FEASIBILITY OF SPENT COFFEE GROUNDS FOR USE IN TURFGRASS SYSTEMS

A Thesis

by

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ABSTRACT

The growing popularity of coffee, and recent rise in popularity of bottled cold-brewed coffee, has resulted in increase in the amount of coffee production. In 2018, the world production was more than 57 Gg of green coffee. After coffee is roasted, ground, and brewed, the spent coffee grounds (SCG) remain, leaving a byproduct that offers many favorable agronomic properties, but also contains caffeine, tannins and phenolic compounds. There is a limited body of research examining effects of SCG on plants, and little to none of this pertains to use in turfgrass systems. Spent coffee grounds have developed a favorable reputation for use on plants and soils. In addition to offering some beneficial properties, research also suggests that SCG may also have toxic effects on some plants species. Therefore, the objectives of this project were to evaluate the feasibility of using SCG as a topdressing source of nutrients or sand root zone amendment in bermudagrass (*Cynodon* spp.) turfgrass systems. Our results demonstrate that although SCG possess a favorable C:N ratio, SCG alone do not produce responses typical of a fertilizer when applied as a topdressing. However, when combined with poultry litter, the SCG organic fertilizer GeoJava, improved turf quality relative to other organic and synthetic commercial fertilizers, including Milorganite, ammonium sulfate, and URI-PEL S.R. In sand root zone amendment evaluations, SCG incorporation promoted a number of favorable responses. Although a small amount of transient bermudagrass chlorosis was noted in the initial weeks following incorporation, these effects soon disappeared. Spent coffee grounds incorporation generally improved both water and nutrient retention properties when compared to peat moss as well as sand alone. The SCG showed comparable to improved levels of extractable soil water during dry-down, and higher levels of tissue N, suggesting effects on enhanced retention of N in the root zone. Considering the observed responses over these two-year field and greenhouse studies, SCG offers potential as a component in organic fertilizers, or directly as an alternative amendment for peat moss in sand-based rootzones.

DEDICATION

To my Mother,

Thank you so much. You may not have always seen the direction that I was going but you always believed in me nonetheless. You have supported me these last 8 years and I can honestly say that I would not be here today without your love and generosity. You have always been an example of success to me and I hope to rise to the heights you have achieved in your own field. I cannot thank you enough for the sacrifices you have made for me and I hope I can someday return even a fraction of the opportunity and joy you have allowed me, now and in my future. I’m ready to break that plate.

I love you, Ma.

Also to my Grandmother,

Grandma, you are the reason I have been so fascinated with plants. Your green thumb has truly inspired me to wonder and learn about these amazing organisms. As a child, I would watch you take a piece of a limb from a plant and use it to propagate an entirely new individual. Back then this concept was truly astonishing in every sense of the word. Today, I know how this happens and a whole lot more. You have always seen plants as living creatures rather than idle decorations and I have always loved that about you. You have genuinely shaped my life grandma and I am forever grateful. I hope to see you and grandpa more when I move closer to home.

I love you both more than you could know.

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This work was supervised by a thesis committee consisting of Dr. Benjamin G. Wherley, Dr. Sam Feagley and Dr. Kevin McInnes of the Department of Soil and Crop Science, and Dr. Leonardo Lombardini in the Department of Horticultural Science.

Reagan Heil helped with the data analysis. Brianna Houser and Garrison Moczygemba provided majority of student labor. All other work and photos were completed independently.

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NOMENCLATURE

ANOVA	Analysis of Variance
DGCI	Dark Green Color Index
NDVI	Normalized Difference Vegetative Index
PSD	Particle Size Distribution
SCG	Spent Coffee Grounds
TESW	Total Extractable Soil Water
TQ	Turf Quality
USGA	United States Golf Association
VWC	Volumetric Water Content

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CHAPTER I

INTRODUCTION

Turfgrass, Sand-Based Rootzones

Turfgrass is a group of widely cultivated monocots that encompasses areas from parks to home lawns to golf courses and sports fields. These stands of grass range in their level of inputs and maintenance based on several factors, including species, variety, climate, soil type and the purpose the turf is being grown for. For example, it is likely that a golf course or sports field will maintain their turf to a higher degree than the average homeowner or recreational facility. When growing any plant, soil type plays a critical role in the amount of inputs and maintenance a particular plant may need. Many times native soils will not be sufficient media for growing a given species, especially when performance is considered. In soils that are high in clay or silt, the ability of water to both infiltrate and percolate through the soil is low. This can cause the water to runoff the surface causing erosion and a lack of soil moisture in the root zone.

Golf course putting greens and high-end grass sports fields use sand-based root zones that allow rapid infiltration and drainage. When well designed, sand provides a surface that is firm and is ready for traffic relatively soon after irrigation or heavy rainfall events, maximizing the amount of time the surface is playable. Design recommendations from the United States Golf Association (USGA) include recommendations on the physical properties of the sand used in construction (ref). Included in the recommended physical properties of sand are particle size distribution, water retention, and permeability. Water retention and permeability are governed in large part by the particle size distribution of the sand. The ability to drain water quickly means the soils retain little water where it is needed in the root zone. Beyond this, sand has a very poor cation exchange capacity (CEC) so, aside from little water, these systems also retain very low concentrations of nutrients (Bigelow, Bowman, & Cassel, 2004). For these reasons, soil amendments have been added to sand-based root zones to increase the water holding capacity and nutrient retention properties making management easier and reducing the amount of water and fertilizer used in these systems.

USGA Sand-Based Rootzones

The USGA recommends creating putting greens using sand-based root zones. The following information is from the 2018 USGA recommendations for constructing a putting green (United States Golf Asscociation, 2018). The general construction of these root zones calls for a cavity to be created where the putting green is to be installed. Once this cavity is created, a wicking barrier can be installed along cavity walls to reduce the amount of tension the native soils surrounding the green place on the water column in the future sand-based root zone. Once the wicking barrier is in place a minimum of 10 cm of pea gravel is placed on top of the cavity floor following the subgrade of the green. The gravel is used, again, to reduce the amount of tension the water column in the sand is placed under, as well as allowing lateral movement to the drain lines. In their 2018 recommendations on putting green construction, the USGA recommends gravel that has a particle size distribution with ≥ 90% of the gravel falling between 2 mm and 12 mm diameter size particles but no particles larger than 12 mm. In addition, ≤ 5% of gravel particles should be smaller than 1 mm in diameter. Atop of the gravel, 30 cm of sand is placed which will act as the putting green root zone. These sands should follow the USGA recommendations indicated in Table 1.1. The reason for the low amount of fine sized particles in the root zone is to leave larger particles that will not pack as densely, allowing the sand a high degree of permeability and drainage. These particles will also prevent rapid and extreme compaction which deprive roots of both oxygen and water, ultimately lowering turf quality.

Golf Course Resource Usage

With some of the largest swathes of highly maintained turfgrass belonging to the golf industry, many resources are used in the pursuit of high-quality turf. It was estimated that there are approximately 6,087 km^2 of maintained turfgrass on golf facilities in the U.S. alone (Golf Course Superintendents Association of America, 2007). With more than 32,000 golf courses around the world and 60% of them in North America (Briassoulis, 2007), golf courses owners and managers are feeling the pressure to