included in the final TSS database. Storm event TSS data having a precision value outside 99% confidence interval for the previous 12 measures were also not included in the final database used to calculate TSS load losses.

3.2.4 Turf Shoot Density and Biomass

Shoot density and standing dry biomass within the turf canopy were assessed ten times during the course of the study. Five 58 mm diameter plugs were collected from each plot along diagonal transect running the length of the plot on 17 July and 13 Nov. 2013, 13 May, 9 July, 15 Sept., and 11 Nov. 2014, and 13 May, 22 July and 23 September 2015. The cores were collected 5 to 7 days after mowing the plots to a height of 50 mm. Shoots were separated from soil at time of counting by cleaning using tap water. A stem containing one or more leaves was considered to be a single turfgrass shoot while a single microclover shoot consisted of a node, leaf and petiole present on the stem of microclover plant. After counting the shoots were gently rinsed in water and placed into oven maintained at 120^{o}C for five days, after which the dry weight of the collected biomass was determined.

3.2.5 Data Analysis

Runoff was expressed as the depth of precipitation lost as runoff for storm events where runoff occurred. Cumulative annual runoff for the two treatments were compared with one another using an unpaired, equal population variance, t-test. Load losses of N, P and TSS as a function of the depth of runoff were pooled for all events where two or more depth increments of runoff were collected. Use of single or separate linear regression line for the two treatments was assessed by the examining the runoff depth by load loss interaction for each of the three response variables. The treatment and date of sampling effects on shoot density and dry mass production were examined by analysis of variances using the SAS Proc Mixed procedure (Littell et al., 2006).

3.3 Results

3.3.1 Runoff

With few exceptions runoff was monitored when the temperature remained above freezing from 1 April to 31 December in 2013 and 2014 and from 1 April to 30 June in 2015. During this time a storm needed to produce at least 6 mm of rainfall to generate runoff from one or more plots. Runoff was defined as any plot producing more than 2 L of flow over the course of the event. Ninety percent of runoff events were associated with storms events having more than 10 mm of rainfall (Figure 3.1). During the aforementioned monitoring period there were a total 53 storm events having at least 10 mm of rainfall with 18 of these events generating runoff from one or more of the plots (Table 3.3). Runoff was measured with confidence for 16 of the 20 runoff events that occurred over duration of the study.

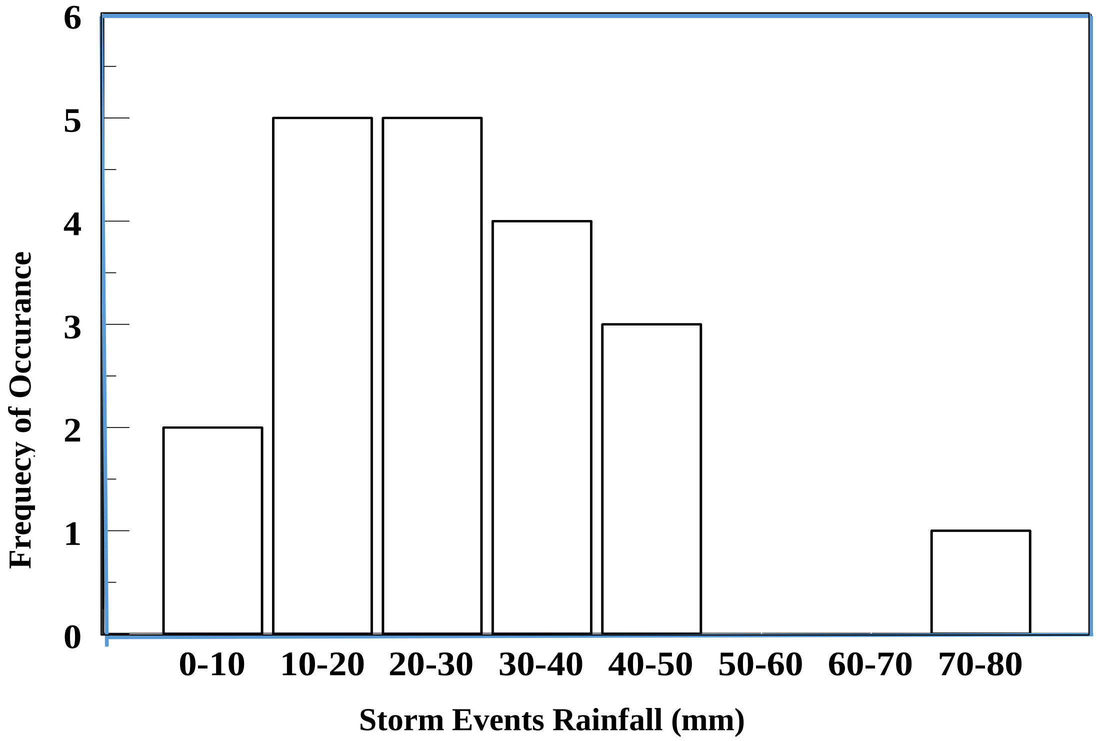

Figure 3.1 Rainfall amount for storms that generated runoff.

Table 3.3 Yearly summary of storm events and runoff data collection at University of Maryland Turfgrass Paint Branch Turfgrass Facility.

Year	Evaluation period	Range in storm event precipitation (mm)	Storm events > 10 mm	Number of storm events runoff detected	Number of events flow summarized	Number of events load summarized
2013	April 1-Dec 31	0.3-40.6	21	8	5	2
2014	Jan 11, April 1-Dec 31	0.3-62.2	21	9	8	4
2015	April 1-June 30	0.3-43.4	11	5	3	3

Figure 3.2 shows the proportion of rainfall that was converted to runoff for storms that generated runoff for each year of the study. Three of the four largest storm events that generated runoff (Figure 3.1) are not included in this summary figure

because runoff flowed back into the flumes during these events. When backflow occurs erroneously high flow rates are recorded by the flow meter. Runoff losses when expressed on an annual basis were consistently lower for the Composted TF+MC treatment that the Fertilized TF treatment. In 2013, 2014 and 2015 runoff losses from the Compost amended TF+MC treatment was 49, 57 and 33 percent lower than that measured in fertilized TF plots respectively. Only the runoff amounts measured in 2013 were significantly different from one another.

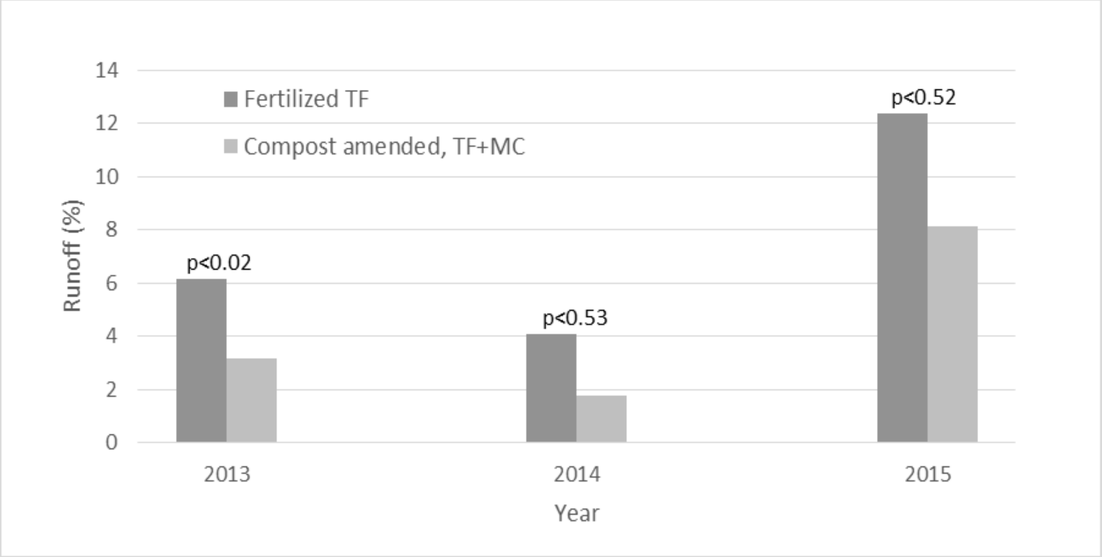

Figure 3.2 Cumulative runoff expressed as a percent of total precipitation for six events that generated runoff in 2013, eight events that generated runoff in 2014 and three events that generated runoff in 2015.

3.3.2 Load Losses in Runoff

Load losses of total-N, total-P and TSS as function of runoff amount are shown by treatment in Figure 3.3. The linear regression coefficient of determination values for N and P load losses ranged from 0.77 to 0.90 indicating that the equations for the two treatments were a moderately good predictors of total N and total P losses up to 15 mm of runoff. The coefficient of determination value for TSS load losses was 0.62 for the fertilized tall fescue and 0.79 for compost amended fescue plus microclover lawn, indicating the regression lines were poor to moderately good predictors of TSS loss. Additionally, the predictive ranges of the two equation was less than 2 mm indicating the potential usefulness of the two equations was only as a predictor of storm first flush losses. In the case of all three pollutants, load losses for a given amount of runoff were greater from the Compost Amended TF+MC plots than from the Fertilized TF plots.

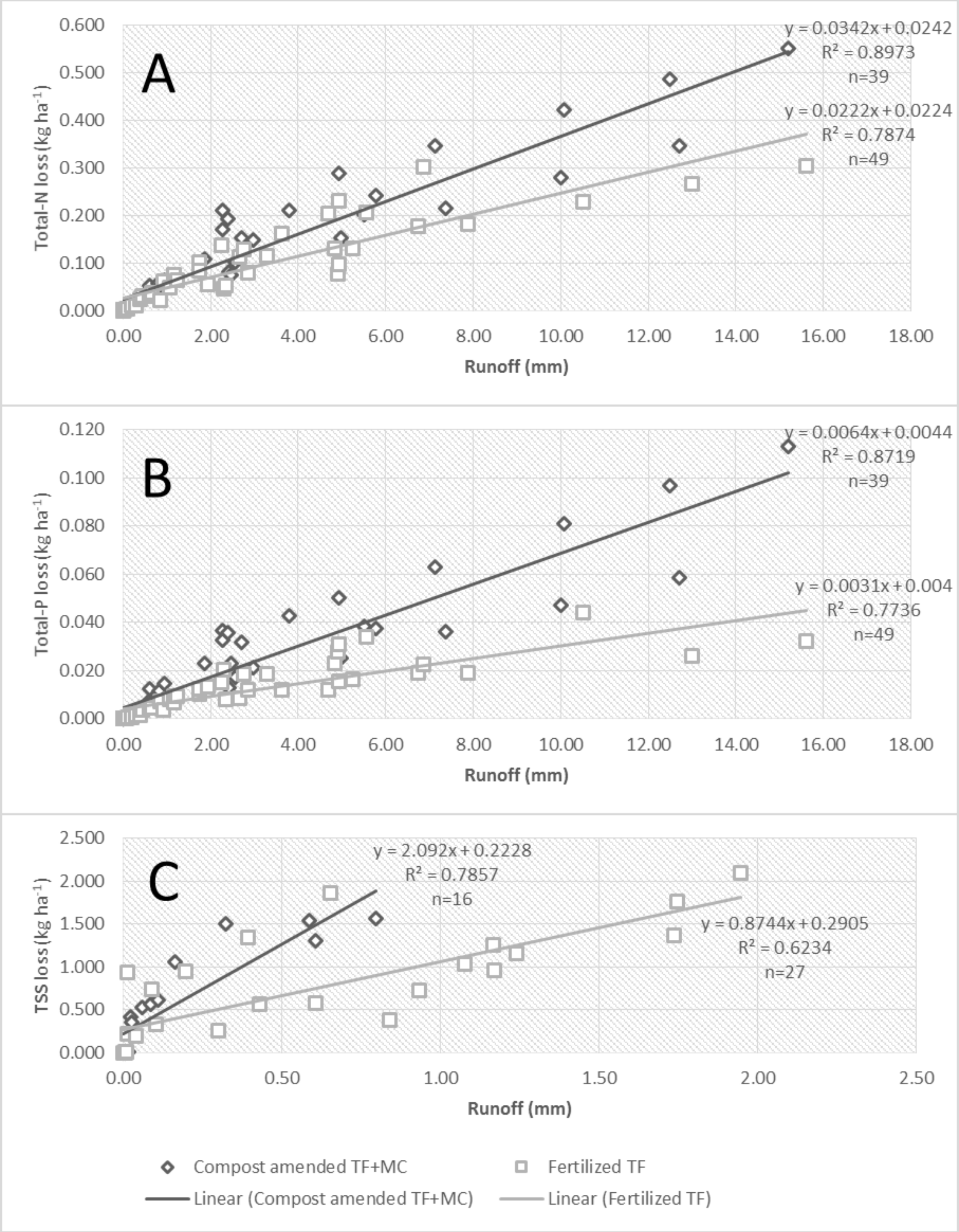

Figure 3.3 Cumulative loss of nitrogen (A), phosphorous (B) and total suspended solids (C) from tall fescue plus microclover lawns established in a compost amended soil, compared to fertilized tall fescue lawns established in non-compost amended soil.

Figure 3.4 shows the percent reduction in runoff that would need to occur from the compost amended TF + MC plots to have total-N and total-P load losses equivalent to that observed from the Fertilized TF plots for runoff amounts up to 15 mm. The percent reduction that would need to occur within compost amended TF+MC plots varies with the amount of runoff that occurs within the Fertilized TF plots; however, once runoff from the Fertilized TF plots plot exceeds 2.5 mm, the percent runoff reduction that needs to occur becomes fairly stable for both nutrients For storms that generate more than 2.5 mm of runoff from the Fertilized TF plots, a runoff reduction of 35 to 37% would be needed from the Compost Amended TF + MC plots to have a N load loss equivalent to that of the fertilized TF plots. In the case of total-P load loss, the required reduction in runoff is 52 to 54%.

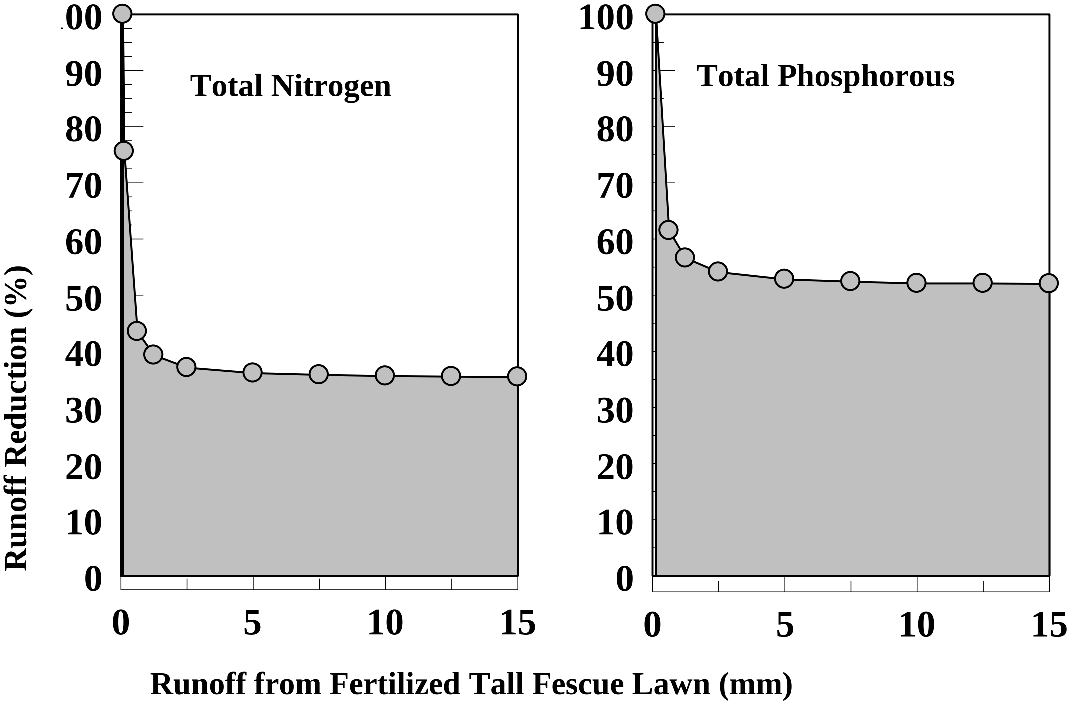

Figure 3.4 Required reduction in runoff from a compost amended tall fescue + microclover lawn needed to reduce total-N and total-P load losses to a level equal to that observed from a fertilized tall fescue lawn.

3.3.3 Shoot Density and Shoot Dry Biomass

A total of 9 shoot collections were conducted in July and November of 2013, May, July, September and November in 2014 and May July September in 2015. Lawn shoot density and biomass production varied with time, with significant differences (P<0.05) between the Compost Amended TF+MC and Fertilized TF treatments being seen on some sampling dates, for both response variables (Tables 3.4, 3.5 and 3.6). Total shoot density production was always higher in Compost Amended TF+MC lawns, than in Fertilized TF lawns, with the difference between the two treatments being significant on 3 of the 4 sampling dates in 2014 (Table 3.5). There was no consistent trend in shoot dry biomass production between the two treatments although significant differences between the two treatments were measured on 2 of the 4 sampling dates in 2014 (Table 3.6). When examining the density of just the tall fescue shoots there was little difference between the two treatments on all 9 sampling dates (Figure 3.5A). In contrast, the mass of tall fescue shoots in the Fertilized TF plots was consistently higher than the mass of tall fescue shoot in the Compost Amended TF+MC plots with difference between the two being significant on 3 of 9 dates (Figure 3.5B).

Table 3.4 Analysis of variance of shoot density and dry biomass in runoff plots at University of Maryland Turfgrass Paint Branch Turfgrass Facility.

Source of variance	Degrees of freedom	Shoot density		Dry mass	
		F Value	Pr>F	F Value	Pr>F
Treatment	1	62.12	<0.0001	0.51	0.4858
Time	8	5.17	0.0018	14.75	<0.0001
Treatment*Time	8	3.53	0.0125	2.87	0.0302
Error	18	45.2	-	0.012	-

Table 3.5 Shoot density in tall fescue plus microclover lawns established in a compost amended soil, compared to fertilized tall fescue lawns established in non-compost amended soil.

Shoot Density (m2)									
Date	Jul-13	Nov-13	May-14	Jul-14	Sep-14	Nov-14	May-15	Jul-15	Sep-15
Lawn Care treatment	12,300	11,200	14,800	12,800	11,800	13,550	15,800	17,750	10,000
BMP treatment	19,000	20,600	23,950	36,750	20,400	21,850	24,550	20,550	11,850
Significance Probability	0.1	0.11	0.32	0.03	0.06	0.04	0.1	0.24	0.29

Table 3.6 Shoot dry mass in tall fescue plus microclover lawns established in a compost amended soil, compared to fertilized tall fescue lawns established in non-compost amended soil.

Shoot dry mass (kg ha^{-1})									
Date	13-Jul	13-Nov	14-May	14-Jul	14-Sep	14-Nov	15-May	15-Jul	15-Sep
Fertilized TF	0.64	0.51	0.86	0.78	0.72	0.76	1.13	1.15	0.81
Compost amended TF+MC	0.45	0.58	0.82	1.03	0.65	0.87	1.25	0.80	0.69
Significance Probability	0.06	0.65	0.82	0.1	0.04	0.04	0.59	0.07	0.31

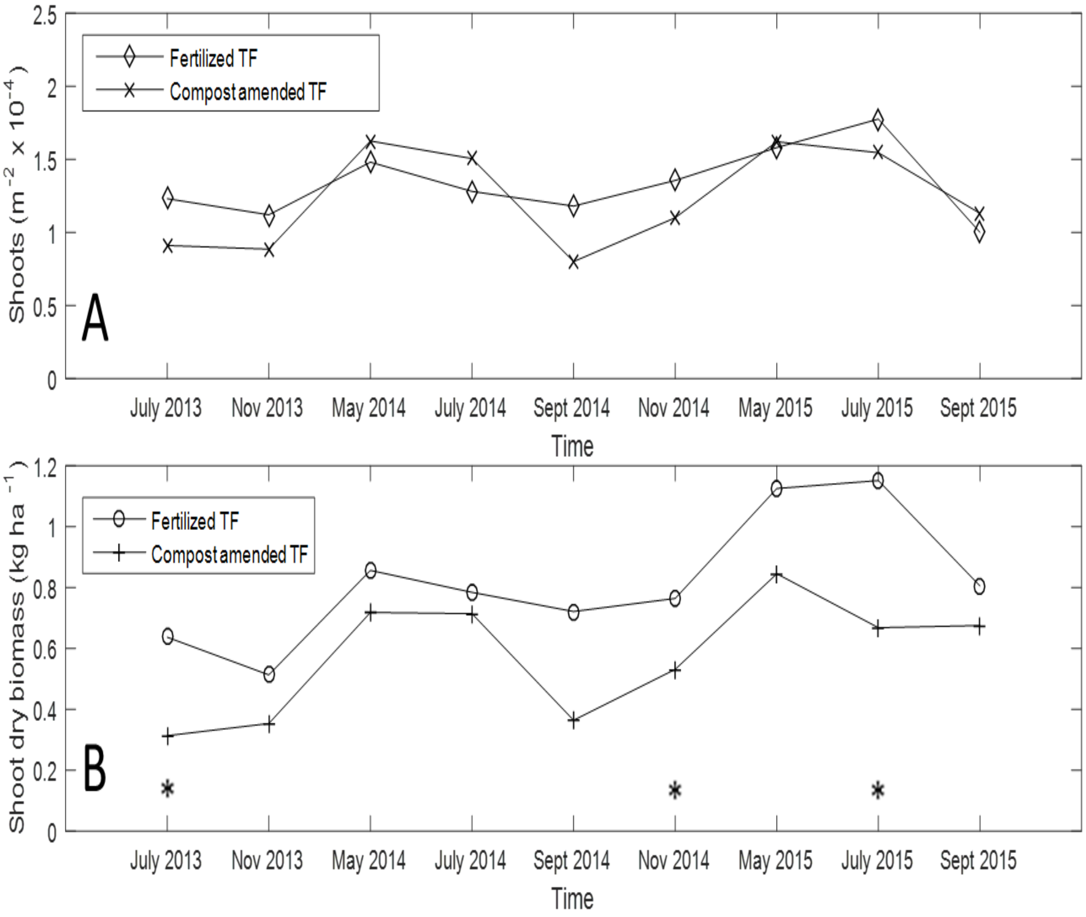

Figure 3.5 Tall fescue shoot density (A) and biomass (B) in compost amended tall fescue plus microclover plots and fertilized tall fescue plots.
* Significantly different at $P < 0.05$ level on date where shown.

3.4 Discussion

The results presented in Figure 3.2 show that regardless of the treatment being examined, runoff losses from turfgrass were fairly low when expressed as a percentage of the amount of rainfall that occurred over the course of a storm event. While the largest runoff event of the year ended up being excluded this figure for each of the three years, there were several high rainfall events that occurred during the growing season that did not generate runoff from any of the plots. More specifically, 62% percent of the storms delivering 10 mm or more of precipitation did not generate runoff, with none of the runoff events occurring in months of July and August (data not shown). Throughout the study runoff generating events were mostly the result of storms occurring when the soil was already wet due to storms occurring a few days earlier. When the soil was dry, runoff did not occur regardless of size of the storm event that occurred. For example, during dry periods that occurred in May of 2015 and August of 2014 storm events producing 35 mm and 63 mm of rainfall on 1 June 2015 and 12 August 2014 respectively, resulted in no runoff being observed from any of the four plots. All rainfall associated with the 1 June storm occurred in less than one hour. Rainfall of this amount and duration falls within the 90% confidence interval for storms having 2 year return frequency in College Park MD, (NOAA, 2014) indicating that storms of very high rainfall intensity were required to generate runoff from the plots when the soil was dry.

Results presented in Figure 3.2 also showed that yearly runoff amounts were always less from the Compost Amended TF+MC plots than the Fertilized TF plots. This occurred because amending the soil with compost likely improved infiltration properties of the soil allowing more rainfall to enter the soil instead of being lost as runoff (Faucette et al., 2004). Increased shoot density is another factor that may have contributed to lower amounts of runoff measured from the Compost Amended TF+MC treated plots. Total shoot density was consistently higher in the Compost Amended TF+MC treated plots than in the Fertilized TF treated plots with difference being significant at 5% and 10% significance probability level on 2 and 5 of the 7 dates shoot density was measured when flow was being monitored. When averaged over the seven dates, clover + tall fescue shoot density was 1.8 times greater in Compost Amended TF+MC treated plots than in the Fertilized TF treated plots (Table 3.5). The presences of high shoot turf densities delays the time to the initiation of runoff by increasing the amount of rainfall held by the turf canopy, and reduces flow in the early stages of runoff by increasing the number of obstructions water must move around to initiate and maintain flow (Easton and Petrovic, 2004; Linde et al., 1995). Linde et al., (2005) measured the shoot densities of creeping bentgrass (*Agrostis stolonifera*) and perennial ryegrass (*Lolium perrene*) and reported that creeping bentgrass possessing a shoot density of 141,000 shoots m^{-2} held 113% more water than perennial ryegrass having a shoot density of 26,100 shoots m^{-2}. Easton and Petrovic (2004) summarized the effect of various fertilizers on Kentucky bluegrass (*Poa pratensis* L.) shoot density and runoff by fitting paired data of each to a simple linear regression model for runoff amounts up to 3. 5 mm. The slope of the regression equation for densities ranging from 5 to 10 shoots cm^2 (50,000 to 100,000 shoots m^{-2}) was -0.45 indicating that a shoot density increase of 2.2 shoots cm^2 would reduce the depth of runoff by 1.0 mm for the conditions of their study.

Large annual differences were seen in proportion of rainfall that was converted to runoff between the two treatments in each year of the study but only the difference measured in the first year of the study was significantly different. Runoff losses from individual plots became more variable with time, or viewed another way, the ranking of the depth of runoff loss from each plot on an event basis became more variable after the first year of the study. This suggests that some settling of soil within the respective plots was occurring over time. Some settling of soil at the interface of the lower plot border and the flashing directing runoff into the cut pipe was observed in the second and third years of the study, but the ranking of runoff loss from the individual plots did not correspond with changes that occurred in the level of the soil at the interface. Moreover, when it became apparent that the soil level dropped below the flashing, the interface was made level again by repacking the lower plot border edge with a small amount of sand and covering the affected area with small strips of sod. In plots of the size utilized in this study the formation of small depressions that develop within the plots over time can alter flow paths which may account for some of the increased variability see in runoff from the plots over time. Soil bulk density measurements collected five years after amending a sandy soil with 240 Mg ha compost (Tester, 1990) suggest that soil properties modified by the incorporation of compost, in the absence of traffic, will be retained for several years after the material is incorporated. Thus while the runoff from individual plots became more variable with time, the lower amount of annual runoff measured in the Compost Amended TF+MC plots over the three year evaluation period is consistent with long term improvement in the physical properties measured in compost amended soils.

Load losses of N and P per unit depth of runoff loss were greater for the Compost Amended TF+MC treated plots than for the Fertilized TF plots with the difference between the two being greater for P than N. The higher load losses of total N measured in the Compost Amended TF+MC plots is likely due to the substantial loading of N that occurred when compost was incorporated into the soil. The addition of 5 cm of yard trimming compost added 3380 ka N ha^{-1} to the soil, an amount far in excess of the N needs of turf even when assuming no more than 10% of applied N was mineralized in any year of the study.

The addition of compost to soil raised Mehllich 3 plant available P from 26 mg kg^{-1} to 43 mg kg^{-1} , which equates to low and medium levels of plant available P, respectively (A&L Eastern Laboratories, Richmond, VA). While soil test P is not always a good predictor of phosphorus losses in runoff from established turfgrass (Soldat and Petrovic, 2008), good predictive relationships have been obtained between soil test P and the cumulative runoff losses P in soils amended with compost. Hansen (et al., 2012) amended the top 5 cm of a sandy clay loam soil with two rates of either a municipal biosolids or dairy manure compost prior to establishing a lawn consisting of bermudagrass (*Cynodon dactylon* L.) and bluestem (*Andropogon gerardii* Vitman). Additional compost + woodchip soil amendment treatments were included as part of this study as were established lawns on non-compost amended soil. After monitoring P losses for 10 storm events, the cumulative total P losses were plotted as a function of acidified NH_4-OAc-EDTA soil test P for the two compost sources. Excellent fits (ie., $r^2 > .98$) were obtained for both compost sources with greater losses being predicted with increasing soil test P for composted dairy manure than the composted municipal biosolids. Good linear regressions fits were also obtained in another turfgrass compost amendment study where Mehlich-3 extractable soil test P concentrations were plotted against total dissolved mass P losses (Hansen et al., 2007).

The amount of P added to the soil from the compost was relatively small (3.2 kg ha^{-1}) when compared to the amount of N suggesting that another factor, such as the increase in pH that companied the addition of compost, may have been responsible for the relatively large increase in Mehlich-3 soil test P that occurred with the addition of the compost. Regardless, the results of this study appear to indicate that large additions of compost can result in elevated losses of P in runoff even when the addition of compost does not result high soil P test.

The Compost Amended TF+MC plots consistently had higher shoot densities than the Fertilized TF plots, although differences between the two treatments were not always statistically significant. The higher shoot densities measured in compost amended TF+MC lawns were associated with less tall fescue biomass indicating the presence of microclover suppressed the growth of tall fescue. The amount of micro clover in the compost amended TF+MC lawns was not considered excessive, although at times the combined growth of the two species was. This can be attributed to the large amount of nutrients supplied by compost over the course of the study.

3.5 Conclusions

In this study it was observed that only a small portion of precipitation was converted to runoff. This applied to both treatments that were examined with the Compost Amended TF+MC plots having 49% less cumulative runoff over the course of the study than the Fertilized TF plots (P=.09). Nitrogen and P concentrations in runoff were higher from the Compost Amended TF+MC plots that the Fertilized TF plots at equivalent depths of runoff. Predictive equations developed from concentration verses runoff depth data indicate that the runoff reductions caused by amending the soil with 5 cm of compost, and using a seed mixture of tall fescue + microclover will have lower mass runoff losses of N than a tall fescue lawn established in non-compost amended soil receiving urea based nitrogen on a schedule similar to that provided by a lawn care company located in the mid-Atlantic region of the US. Phosphorus loss in runoff from the two lawn types however will likely be about the same. The results of this study are supportive of the use of large volumes of compost and the use of microclover containing seed mixture as a means to reduce stormwater runoff and N pollutant loading from runoff. A longer term study is needed to assess the potential of microclover to persist and supply N to tall fescue, as well as to determine the long term ability of a compost amended soil to reduce runoff from established lawns.

Chapter 4: Compost Sources and Straw Thickness Effect on Tall Fescue and Clover Mixture Lawn Establishment

4.1 Introduction

Areas subjected to recent construction activity frequently possess poor soil physical and chemical conditions. Infertile subsoil is often intermixed and compacted with topsoil as part of the final grading operation at such sites. Turfgrass establishment in compacted infertile soil often results low density lawns which increase the potential for runoff (Carrow et al., 2001) and may prompt increased homeowner lawn fertilizer use in response to social pressures to achieve and maintain a certain lawn aesthetic (Carrico et al., 2012). To reduce runoff from areas recently subjected to construction activities, stormwater regulations and water conservation programs in several regions of the country now promote the practice amending soil with large amounts of compost prior to establishing turfgrass. Examples of such programs include the State of Washington, which requires that the topsoil of recently graded areas contain at least 5% organic matter prior to turfgrass establishment (WSDE 2014) and Denver Water, which requires any newly licensed premises in metropolitan Denver seeking to irrigate turfgrass or landscape areas to amend the top 15 cm of soil with at least 3.3 cm of compost prior to establishment. Additionally, the state stormwater manuals of Virginia and Pennsylvania specify high volume compost amendment of topsoil as a stormwater best management practice for compacted soils where turf is to be established.

The addition of high volume amounts of compost can also reduce the fertilizer needs of a newly established lawns. Many municipal composters in the US produce compost from yard trimmings, or biosolids. Mature yard trimmings compost typically contains from 1 to 1.5% N (Hartz, 2009) while the range in the N content of a mature biosolid compost has been reported to be much larger (Sommers et al., 1977). While the rate of N mineralization is highly variable, first year release rates of N from mature compost have been reported to typically range from 6 to 11% for biosolid and yard trimmings compost (Tester, 1977; Epstein, 1978; and Amlinger, 2003). The minimal first year N fertilization needs for a newly established tall fescue lawn in Maryland is 110 to 150 kg ha^{-1} (Turner 2013), after which this amount drops to 88 to 120 kg ha^{-1} in subsequent years (Turner, 2013). The incorporation of 150 Mg ha^{-1} of a compost containing 1% N and having an N mineralization rate of 10% would likely supply all the N needs of a first year tall fescue lawn. A typical high volume compost application rate is amending 2 parts soil with 1 part compost, or a surface application of 5 cm compost (Pit et al., 1999; Reinsch et al., 2007). Using the mid- point of the bulk densities for yard trimmings and biosolid compost reported by Reinhart et al (1993) Day et al., (1998) and Spellman, 1997 (518 kg m^{-3}), a 5 cm surface layer of compost would result in the application of 259 Mg ha^{-1} of compost. This calculation suggests that no to very little N fertilizer would be required in the second year following the incorporation of 5 cm of compost, but after that period some supplemental N may be required to maintain turf density and color.

Introducing clover into lawns has been proposed as a way to maintain turf color and density in lawn areas that receive little fertilizer (McCurdy et al., 2015). The degree to which this can be accomplished will depend on ability of clover to uniformly persist in lawns subjected to various cultural practices and environmental conditions, as well as the amount N clover provides the grass portion of the lawn. Nitrogen transfer from clover to cool season grass species has been reported to range from 29 to 73 kg N ha^{-1} yr^{-1} (Cowling 1982). In a pasture of mature tall fescue and clover Mallarino et al., (1990) reported that 29 to 49 kg N ha^{-1} yr^{-1} fixed by clover was transferred to tall fescue. More recently, Sincik and Acikgoz (2007) reported that 10 to 34 kg N $ha^{-1}yr^{-1}$ was transferred from white clover to three cool season grass species three years after establishing the grass plus clover mixtures. McCurdly et al., (2015) concluded that the inclusion of white clover into bermudagrass is a viable option to reduce the amount of supplement N that is needed to maintain the growth of this grass.

Clover growth is suppressed by high nitrogen availability with greater suppression being observed with the use of ammonium based fertilizers than nitrate based fertilizers (Blackman, 1938). The strategy of using turfgrass seed mixtures that include clover as means to supply N to turf may be a difficult one to employ in soils amended with high amounts of compost because of the initial release of high amounts of N from the compost during turf establishment. Moreover, the composition of N in the compost may dictate which types of compost should be used when there is a desire to both amend the soil to both reduce runoff and support the growth of leguminous species that will reduce turf N needs once the compost is no longer able to supply all of N needs of the turf. Sainz et al. (1998) examined the growth of red clover (*Trifolium pratense* L) grown in the b-horizon of a urban soil amended with either 10% by volume of an immature urban solid waste compost, or the same amount of vermicompost and found that clover growth was approximately five times greater in the vermicompost amended soil than in urban solid waste compost. Although the various forms of nitrogen in the compost were not measured in this study, it is well know that immature composts typically contain high amounts of ammonium ions (Barker 2001, Breslin, 1995). Given the wide spread production of both yard trimmings and biosolids compost there is a need to identify which type of compost is better suited for promoting the growth of clover in soils amended with compost.

New seedlings within residential areas often involve the use of straw. Its presence reduces erosive losses of topsoil, balance soil temperature and limits evaporative moisture losses during seed germination and early seedling growth (McCalla & Duley 1946; Unger 1978; Groen and Woods 2008). Due to the diminutive size of newly germinated clover seedings, the presence of a thick straw layer, which is sometimes found at constructions sites, could potentially impact the seedling growth and subsequent establishment of this species.

Turf color, quality and growth are highly depended on the availability of soil moisture. The addition of large amounts of compost to the soil can increase both the water retention capacity and the amount of plant available water held by the soil. For example, Epstein (et al., 1976) rototilled 240 Mg ha^{-1} of sewage sludge compost into a silt loam soil and reported that the addition of this amount compost increased the plant available water from 12.5% to 14.5%. Straw can aid in the preservation of soil moisture by acting as mulch over bare soil and newly seeded turfgrass sites (Harris and Yao, 1923; Barkley et al., 1965) and by increasing the water infiltration into a recently cultivated soil (Dudley et al., 1939). Little is known however, about the longer term effect of decaying straw cover on soil moisture preservation once near to full vegetative cover is achieved. In mature turf swards, the fraction of water loss attributable soil evaporation is considered to be small, suggesting that little benefit in moisture retention will be derived from the presence of decaying straw on the soil surface. For example using the transpiration coefficient, crop evapotranspiration ratios relationships developed by Al-Kaisi et al., (1989) and further verified by Choudhury et al., (1994) for multiple crop canopies**,** a dense tall fescue sward having a leaf area index of 3.5 (Kopec et al., 1987), is predicted to have about 87% of the measured evapotranspiration (ET) loss from the canopy occur in the form of plant transpiration losses when the turf is well supplied with water (ie., when actual ET is close to potential ET). Given the restrictions placed on irrigation of turfgrass in many regions of the country, the potential value of straw and compost in retaining soil moisture should be examined to see if the use of these two materials can reduce the need for supplemental irrigation.

The objectives of this study were to 1) determine the effect of straw amount and compost type on the establishment and growth of 95% tall fescue + 5% microclover seed mixture, and to 2) determine the effects of straw amount and compost type on soil moisture loss in a recently established tall fescue and microclover lawn.

4.2 Materials and Methods

The effect of compost when used as a soil amendment and straw amount on the establishment of a tall fescue plus microclover seed mixture was examined in two studies that took place at the University of Maryland Paint Branch Turfgrass Research and Education Center (PBTREC) in College Park MD. The first study, which was conducted in 2013 and 2014, is referred to as Study I. The second study, which took place in 2014 and 2015 is referred to as Study II. The two establishment site locations were located 0.13 km from one another with soil at both sites being mapped as Russett-Christiana complex (fine-loamy, mixed semiactive, mesic Aquic Hapludults). The soil at the Study I site was a loam soil that containined 32 g kg^{-1} organic matter, 24 mg kg^{-1} P, 113 mg kg^{-1} K and had a pH of 6.1. The soil at the Study II site was a sandy loam soil that contained 28 g kg^{-1} organic matter, 66 mg kg^{-1} P, 89 mg kg^{-1} K and had a soil pH of 5.8.

4.2.1 Study Treatments

Treatments were applied to 3 m by 1.8 m plots and consisted of three soil amendment treatments and three rates of straw broadcast over the top of the finished seedbed. The three soil amendment treatments consisted of 5 cm of either a yard trimmings compost (Leafgro® ; Maryland Environmental Services, MD) or a biosolid based compost (Orgro®, Veolia North America, MD) incorporated to a depth of 13 cm plus a non-amended control treatment. The chemical and physical characteristics of the two compost are provided in Table 4.1 and Table 4.2. Based on analysis of these materials the incorporation of 5 cm of the yard trimming compost delivered 3660 kg N ha^{-1}, 71 kg P ha^{-1} and 702 kg K ha^{-1} to the soil in Study I and 2030 kg N ha^{-1}, 196 kg P ha^{-1} and 651 kg K ha^{-1} to the soil in Study II. Similarly, the incorporation of 5 cm of the biosolid compost added 6398 kg N ha^{-1} 28 kg P ha^{-1} 121 kg K ha^{-1} to the soil in Study I and 5654 kg N ha^{-1}, 3274 kg P ha^{-1} and 137 kg K ha^{-1} to the soil in Study II. The two compost treatments received no additional nutrient additions throughout the study while the non-amended control received 73 kg N ha^{-1}, 22 kg P ha^{-1}, and 21 kg K ha^{-1} as described below.

Table 4.1 Chemical properties of composts sources used in Study I.

Compost	Unit	Orgro®	Leafgro®
Soluble salts	(ds M^{-1})	9.2	1.8
Total N	(%)	2.9	2.1
Organic Matter		45.3	54.6
Organic Carbon		24.5	29.5
Moisture		11.8	28.1
NO_3-N	(mg kg^{-1})	116	244
NH_4-N		4613	13
P		243	659
K		1068	6490
Ca		4246	12699
Mg		1165	3106
Bulk Density	(g cm^{-3})	0.5	0.47
C/N ratio		8.4	13.8
pH		7	7.2

Table 4.2 Chemical properties of compost sources used in Study II.

Compost	Unit	Orgro®	Leafgro®
Soluble salts	(ds M^{-1})	9.5	2
Total N	(%)	2.1	1.8
Organic Matter		37.9	51.4ǂ
Organic Carbon		20.5	27.9ǂ
Moisture		38.1	35.5
NO$_3$-N	(mg kg^{-1})	447	25.9
NH$_4$-N		10282	61
P		11900	1400
K		500	4500
Ca		9300	14200
Mg		1600	5200
Bulk Density	(g cm^{-3})	0.5	0.56
C/N ratio		9.9	15ǂ
pH		6.8	7.1

ǂ Initial organic matter and organic carbon results were well below the expected range. Reported results for organic matter and organic carbon are from the analysis of second sample collected from the same pile of compost, one year later.

Compost was added to plots receiving this treatment by filling a box having volumetric dimensions equivalent to a 5 cm surface application of compost. The compost was spread over the plot using garden rakes and then tilled into soil using 1 pass of a walk behind rototiller. The plots were then rolled in 2 directions using a large paver-type roller after which the plot was seeded with a mixture containing 95% Faith tall fescue and 5% ‘Pirouette’ microclover, at a rate of 342 kg ha^{-1}. The microclover seed was coated with (*Rhizobium leguminosarum* biovar *trifolii*). The non-compost amended control plots were rototilled and rolled in the same manner as the compost amended plots. Additionally, the non-composted amended plots received 39 kg N ha^{-1} on the day of seeding using an 18-24-12 starter fertilizer. Superimposed over the three soil amendment treatments was the application of 0, 5 and 10 metric ton ha^{-1} (t ha^{-1}) of dry wheat (*Triticum spp*) straw. Straw treatments were spread unchopped by hand. To minimize straw movement off of the plots caused by wind all plots receiving straw were covered with bird netting which was then secured to the surface of the soil using sod staples. The netting was removed prior to the first mowing. Compost incorporation occurred on 26 and 27 Sept. 2013 in Study I with the plots being seeded on 30 Sept. 2013. Compost incorporation and the date of seeding in Study II were 17 Sept. 2014 and 2 Oct. 2014 respectively.

4.2.2 Regular Maintenance of the Plots

Regular mowing of the plots was initiated after collecting the first set of visual observations in the spring of the year with turf being mowed at 5 cm at least every two weeks, but in most instances every week with the clippings being returned. Plots not receiving compost received a single application of 34.2 kg N ha^{-1} as sulfur coated urea (43-0-0) on 5 June 2014 in Study I and 6 May 2015 in Study II. The study areas were irrigated only when severe drought stress symptoms were expressed by the turf.

4.2.3 Data Collection

Visual percent turf cover ratings where 100% represents no bare soil or straw areas seen within the plot and 0% represents no verdure present within the plot, were collected in Study I on 28 Mar., 28 July, and 6 Oct. 2014 and on 30 Mar., 6 May, 5 June, 21 July, 27 Aug., 9 Nov., 2015 in Study II. Visual Color ratings were collected on 21 May, 28 July and 6 Oct. 2014 in Study I and on 6 May, 5 June, 21 July, 27 Aug., and 9 Nov. 2015 in study II. Color was assessing using a 1 to 9, scale with 9 being equal to the darkest green color and 1 equal to brown colored turf. Percent visual clover cover in the plots was assessed on 31 Mar., 21 May, 3 June, 28 July and 6 Oct. 2014 in Study I and on 30 Mar., 6 May, 5 June, 21 July, 27 Aug., and 9 Nov. 2015 in Study II. Visual overall quality ratings were collected at or near the end of the two studies to assess the overall appearance of the turf once full turfgrass cover had been achieved. Quality measurements were based on the integrated appeal of turfgrass color, coverage, and uniformity of the turfgrass using a scale from 1 to 9 where 9 is attainment of highest quality turf possible. The presence of brown patch (*Rhizoctonia solani*) within the plots was accessed on 27 Aug. 2015 in Study II by visually estimating the percentage plot area that was affected by this disease.

Soil moisture loss over time was measured to depth of 15 cm by Time Domain Reflectometry (6050X1 TRASE System I; Soil Moisture Equipment Corp, Santa Barbara CA). Three measurements were collected at equally spaced intervals from one another within a plot each time an assessment of soil moisture took place. The average of the three measurements was used as plot soil volumetric moisture content for the day. Measurements were collected in morning with sampling taking place at various intervals of time depending weather conditions that were expected to result in rainfall. Readings were collected before the expected rainstorm.   The collection of soil moisture data was restricted to the months of July and August and was initiated whenever the moisture in the top 15 cm of soil was wetted to near field capacity from previously occurring rainstorms, and additionally, when the weather forecast for the upcoming week predicted no rainfall. Measurements were collected until naturally occurring rainfall rewetted more than top few (i.e., 1-3 cm) centimeters of soil. The data collection periods from the well moisten state reading to the reading collected before an increase in soil moisture was measured are referred to as dry down periods and occurred from 18 July to 11 Aug. 2014 in Study I and from 8 July to 25 July, 31 July to 9 Aug. and from 12 Aug. to 18 Aug. 2015 in Study II.

4.2.4 Data Analysis

A randomized complete block experimental design was used to assign treatments to individual plots within the two study areas. Each soil amendment by straw rate treatment combination was replicated three times in each study. All response variable treatment effects were subject to analysis of variances using the SAS Proc Mixed procedure (Littell et al., 2006). The SAS LSMEANS procedure was used to compare treatment means when the simple or interactive source effects were found to statistically significant at α=0.05 level.

4.3 Results and Discussion

Daily precipitation and maximum temperature data for time intervals associated with Study I and Study II are shown in Figures 4.1 and 4.2 respectively. Rainfall and daily maximum temperature shortly after seeding in both studies were sufficient to trigger prompt seeding emergence, however a multi-day rainfall event that occurred shortly after seeding the first study caused some seed washout in plots not covered with straw. This slowed the establishment of turf in these plots as discussed below. No other adverse effects were attributed to weather that occurred over the course of the two studies.

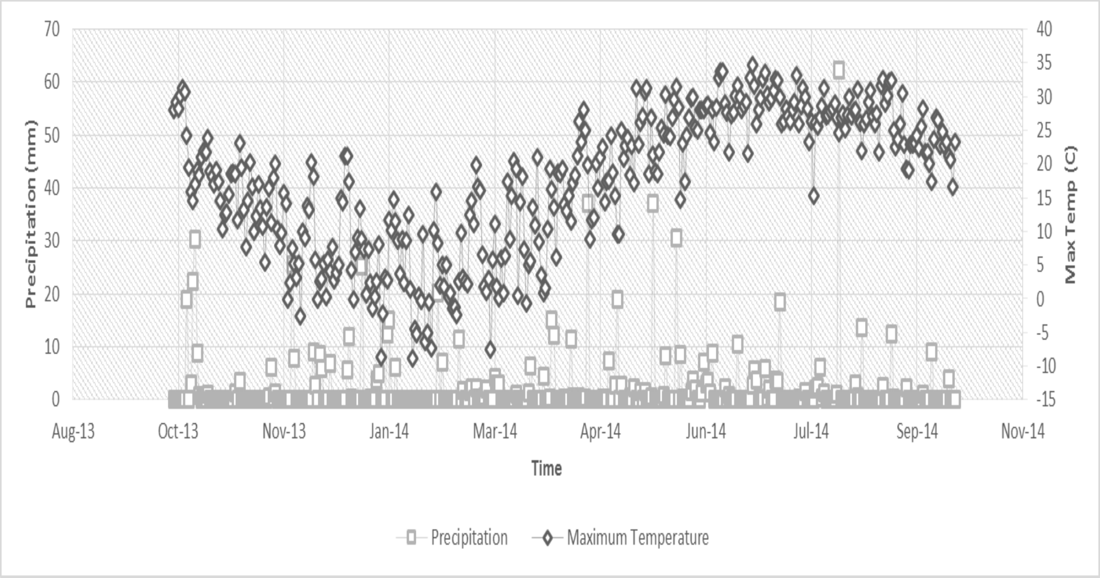

Figure 4.1 Precipitation and maximum daily temperature for Study I which took place from 1 October 2013 to 6 October 2014.

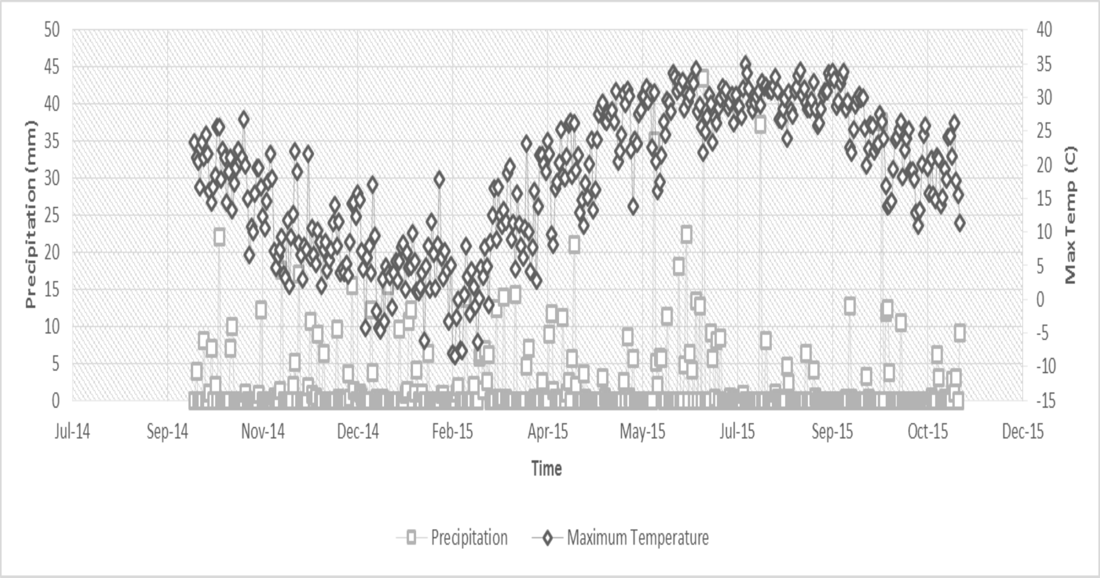

Figure 4.2 Precipitation and maximum daily temperature for Study II which took place from 2 October 2014 to 9 November 2015.

4.3.1 Turf Cover

Turfgrass establishment was assumed to be complete when plot turf cover exceeded > 95%. Almost all plots achieved this by 6 Oct. 2014 in Study I. In Study II most plots reached this level of cover by 27 Aug.2015, In the plots that did not achieve 95% turf cover by 27 August, almost no increase in cover was seen on subsequent rating dates. In both studies the time by straw interaction was significant as was the time by compost interaction (Table 4.3 and 4.4). In the case of the former interaction, there was a consistent trend in the 5 ton ha^{-1} straw treatment of having the highest turf cover in Study I with turf cover being greater than the no straw treatment on two of the three evaluation dates (Table 4.5). In Study II the no straw and 5 t ha^{-1} straw treatments had similar levels of turf cover on all six evaluation dates with both of these treatments achieving full cover by 27 Aug. 2015 (Table 4.6). With the exception of the first rating date in Study I the 10 t ha^{-1} straw treatment had the lowest percent cover all evaluation dates in both studies. The 5 ton ha^{-1} straw treatment had higher turf cover than the 10 t ha^{-1} straw treatment on all evaluation dates in both studies. It was apparent that hand applying non-chopped straw at the 10 ton ha^{-1} rate in Study II resulted in matting of the straw in portions of the plot which effectively smothered both newly emerging tall fescue and microclover seedlings. This created bare spots within the plots receiving this treatment that did not fill in over the course of the study. The low rate of turf cover in seen in the no straw treatment plots on the first evaluation date in Study I was the result of a rainstorm that occurred shortly after broadcasting the seed in Study I. This rainstorm delivered 76 mm of precipitation within 6 days of seeding plots and washed-out some seed from plots not receiving straw. While it was not possible to quantify the amount of seed washout that occurred, the lost was relatively uniform within most plots resulting in a delay to the attainment of full cover rather that the creation of bare soil areas within the plots.

Table 4.3 Study I analysis of variance for the effect of soil amendments, straw depth and time on visual percent turf cover, visual percent clover cover, visual turf color and visual turf quality.

Source of variance	Cover			Clover			Color			Quality		
	df	F Value	Pr>F	df	F Value	Pr>F	df	F Value	Pr>F	df	F Value	Pr>F
Soil Amendments (SA)	2	5.9	P=0.004	2	46.25	P<0.001	2	34.62	P<0.001	2	14.06	P<0.001
Straw	2	34.44	P<0.001	2	8.94	P<0.001	2	19.22	P<0.001	2	4.11	P=0.04
SA *Straw	4	2.47	P=0.05	4	1.75	P=0.14	4	0.42	P=0.8	4	0.15	P=0.96
Time	4	49.72	P<0.001	5	65.81	P<0.001	3	21.23	P<0.001	-	-	-
SA*Time	8	2.14	P=0.04	10	13.81	P<0.001	6	2.27	P=0.046	-	-	-
Straw*Time	8	13.57	P<0.001	10	4.47	P<0.001	6	6.53	P<0.001	-	-	-
SA*Straw*Time	16	1.39	0.17	20	1.36	0.16	12	0.32	P=0.98	-	-	-
Error	44	72.11	-	50	94.79	-	35	0.72	-	8	0.44	-

Table 4.4 Study II analysis of variance for the effect of soil amendments, straw depth and time on visual percent turf cover, visual percent clover cover, visual turf color and visual turf quality.

Source of variance	Cover			Clover			Color			Quality		
	df	F Value	Pr>F	df	F Value	Pr>F	df	F Value	Pr>F	df	F Value	Pr>F
Soil Amendments (SA)	2	3.25	P=0.04	2	56.99	P<0.001	2	159.6	P<0.001	2	5	P=0.01
Straw	2	79.9	P<0.001	2	47.8	P<0.001	2	0.3	P=0.74	2	4.71	P=0.02
SA*Straw	4	3.77	P=0.007	4	12.64	P<0.001	4	3.19	P=0.02	4	2.34	P=0.07
Time	5	64.02	P<0.001	5	42.99	P<0.001	4	71.78	P<0.001	1	31.86	P<0.001
SA*Time	10	1.89	P=0.05	10	12.91	P<0.001	8	10.92	P<0.001	2	9.21	P<0.001
Straw*Time	10	19.87	P<0.001	10	8.81	P<0.00	8	2.93	P<0.01	2	2.86	P=0.07
SA*Straw*Time	20	0.84	0.66	20	3.29	P<0.001	16	1.19	P=0.29	4	3.15	P=0.03
Error	53	31.2	-	53	59.3	-	44	0.27	-	17	0.38	-

Table 4.5 Effect of soil amendment and straw amount on visual percent turf cover and visual percent clover cover in Study I.

Treatment	Turf Cover 3/28/14	Turf Cover 7/28/14	Turf Cover 10/6/14	Clover Cover 5/21/14	Clover Cover 6/3/14	Clover Cover 7/28/14	Clover Cover 10/6/14
	%						
Soil Amendments							
Mineral Fertilizer	69ab†	87a	97ab	19a	21a	55a	68a
Yard Trim Compost	66b	83a	96b	13ab	7b	36b	44b
Biosolid Compost	79a	88a	98a	7b	1b	7c	4c
Straw							
t ha^{-1}							
0	53C	84AB	97B	10A	14A	45A	47A
5	93A	92A	99A	15A	12AB	39A	45A
10	68B	82B	96B	13A	3B	14B	25B

† Numbers followed by the same letters in columns are not significantly different at a α = 0.05 According to Fisher's LSD means separation test. The upper case letters were used to express the mean separation test results of straw amount while the small case letters were used to express the mean separation test results of nitrogen souces.

Table 4.6 Effect of soil amendment and straw amount on visual percent turf cover in Study II.

Treatment	Turf Cover 3/30/15	Turf Cover 5/6/15	Turf Cover 6/5/15	Turf Cover 7/21/15	Turf Cover 8/27/15	Turf Cover 11/9/15
	%					
Soil Amendments						
Mineral Fertilizer	71a†	78ab	80b	89a	91a	91a
Yard Trim Compost	69a	76b	79b	88a	94a	94a
Biosolid Compost	71a	82a	89a	91a	93a	93a
Straw						
t ha^{-1}						
0	85A	90A	92A	92A	95A	95A
5	85A	88A	90A	94A	95A	95A
10	41B	59B	66B	82B	88B	88B

† Numbers followed by the same letters in columns are not significantly different at a α = 0.05 according to Fisher's LSD means separation test. The upper case letters were used to express the mean separation test results of straw amount while the small case letters were used to express the mean separation test results of nitrogen souces.

The effect of soil amendment treatment on turf cover was most apparent on 28 Mar. 2014 in Study I and on the 6 May and 5 June ratings in Study II. The biosolid compost treatment had higher turf cover than the yard trimming compost on all three dates. The differences seen in the two treatments is likely due to the greater amount of inorganic N (NO_3-N NH_4-N) in the biosolid compost when compared to the other two soil amendment treatments. In Study I the biosolid compost treatment contained 18 times more inorganic N when compared with yard trimming compost while in Study II, the biosolid compost had 120 times more inorganic N in the compost compared with yard trimming compost treatment (Table 4.1 and 4.2). The results of both studies indicate the biosolid compost can provide more available nitrogen to turfgrass during the establishment phase than yard trimming compost treatment. The biosolid compost also had more turf cover on 5 June 2015 in Study II than the non-amended mineral fertilizer treatment. On all other evaluation dates in both studies there was no meaningful difference in percent turf cover between these two treatments. The difference in cover between the biosolid and non-amended fertilizer treatment on 5 June 2015 is likely a consequence of the minimal amount of fertilizer supplied to the turf grown in the non-amended soil. Over the course of Study II the non-amended fertilizer treatment received a total of 73 kg N ha^{-1} of N, which is considered to be low for newly established lawn (Turner 2013). Up until the 6 May rating date the mineral fertilizer treatment had only been fertilized once, which was on the day of seeding (2 Oct. 2014).

4.3.2 Percent Clover Cover

In Study I the time by straw interaction was significant for the percent clover present in the plots as was the time by soil amendment interaction. (Table 4.3). In Study II the effect of the straw and soil amendment treatments on clover percentage changed over time with the temporal changes for one treatment being dependent on the level of the other. (Table 4.4). In Study I on all four evaluation dates the non-compost amended plots had significantly higher clover coverage than the plots amended with yard trimmings or biosolid compost (Table 4.5). By the 28 July rating date a substantial increase in the amount of clover present in the plots amended with yard trimming compost was observed relative to earlier measurements collected from these plots. In contrast, little to no improvement was seen in percent clover present plots amended with biosolid in summer and fall of 2015. This resulted in a higher percent of clover being present in yard trimming amended plot when compared to the biosolid amended plots in summer and fall of 2015. In the case of the straw treatments in Study I, the 0 and 5 t ha^{-1} straw treatments had comparable plot clover cover, with the two treatments having higher clover cover than the 10 t ha^{-1} on all evaluation dates except 21 May , when the clover in all three straw thicknesses treatments were not statistically different from one another.

In Study II a significantly higher percent clover was seen in plots amended with yard trimming compost when compared to non-amended and biosolid amended plots on 6 May, 5 June and 21 July 2015 at the 0 t ha^{-1} straw rate but not at the 5 and 10 t ha^{-1} straw rate (Figure 4.3). At the time of the late summer and fall ratings, there was a consistent trend of a greater amount of clover being present in plots amended with yard trimming compost than in non-amended plots receiving no straw but the difference between the two treatments was not statistically different. At the 5 t ha^{-1} straw rate, the non-amended plots and those that received the yard trimmings compost had higher clover cover on 27 Aug. and 9 Nov. 2015 than did plots that received that received the biosolid amendment treatment. At the 10 t ha^{-1} straw rate in Study II there was little difference in clover cover between the three amendment treatments on all five dates percent visual clover cover was evaluated. The generally low levels of clover found in the biosolid amended plots was likely due to the high amount of nitrogen applied with this material. More specially, the high amount of ammonium nitrogen present in biosolid compost (Table 4.1 and 4.2) likely reduced the growth of clover in both studies. The results of this study are in agreement with those McAuliffe et al., (1958) and Blackman (1938) who reported that use of ammonium containing mineral fertilizers will reduce the portion of clover in a mixed grass and clover sward. Herbage yields of mixed grass and clover sward in response various rates conducted by Reid (1970) suggest that annual nitrogen fertilization levels in excess of 222 kg ha^{-1} will lead to decline in the proportion of clover in a mixed white clover and perennial ryegrass sword. When the commonly assumed nitrogen mineralization rate of 10% per year for biosolid based compost is applied to biosolid compost used in this study, the incorporation of 5 cm this compost would mineralized 366 (Study I) to 640 (Study II) kg N ha^{-1} in the first year of turf establishment. Thus both nitrogen source and amount contributed to the low microclover levels seen in the plots that received the biosolid compost.

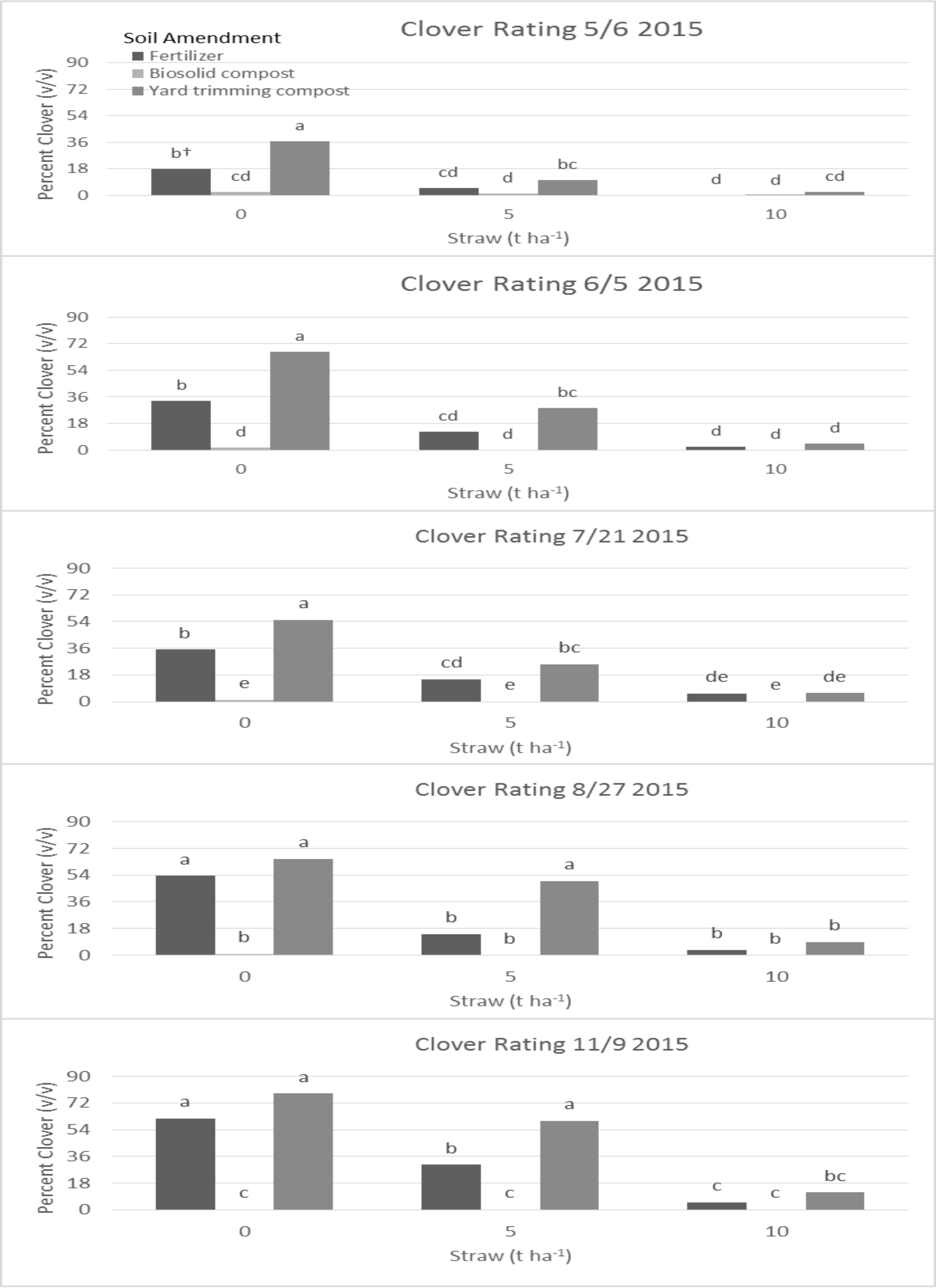

Figure 4.3 Turf visual clover time by soil amendment by straw amount interaction observed in Study II.

† Bars with same letters are not significantly different at a $\alpha = 0.05$ according to Fisher's LSD means separation test.

4.3.3 Turf Color

In both studies I and II the effect of the straw and soil amendment treatments on turf color varied with time, with the temporal effects of two treatments being independent of one another (Table 4.7 and 4.8). Except on 21 May 2014 in Study I, turf established in soil amended with yard trimming compost had lower color performance than turf established in soil amended with biosolid compost. The biosolid amended treatment had darker colored turf on all rating dates in both studies when compared to the non-amended fertilized soil treatment. Turf grown in the non-amended mineral fertilizer plots had color that was equivalent to, or lower than, turf grown in soil amended in yard trimmings compost. According to Heckman et al., (2000) turf color is mainly influenced by the availability soil inorganic nitrogen. Therefore the presence of more plant available nitrogen in the biosolid amended soil was likely responsible for this treatment consistently having the darkest turf color.

In Study I the application of 10 t ha^{-1} resulted lighter green colored turf on the first two evaluation dates when compared to the plots that did not receive straw. This might due to the reason that the 10 t ha^{-1} straw treatment was too thick and shaded a portion turfgrass which lowered chlorophyll production (Koh et al., 2003). There was no difference in color between the 0 and 5 t ha^{-1} straw treatments on any of the three evaluation dates. By the last evaluation which, occurred approximately one year after seeding, there was no difference in color among the three straw treatments. In Study II the no-straw and 10 t ha^{-1} straw treatments had similar color on four of the five rating dates. There was no consistent trend in color differences between the no straw and 5 t ha^{-1} straw treatments in Study II.

Table 4.7 Effect of soil amendment and straw amount on turf visual color and turf quality in Study I.

Treatment	Color			Quality
	5/21/14	7/28/14	10/6/14	10/6/14
	1-9			
<u>Soil Amendments</u>				
Mineral Fertilizer	5b†	7.2b	6c	6.4b
Yard Trim Compost	6.5a	7.5b	6.4b	5.9b
Biosolid Compost	7.7a	8.5a	7a	7.6a
<u>Straw</u>				
t ha^{-1}				
0	7.1AЛ[	8.0A	6.5A	6.2B
5	7.2A	7.7AB	6.4A	7.1A
10	5.2B	7.5B	6.4A	6.6AB

† Numbers followed by the same letters in columns are not significantly different at a α = 0.05 According to Fisher’s LSD means separation test. The upper case letters were used to express the mean separation test results of straw amount while the small case letters were used to express the mean separation test results of nitrogen souces.

Table 4.8 Effect of soil amendment and straw amount on turf visual color and quality in Study II.

	Color					Quality	
Treatment	5/6/15	6/5/15	7/21/15	8/27/15	11/9/15	8/27/15	11/9/15
					1-9		
Soil Amendments							
Mineral Fertilizer	5.8b†	6.1b	6.4c	7.7c	7.6c	6.3b	7.1b
Yard Trim Compost	5.7b	5.8b	7.1b	8.5b	8.1b	7.3a	7.4b
Biosolid Compost	7.4a	8.9a	8.9a	9a	8.7a	6.6b	8.2a
Straw							
t ha^{-1}							
0	6.6A	6.6B	7.3B	8.3A	8.2A	6.7AB	7.9A
5	6.4A	7.2A	7.7A	8.2A	8B	7.3A	7.7AB
10	5.9A	7.2A	7.3B	8.6A	8.2A	6.3B	7.2B

† Numbers followed by the same letters in columns are not significantly different at a $\alpha = 0.05$ According to Fisher's LSD means separation test. The upper case letters were used to express the mean separation test results of straw amount while the small case letters were used to express the mean separation test results of nitrogen souces.

4.3.4 Turf Quality

Turf quality was highest in plots amended with the biosolid compost at the end of Study I (Table 4.7). A decline in quality was noticed in Study II on 27 Aug. 15 relative to the yard clippings compost treatment. The decline in quality was the result of higher infection levels of Brown Patch (*Rhizoctonia solani*) within the biosolids compost treated plots in Study II (data not shown). When the blighted turf areas disappeared in the fall of 2015 turf quality in the biosolid amended plots were the highest of the three soil amendment treatments. The use of 5 t ha^{-1} straw resulted in higher turfgrass quality Study I when compared with the plots receiving no straw. A higher quality rating was given to 5 t ha^{-1} straw treatment in Study I because the visual density and uniformity of the turf was better in these plots than in the plots that were not covered with straw. The difference in the two treatments can be traced back to the beginning of study when lack of surface cover in no straw treatment plots resulted in washout of some the seed in these plots. In Study II the presence of straw had no consistent effect on turf quality when compared to the plots that were not covered with straw at the beginning of the study.

4.3.5 Soil Moisture Loss

Total soil moisture loss during the single dry down period measured in Study I, and the three dry down periods measured in Study II, are shown in Figure 4.4 and Figure 4.5, respectively. Included in these figures is the average initial moisture content at beginning of the dry down. Soil moisture losses were greater in Study II than Study I because a total of 14 mm of rainfall fell during 24 day period measurements were collected in Study I (Figure 4.1). In contrast, the maximum precipitation that occurred during the three dry downs in Study II was 1.5 mm.

In the single dry down period measured in Study I, moisture loss from the biosolid compost amended plots was greater than from the non-amended mineral fertilizer plots regardless of the amount of straw that was applied to the plot. At the 0 and 5 t ha^{-1} straw rate there was no difference in the amount of soil moisture loss over the dry down period for the two compost sources. Soil moisture loss in the plots receiving the yard trimming compost was less than that of the biosolid compost amended plots at 10 t ha^{-1} straw rate.

In Study II, soil moisture levels were higher at the beginning of the dry down period than in Study I for all three dry downs periods that took place in this study. Statistically significant treatments effects on soil moisture loss were limited to the 12 Aug. to 18 Aug. dry down period in Study II. With the exception of the non-amended mineral fertilizer treatment plots receiving 5 t ha^{-1} straw, plots amended with the biosolid compost had higher soil moistures losses than yard trimmings and mineral fertilizer treatment at all 3 rates of straw. While there was no statistical difference in the amount of soil moisture loss from the various treatment during the 8 July to 25 July and 31 July to 9 Aug. dry downs, the trend of higher soil moisture losses with use of biosolid compost is also present in the data of these two dry downs.

The data from all four dry down periods suggests that the large amount of available nitrogen associated with the use of the biosolid compost is resulting more turfgrass growth in these plots, which in turn increased turfgrass water use. The use of straw had no effect on the moisture loss for plots that received the biosolid compost but did reduce soil moisture loss within the non-amended mineral fertilizer plots and those that received the yard trimming compost when applied at the rate of 10 t ha^{-1}. Reduced growth associated with the lower amounts of available nitrogen in these treatments was likely responsible for lower soil moisture losses. The biomass associated with the highest rate of straw application may have immobilized some of plant available nitrogen in the non-amended mineral fertilizer plots and yard trimming amended plots. Straw in a degraded state was visible in plots that received 10 t ha^{-1} rate of this treatment at the time moisture measurement were collected. In contrast none to very little straw was seen in the plots that received 5 t ha^{-1} straw at this time.

The moisture conserving properties of straw during turf seedling establishment are well known (Barkley et al., 1965). During seeding establishment the portion of soil surface covered with vegetation is small with a corresponding small loss of soil moisture via plant transpiration. As mentioned previously, when near full turf cover is achieved most of the soil moisture loss in the root zone occurs via plant transpiration. Thus once a grass canopy resides above the straw that remains from the initial seeding, the reduction in soil moisture measured at that time is likely the result of a reduction in plant transpiration arising from reduced plant growth rather than straw acting a mulch to suppress soil surface evaporation.

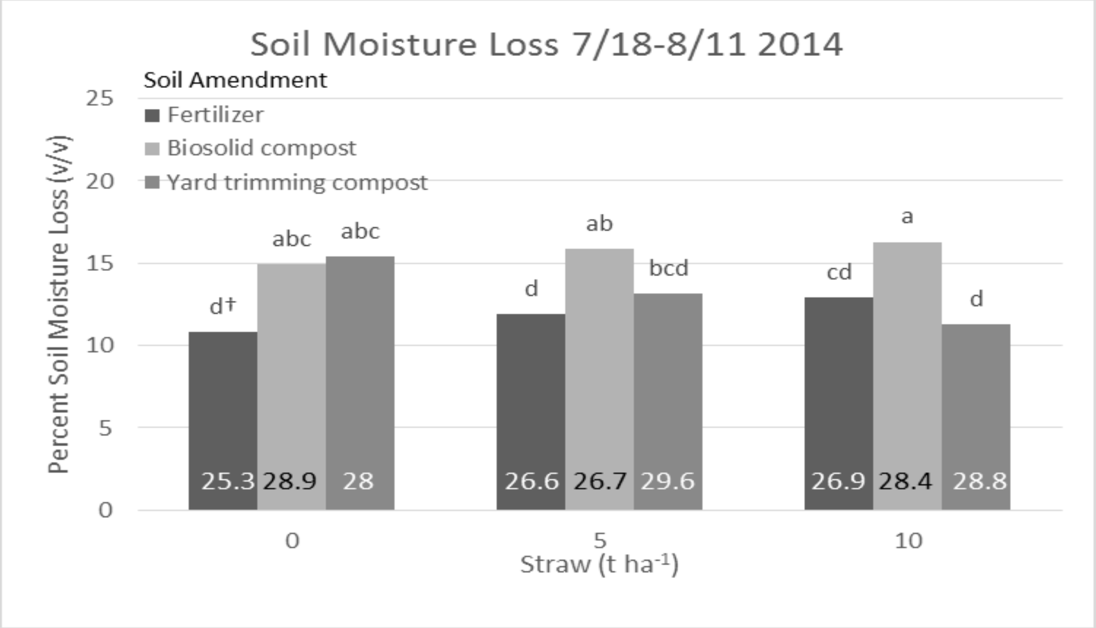

Figure 4.4 Effect of soil amendment and straw amount on soil moisture loss in Study I.

† Histograms with same letters are not significantly different at a α = 0.05 according to Fisher's LSD means separation test. Number within each histogram is initial soil moisture content at start of dry down.

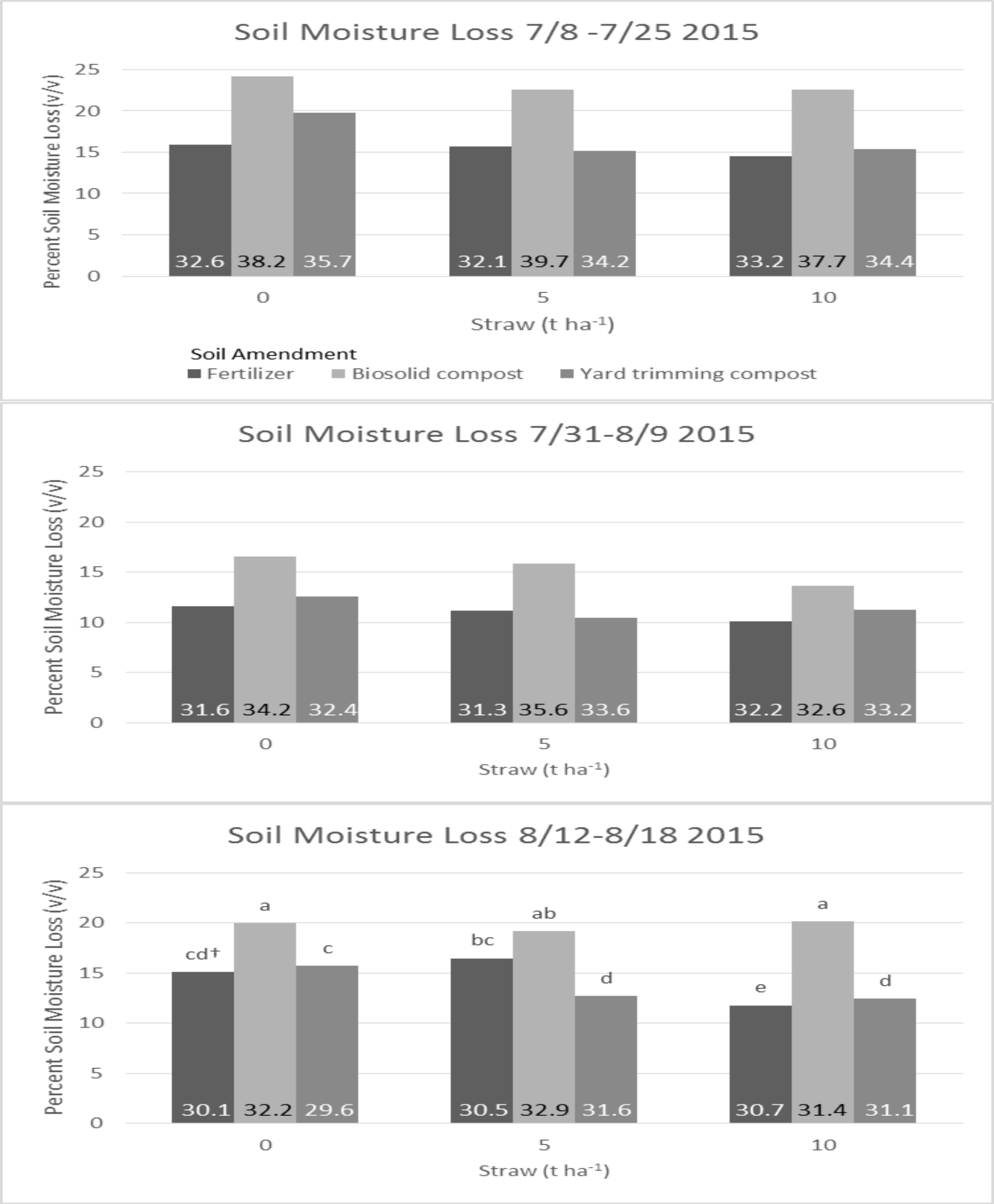

Figure 4.5 Effect of soil amendment and straw amount on soil moisture loss measured during three naturally occurring dry down periods that took place in Study II. Number within each histogram is initial soil moisture content at start of dry down.

† Bars with same letters are not significantly different at a α = 0.05 according to Fisher's LSD means separation test. Bars do not have letters means the interation between the two treatments were not significantly different, therefore each treatment combination was not compared with each other.

4.4 Conclusion

Among the three compost treatments, use of biosolid compost resulted in similar, or quicker turfgrass establishment, darker turf color, and better overall quality at end of each study than in non-amended plots receiving a mineral fertilizer, or plots amended with yard trimming compost. Plots amended with the biosolid compost however had greater soil moisture losses than the mineral fertilizer and yard trimmings compost treatments suggesting that the high amount of available nitrogen associated with this treatment promoted more rapid rates of growth than the mineral fertilizer and yard trimmings compost treatments. Lush rapid growth in the summer is usually associated with deleterious effects on cool season turfgrasses and in the Study II a higher incidence of brown patch was seen in the plots amended with biosolid compost. Even though biosolid compost plots had better quality and color performance compared with yard trimming compost plots, the deleterious effects of this material on the presence of clover effectively rules out its use when the goal is to establish a lawn consisting of mixture of microclover and a cool season turfgrass species such as tall fescue. Use of the yard trimming compost resulted in clover cover that was lower than the mineral fertilizer treatment in Study I, however the overall amount of clover cover present at the end of the study in these plots was sufficient to recommend the use of this compost. Moreover, in Study II clover cover in the plots amended with the yard trimmings compost were equal to or higher that clover cover in plots that received the mineral fertilizer.

The suppressive effect of 10 t ha^{-1} straw on microclover cover indicates that the use of this rate of straw should be avoided when establishing a new lawn where the inclusion of this species is desired. That said, it is possible a different result might be obtained than that observed in Study I and II when the straw is chopped or shredded during broadcasting of the material. While the use of 5 t ha^{-1} straw initially suppressed clover cover in Study II, its use, in combination with incorporation of 5 cm of yard trimmings compost, provided sufficient clover cover to recommend the use of this treatment combination as a way to lower fertilizer use and lessen runoff (see chapter 3 results).

The results of Study I one suggest amending soil with 5 cm of yard trimming compost in combination with 5 t ha^{-1} straw may also preserve soil moisture when compared to not broadcasting straw at the time of seeding. Further investigation of the effect of straw on the preservation of soil moisture in established lawns is warranted. More specifically, there is need to determine the degree to which straw applied at the time of seeding can reduce the irrigation requirement of a lawn in regions of US where turf water use and irrigations needs are greater than in the temperate humid region where this investigation took place.

References

Al-Kaisi, M., L.J. Brun, and J.W. Enz. 1989. Transpiration and evapotranspiration from maize as related to leaf area index. Agric. For. Meteorol. 48:111-116.

Aggelides, S. M. and P. A. Londra, 2000. Effects of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil. Bioresour. Technol. 71:253-259.

Albiach R., R. Canet, F. Pomares and F. Ingelmo, 2001. Organic matter components and aggregate stability after the application of different amendments to a horticultural soil. Environ. Pollut. 76:125–129.

American Public Health Association, 2005. Standard Methods for the Examination of Water and Wastewater 21st ed. Method 2540 D. Total suspended solids.

Amlinger, F., B. Götz, P. Dreher, J. Geszti and C. Weissteiner, 2003. Nitrogen in biowaste and yard waste compost: dynamics of mobilisation and availability—a review, Eu. J. Soil Biol., 39(3):107–116.

Atwell, B. J., Kriedemann and P. E., Turnbull, 1999. Plants in action: adaptation in nature, performance in cultivation. MacMillan Education Australia, Melbourne.

Balousek,J. D. P. E., 2003. Quantifying decreases in stormwater runoff from deep tilling, chisel plowing and compost-amendment. Dane County Land Conservation Department. (https://www.countyofdane.com/lwrd/landconservation/papers/quantifyingdecreasesinswrunoff.pdf) (Last accessed on 9 Jan 2016)

Barker, A.V., J.E. Rechcigl, and H.C.MacKinnon, 1997. Composition and uses of compost. Agricultural uses of by-products and wastes. Am. Chem. Soc., 140-162.

Barker, A., 2001. Evaluation of composts for growth of grasss sod. Commun. Soil Sci. Plant Anal., 32(11-12):1841-1860.

Barkley, D. G., R. E. Blaser, and R. E. Schmidt, 1965. Effect of mulches on microclimate and turf establishment. Agron. J., 57(2):189-192.

Barzegar, A. R., P. N. Nelson, J. M. Oades and P. Rengasamy, 1997. Organic matter, sodicity, and clay type: influence on soil aggregation. Soil Sci. Soc. Am. J. 61:1131-1137.

Berner, A., Wullschleger, I. and Alföldi, T., 1996. Estimation of N-release and N-mineralization of garden waste composts by the mean of easily analysed parameters. In The Science of Composting (pp. 1078-1082). Springer Netherlands.

Blackman. G. E., 1938. The interaction of light intensity and nitrogen supply in the growth and metabolism of grasses and clover (Trifolium repens), I the effects of light intensity and nitrogen supply on the clover content of the sward. Ann. of Bot., 2:257-280.

Bordeleau, L. M. and D. Prevost, 1994. Nodulation and nitrogen fixation in extreme environments. Plant Soil 161:115–124.

Breslin, V. T., 1995. Use of MSW compost in commercial sod production. Biocycle 36(5):68-72.

Bresson, L. M., C. Koch, Y. Le Bissonnais, E. Barriuso and V. Lecomte, 2001. Soil surface structure stabilization by municipal waste compost application. Soil Sci. Soc. Am. J. 65:1804–1811.

Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A.N. Sharpley and V. H. Smith, 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol. Applic. 8:559–568.

Carrico., A. R., J. Fraser and J. T. Bazulin, 2012. Green with envy: psychological social predictors of lawn fertilizer application. Environ. and Behavior, 45:427-454.

Carrow, R. N., D. V. Waddington and P. E. Rieke, 2001. Turfgrass Soil Fertility & Chemical Problems: Assessment and Management. John Wiley & Sons.

Celik, I., I. Ortas and S. Kilic, 2004. Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil. Soil Tillage Res. 78: 59–67.

Chen, L. M., 1997. Nitrogen and iron nutrition of plants as induced by composts and compost microorganisms. Doctoral Dissertation, The Ohio State University

Cheng, H. F., W. P. Xu, J. L. Liu, Q. J. Zhao, Y. Q. He and G. Chen, 2007. Application of composted sewage sludge (CSS) as a soil amendment for turfgrass growth. Ecol. Eng. 29:96–104.

Chesapeak Bay Program. 2008. Chesapeake Bay 2007 Health and Restoration Assessment.(http://www.chesapeakebay.net/publications/title/chesapeake_bay_2007_health_and_restoration_assessment) (Last accessed on 9 Jan 2016)

Chesapeak Bay Program. 2013. Recommendations of the Expert Panel to Define Removal Rates for Urban Nutrient Management. Chesapeake Bay Program Approved Final Report. (http://www.chesapeakebay.net/documents/Final_CBP_Approved_Expert_Panel_Report_on_Urban_Nutrient_Management--short.pdf) (Last accessed on 9 Jan 2016)

Choudhury, B.J., N.U. Ahmed, S.B Idso, R.J. Reginato, and C.J. Daughtry. 1994. Relations between evaporative coefficients and vegetative indices studied by model simulations. Remote Sens. Environ. 50:1-17.

Cogger, C. G., 2005. Potential compost benefits for restoration of soils disturbed by urban development. Compost Sci., Vol. 13:243-251.

Courtney, R. G. and G. J. Mullen, 2008. Soil quality and barley growth as influenced by the land application of two compost types. Bioresour. Technol. 99:2913–2918.

Cowling, D. W. 1982. Biological N fixation and grassland production in the United Kingdom. Phil. Trans. R. Soc. Lond. B. 296: 397-404.

Cox. D., D. Bezdicek and M. Fauci,. 2001. Effects of compost, coal ash, and straw amendments on restoring the quality of eroded Palouse soil. Biol. Vert. Soils, 33: 365-372.

Curtis, M. J. M. E. and V. P. Claassen, 2007. Using compost to increase infiltration and improve the revegetation of a decomposed granite roadcut. J. Geotech. Environ. Eng.133:215-218.

Day, M., M. Krzymien, K. Shaw, L. Zaremba, W. R Wilson, C. Botden and B. Thomas 1998. An investigation of the chemical and physical changes occurring during commercial composting. Compost Science & Utilization, 6(2):44-66.

DeHaan, S., 1981. Results of municipal waste compost research over more than fifty years at the Institute for Soil Fertility at Haren/Groningen, the Netherlands. Neth. J. Agric. 29:49–61.

Devitt, D. A, R. L. Morris. and D.C. Bowman, 1990. Response of tall fescue to composted sewage sludge used as a soil amendment. J. Plant Nut. 13(9):1115–1139.

Dickerson, G. W., 2004. Description and use of municipal solid waste composts in New Mexico. (http://aces.nmsu.edu/pubs/_circulars/circ562.html) (Last accessed on 9 Jan 2016)

Duley, F.L., and L.L. Kelley. 1939. Effect of soil types, slopes and surface condition on intake of water. Nebraska Agr. Exp. Sta. Res. Bul. 112.

Easton, Z. M. and A. M. Petrovic, 2004. Fertilizer source effect on ground and surface water quality in drainage from turfgrass J. Environ. Qual. 33:645–655.

Easton, Z. M., A. M. Petrovic, D. J. Lisk, and I. M. Larsson-Kovach, 2005. Hillslope position effect on nutrient and pesticide runoff from turfgrass. Int. Turfgrass Soc. Res. J, 10:121-129.

Ebeling, A. M., L. G. Bundy, J. M. Powell and T. W. Andraski, 2002. Dairy diet phosphorus effects on phosphorus losses in runoff from land-applied manure. Soil. Sci. Soc. Am. J. 66: 284-291.

Environment Protection Association. 1998. An analysis of composting as an environmental remediation technology EPA530-R-98-008.

Environment Protection Association. 2014. Municipal solid waste generation, recycling, and disposal in the United States: facts and figures for 2012 EPA-530-F-14-001

Epstein, E.L., J. M. Taylor and R. L. Chancy, 1976. Effects of sewage sludge and sludge compost applied to soil on some soil physical and chemical properties. J. Environ. Qual., 5:422-426.

Epstein, E., D. B. Keane, J. J. Meisinger and J. O. Legg, 1978. Mineralization of nitrogen from sewage sludge and sludge compost, J. Environ. Qual. 7:217-221.

Erisman, J. W., M. A. Sutton, J. Galloway, Z. Klimont and W. Winiwarter, 2008. How a century of ammonia synthesis changed the world. Nature Geosci., 1:636–639.

Faucette, L. B., L. M. Risse, M. A. Nearing, J. W. Gaskin and L. T. West, 2004. Runoff, erosion, and nutrient losses from compost and mulch blankets under simulated rainfall. J. Soil Water Conserv., 59:154-160.

Foley, B. J. and L. R. Cooperband, 2002. Paper mill resduals and compost effects on soil carbon and physical properties. J. Environ. Qual. 31(6):2086-2095.

Forester, J. C., W. Zech and E. Wiirdinger, 1993. Comparison of chemical and microbial methods for the characterization of the maturity of composts from contrasting sources. Biol. Fertil. Soils 16:93-99.

Frame, J and P. Newbould, 1986. Agronomy of white clover. Adv. Agron. 40:1–88.

Frings, J. F. J., 1976. The rhizobium-pea symbiosis as affected by high temperatures. Thesis. Wageningen Agricultural University, Wageningen. 76 p.

Gardner, D. S. and J. A. Taylor, 2002. Change over time in quality and cover of various turfgrass species and cultivars maintained in shade. Hort. Technol., 12(3):465-469.

Gentilucci, G., J. A. Murphy and D. E. Zaurov, 2001. Nitrogen requirement for kentucky bluegrass grown on compost amended soil. Inter. Turf. Soc. Res. J. 9:382-387.

Gilley, J. E. and B. Eghball, 2002. Residual effects of compost and fertilizer applications on nutrients in runoff. Biol Systems Eng.: Papers and Publications, 22.

Giusquiani,P. L., M . Pagliai, G. Gigliotti, D. Businelli, and A. Benetti, 1995. Urban waste compost: effects on physical, chemical, and biochemical soil properties. J. Environ. Qual. 24:175-182.

Gouin, F. R., 1993. Utilization of sewage sludge compost in horticulture HortTechnol., 3:161–163.

Groen, A. H., and S. W. Woods, 2008. Effectiveness of aerial seeding and straw mulch for reducing post-wildfire erosion, north-western Montana, USA. Int. J. Wildl. Fire, 17:559-571.

Gross, C. M., J. S. Angle, R. L. Hill, and M. S. Welterlen, 1991. Runoff and sediment losses from tall fescue under simulated rainfall. J. Environ. Qual. 20:604–607.

Guidi G., A. Pera, M. Giovannetti, G. Poggio and M. Bertoldi, 1988. Variations of soil structure and microbial population in a compost amended soil. Plant Soil 106: 113–119.

Hansen, N. E., D. M. Vietor, C. L. Muster, R. H. White and T. L. Provin, 2007. Runoff water quality from turfgrass established using volume-based composted municipal biosolids applications. J. Environ. Qual. 36:1013-1020.

Hargreaves, J. C. M. S. Adl and P.R. Warman, 2008. A review of the use of composted municipal solid waste in agriculture Agriculture, Ecosys. Environ. 123:1–14.

Harrell, M. S. and G. L. Miller, 2005. Composted yard waste affects soil displacement and roadside vegetation. HortScience 40:2157-2163.

Harris, F. S. and H. H. Yao, 1923. Effectiveness of mulches in preserving soil moisture. J. Agric. Res., 9:727-742.

Harrison, R. B., M. A. Grey, C. L. Henry and D. Xue, 1997. Field test of compost amendment to reduce nutrient runoff. Prepared for the city of redmond. College of Forestry Resources, University of Washington, Seattle.

Hartz, T., 2009. Nutrient value of compost, UC Organic Soil Fertility Management Symposium. (http://vric.ucdavis.edu/events/2009_osfm_symposium/UC%20Organic%20Symposium%20010609%2005b%20Hartz.pdf) (Last accessed on 9 Jan 2016)

Hartz, T. K., J. P. Mitchell and C. Giannini, 2000. Nitrogen and carbon mineralization dynamics of manures and composts. HortScience 35:209–212.

Heckman, J. R., H. Liu, W. Hill, M. DeMilia and W. L. Anastasia, 2000. Kentucky bluegrass responses to mowing practice and nitrogen fertility management. J. Sust. Agri., 15(4):25-33.

Heijden, S. A. and N. Roulund, 2010. Genetic gain in agronomic value of forage crops and turf. In C. Huyghe (ed.) A Review of Sustainable Use of Genetic Diversity in Forage and Turf Breeding, 247-260.

Hirai, M. F., V. Chanyasak, and H. Kubota, 1983. A standard measurement for compost maturity. Biocycle 24:54-56.

Iglesias-Jimenez, E. and C. Alvarez, 1993. Apparent availability of nitrogen in composted municipal refuse. Biol. Fert. Soils 16:313–318.

Kalbitz, K., S. Solinger, J. H. Park, B. Michalzik and E. Matzer, 2000. Controls on the dynamics of dissolved organic matter in soils: a review. Soil Sci. 165:277–304.

Kelling, K. A. and A. E. Peterson, 1975. Urban lawn infiltration rates and fertilizer runoff losses under simulated rainfall. Soil Sci. Soc. Am. J., 39:348-352.

Kemper, W. D. and R. C. Rosenau, 1986. Aggregate stability and size distribution in methods of soil analysis. Part 1: Physical and mineralogical methods. (Ed. A. Klute.) Am. Soc. Agron.-Soil Sci. Soc. Am., 425–442.

Khaleel, R., K. R. Reddy and M. R. Overcash, 1981. Changes in soil physical properties due to organic waste applications: a review. J. Environ. Qual. 10:133-141.

Kibert, C. J., 2012. Sustainable construction: green building design and delivery. John Wiley & Sons.

Knoepp J. D., J. M. Vose, J. L. Michael and B. C. Reynolds, 2012. Imidacloprid movement in soils and impacts on soil microarthropods in southern Appalachian eastern hemlock stands J. Environ. Qual., 41:469–478.

Koh, K.J., G.E. Bell, D.L. Martin, and N.R. Walker, 2003. Shade and airflow restriction effects on creeping bentgrass golf greens. Crop science, 43:2182-2188.

Kopec, D.M., J.M. Norman, R.C. Sherman, and M.P Peterson. 1987. An indirect method for estimating leaf area index. Crop Sci. 27:1298-1301.

Landschoot, P. and A. McNitt, 1994. Improving turf with compost. Biocycle, 35(10):54-57.

Lantinga, E. A., 2000. Management and output of grass-clover swards in mixed farming systems. In: Rook, A.J., Penning, P.D. (Eds.), Grazing Management. Br. Grassl. Soc., Reading, UK, 241–242.

Law, N., L. Band and M. Grove, 2004. Nitrogen input from residential lawn care practices in suburban watersheds in Baltimore County, MD. J. Environ. Plann. Manage., 47:737-755.

Lax, A.and F. García-Orenes, 1993. Carbohydrates of municipal solid wastes as aggregation factor of soils. Soil Technol. 6:157–162.

Legard, S. F. and K. W. Steele, 1992. Biological nitrogen fixation in mixe legume/ grass pasytures. Plant Soil, 141:137-153.

Legard,S. F., M. S Sprosen, J. W Penno and G. S Rajendram, 2001. Nitrogen fixation by white clover in pastures grazed by dairy cows: temporal variations and effects of nitrogen fertilization. Plant Soil, 229:177–187.

Linde, D. T., T. L. Watschke and A. R. Jarrett, 1997. Surface runoff comparison between creeping bentgrass and perennial ryegrass turf. J. Turfgrass Manage. 2:11–33.

Linde, D. T., T. L. Watschke, A. R. Jarrett and J. A. Borger, 1995. Surface runoff assessment from creeping bentgrass and perennial ryegrass turf. Agron. J. 87:176–182.

Linde, D. T. and L. D. Hepner. 2005. Turfgrass seed and sod establishment on soil amended with biosolid compost. Hort. Technol. 15:577-583.

Littell, R. C., W. W. Stroup, G. A. Milliken, R. D. Wolfinger and O. Schabenberger, 2006. SAS for mixed models. SAS Institute Inc., Cary, NC

Loschinkohl, C. and M. J. Boehm., 2001. Composted biosolids incorporation improves turfgrass establishment on disturbed urban soil and reduces leaf rust severity. HortScience 36:790-794.

Lush, W. M. and Rogers, M. E., 1992. Cutting height and the biomass and tiller density of Lolium perenne amenity turfs. J. Appl. Ecol., 611-618.

MacDuff, J. H, S. C. David and I. A. Divisdon, 1996. Inhibition of N2 fixation by white clover (Trifolium repens L.) at low concentrations in NO− 3 in flowing solution cultue. Plant Soil 180, 287–295.

Maguire, R. O., D. A. Crouse and S. C. Hodges, 2007. Diet modifi cation to reduce phosphorus surpluses: A mass balance approach. J. Environ. Qual. 36:1235–1240.

Mallarino, A. P., W. F. Wedin, C. H. Perdomo, R. S. Goyenola and C. P. West, 1990. Nitrogen transfer from white clover, red clover, and birdsfoot trefoil to associated grass. Agron. J., 82:790–795.

Mallin, M. A. and T. L. Wheeler, 2000. Nutrient and fecal coliform discharge from costal North Carolina golf courses. J. Environ. Qual. 29:979–986.

Markham, T. D., 1998. Use of composts in sandbased putting greens and their impact on turf establishment and health. MS thesis, The Ohio State Univ., Columbus.

Martens, D. A. and W. T. Frankenberger, Jr. 1992. Modification of infiltration rates in an organic-amended irrigated soil. Agron. J., 84:707-717.

Maryland Department of Agriculture 2011. Maryland's lawn fertilizer law. (http://mda.maryland.gov/resource_conservation/Documents/fertilizerwebpage.pdf) (Last accessed on 9 Jan 2016)

Maryland Department of Environment 2007. Maryland stormwater management act. (http://mde.maryland.gov/programs/water/stormwatermanagementprogram/pages/programs/waterprograms/sedimentandstormwater/swm2007.aspx) (Last accessed on 9 Jan 2016)

Matula, S. and C. Dirksen, 1989. Automated regulating and recording system for cylinder infiltrometer. Soil Sci. Soc. Am. J. 53:299-302.

McAuliffe, C., D. S. Chamblee, H. Uribe-Arango and W.W. Woodhouse, 1958. Influence of inorganic nitrogen on nitrogen fixation by legumes as revealed by N Is. Agron. J. 50:334-337.

McBride, M. B., 1995. Toxic metal accumulation from agricultural use of sludge: are USEPA regulations protective? J. Environ. Qual. 24:5-18.

McCalla, T. M. and F. L.Duley, 1946. Effect of crop residues on soil temperature. J. Am. Soc. Agron. 38(1):75-89

McCurdy, J. D., 2015. White clover inclusion within a bermudagrass lawn: effects of supplemental nitrogen on botantical composition and nitrogen cycling. Crop Sci: 54:1796-1803.

McNeill, A. M. and M. Wood, 1990. 15N estimates of nitrogen fixation by white clover (Trifolium repens L.) growing in a mixture with ryegrass (Lolium perenne L.). Plant Soil 128:265–273.

Mehta, Y., S. Joshi and A. Mehta, 2011. Composting: a tool to save earth and go green. Int. J. Res. Comm. Manage. 2(5):113-115

Minnesota Department of Agriculture. 2007. Report to the minnesota legislature: effectiveness of the minnesota phosphorus lawn fertilizer law. Minnesota Department of Agriculture, Pesticide and Fertilizer Management Division, 15 March 2007. 41 p.

Moreno, J. L., C. Garcı´a, T. Herna´ndez and J. Pascual, 1996. Transference of heavy metals from a calcareous soil amended with sewage-sludge compost to barley plants. Biores. Technol. 55 (3):251–258.

Murray, P. J. and R. O. Clements, 1998. Transfer of nitrogen between clover and wheat: Effects of root herbivory. Eur. J. Soil Biol. 34:25–30.

Nelson, D. W. and L. E. Sommer., 1982. Total carbon, organic carbon, and organic matter. p. 539-579. In A.L. Page (ed.) Methods of Soil Analysis. 2nd Ed. ASA Monogr. 9(2). Amer. Soc. Agron. Madison, WI.

Nesheim, L. and B. C. Boiler, 1991. Nitrogen fixation by white clover when competing with grasses at moderately low temperatures. Plant Soil 133:47-56.

New Jersey.2010.Get the phosphorus out. (http://www.hamiltonnj.com/government/pdf/EPI pdf/StormWaterManagement/getthe-phosphorus-out.pdf.) (Last accessed on 9 Jan 2016)

Nimmo., J. R. and K. S. Perkins, 2002. Agrregate stability and size distribution, In Dane., J. H., and G. C. Tepp, eds., Methods of soil analysis, part 4-Physical methods; Madison, Wisconsin, Soil Sci. Soc.Am, 317-328.

NOAA'S National Weather Service, 2014 NOAA Atlas 14 point precipitation frequency estimates: MD (http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=md) (Last accessed on 11 April 2016)

Ojeda, G., J. M. Alcaniz and O. Ortiz, 2003. Runoff and losses by erosion in soils amended with sewage sludge Land Degrad. Dev., 14:563–573.

O'Malley, M., A. G. Brown, E. F. Hance and M. E. Setting, 2011. The fertilizer use act of 2011, Maryland Department of Agriculture. (https://extension.umd.edu/sites/default/files/_docs/FertilizerLaw_Facts_final.pdf) (Last accessed on 9 Jan 2016)

O'Malley, M., A. G. Brown. and S. T. Wilson, 2007. Stormwater Management Act of 2007. (http://www.mde.state.md.us/assets/document/Stormwater%20Act%202007%20Update.pdf) (Last accessed on 9 Jan 2016).

Patton C. J., and J.R. Kryskalla 2003. Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory-Evaluation of alkaline persulfate digestion as an alternative to Kjeldahl digestion for determination of total and dissolved nitrogen and phosphorus in water. Water-resources investigations report 03-4174. 40 p. U.S. Geological Survey. Denver Colorado.

Pennsylvania Stormwater 2006. Pennsylvania storm water best management practices manual. BMP 6.7.3: Soil Amendment and Restoration 363-0300-002 page 221 of 257 (http://www.stormwaterpa.org/assets/media/BMP_manual/07_Chapter_6.pdf) (Last accessed on 9 Jan 2016)

Pit, R., J. Lantrip, R. Harrison, C. L. Henry and D. Xue, 1999. Infiltration through disturbed urban soils and compost-amended soil effects on runoff quality and quantity EPA/600/R-00/016 December 1999

Provin, T. L. A. L. Wright, F. M. Hons, D.A. Zuberer and R. H. White, 2008. Seasonal dynamics of soil micronutrients in compost-amended bermudagrass turf. Sci. Direct Biores. Technol. 99:2672-2679.

Reid, D., 1970. The effects of a wide range of nitrogen application rates on the yields from a perennial ryegrass sward with and without white clover. J. Agric. Sci., 74:227-240.

Reinhart D. R., A. R. deForest, S. J. Keely and D. R. Vogt., 1993. Composting of yard waste and wastewater treatment plant sludge mixtures, Compost Sci. Utilization 1(2):58-64

Reinsch, C. T., D. M. Admiraal, B. I. Dvorak, C. A. Cecrle, T. G. Franti and J. S. Stansbury, 2007. Yard waste compost as a stormwater protection treatment for construction sites. Water Environment Research, 79:868-876.

Rice, W., A, Rice, D. C. Penney and M. Nyborg, 1977. Effects of soil acidity on rhizobia numbers, nodulation and nitrogen fixation by alfalfa and red clover. Can. J. Soil Sci. 57:197–203.

Rowaan, P. A., 1949. Stadsvuilcompost als meststof. Maandbl. landb. Voorl. 6:190-194.

Sainz, M. J., M.T. Taboada-Castro and A. Vilarino., 1998. Growth mineral nutrition and mycorrhizal colonization of red clover and cumber plants grown in soil amended with composted urban wastes. Plant Soil. 205:85-92.

Schueler, T., 2010. The clipping point: Turf cover estimates for the Chesapeake Bay Watershed and management implications. Chesapeake Stormwater Network Technical Bulletin, 3.

Sikora, L. J., C. F. Tester, J. M. Taylor and J. F. Parr., 1980. Fescue yield response to sewage sludge compost amendments. Agron. J. 72:79–84.

Sims, J. T., A. C. Edwards, O. F. Schoumans and R. R. Simard, 2000. Integrating soil phosphorus testing into environmentally based agricultural management practices. J. Environ. Qual., 29:60-71.

Sincik, M., and E. Acikgoz., 2007. Effects of white clover inclusion on turf characteristics, nitrogen fixation, and nitrogen transfer from white clover to grass species in turf mixtures. Commun. Soil Sci. Plant Anal. 38:1861–1877.

Sloan, J. J., R. H. Doedy, M. S. Dolan and D. R. Linden., 1997. Long-term effects of biosolids applications on heavy metal bioavailability in agricultural soils. J. Environ. Qual. 26:966- 974.

Soil Science Society of America. 2015. Glossary of soil science terms. (https://www.soils.org/publications/soils-glossary#) (Last accessed on 9 Jan 2016)

Soldat, D. J. and A. M. Petrovic, 2008. The fate and transport of phosphorus in turfgrass ecosystems. Crop Sci., 48:2051-2065.

Sommers, L. E., 1977. Chemical composition of sewage sludge and analysis of their potential use as fertilizers, J. Environ. Qual. 6:225-232.

Spargo, J. T., G. K. Evanylo and M. M. Alley., 2006. Repeated compost application effects phosphorus runoff in the virginia piedmont. J. Environ. Qual. 35:2342-2351.

Spellman F. R., 1997 Wastewater biosolids to compost. Technomic Publishing Company, Lancaster, PA, 71-72.

Sprent, J. I., 1971. The effects of water stress on nitrogen fixing root nodules. III. Effects of osmotically applied stress. New Phytologist 71:451–460.

Sullivan, D. M., A. I. Bary, T. J. Nartea, E. A. Myrhe, C. G. Cogger and S. C. Fransen, 2003. Nitrogen availability seven years after a high-rate food waste compost application Compost Sci Util, 11, 265–275.

Stratton, M. L., A.V. Barker and J. E. Rechcigl, 1995. Compost. In: Rechcigl, J. E. (Ed.), Soil Amendments and Environmental Quality. CRC Press, USA, 249–309.

Tester, C. F., 1990. Organic amendment effects on physical and chemical properties of a sandy soil. Soil Sci. Soc. Am. J. 54:827-831

Tester, C. F., L. J. Sikora, J. M. Taylor and J. F. Parr, 1977. Decomposition of sewage sludge compost in soil: I. Carbon and nitrogen transformation, J. Environ. Qual. 6(4): 459-462

Tukey, P., 2007. The organic lawn care manual. Storey Publishing North Adams, MA

Turner, M. S., G. A. Clark, C. D. Stanley and A. G. Smajstrla, 1994. Physical characteristics of a sandy soil amended with municipal solid waste compost Soil Crop Sci. Soc. Florida Proc., 53:24–26.

Turner, T., 2013 Fertilizer recommendations for commercially maintained lawns and turfgrass in Maryland. University of Maryland Turfgrass Technical Update, TT115.

Tyler, R., 1996. Winning the organics game; ASHS Press: Alexandria, VA U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response 1994 EPA530-R-94-003

Unger, P. W., 1978 Straw mulch effects on soil temperatures and sorghum germination and growth. Agron. J., 70(5), 858-864.

Vincent, J. M., 1965. Environmental factors in the fxation of nitrogen by the legume. In Soil Nitrogen. Eds. W V Bartholomew and F C Clark. pp 384–435. Am. Soc. Agron., Madison, WI

Virginia's Legislative Information System. 2011. House bill 1831 fertilizer; regulation of application and labeling (https://lis.virginia.gov/cgi-bin/legp604.exe?111+sum+HB1831) (Last accessed on 9 Jan 2016)

Walker, D. J., R. Clemente and M. P. Bernal, 2004. Contrasting effects of manure and compost on soil pH, heavy metal availability and growth of Chenopodium album L. in a soil contaminated by pyritic mine waste. Chemosphere, 57:215-224.

Wilkinson, K. J., J. C. Negre and J. Buffle, 1997. Coagulation of colloidal material in surface waters: the role of natural organic matter J. Contam. Hydrol., 26: 229–243.

Woltemade C., 2010. Impact of residential soil disturbance on infiltration rate and stormwater runoff. J. Am. Water Res. Assoc. 46: 700–711.

Wright, A. L., T.L. Provin, F. M. Hons, D. A. Zuberer and R. H. White, 2008. Compost impacts on dissolved organic carbon and available nitrogen and phosphorus in turfgrass soil. Waste Manage. 28:1057–1063.

WSDE Washington Soil Department of Ecology. 2014. 2012 Stormwater management manual for western washington, as amended in December 2014 (The 2014 SWMMWW)

Wu, L. and M.B. McGechan., 1999. Simulation of nitrogen uptake, fixation and leaching in a grass/clover mixture. Grass Forage Sci. 54:30-41.

Zhang, M., D. Heaney, B. Henriquez, E. Solberg and E. Bittner, 2006. A four-year study on influence of biosolids/MSW cocompost application in less productive soils in Alberta: nutrient dynamics. Compost Sci., 14:68-80.

Zhang, M., S. S. Malhi, R. Panasuik and B. Henriquez., 2010. Response of turfgrass growth in a black chernozemic soil amended with municipal solid/biosolid waste compost. J. Plant Nutr. 34:183–205.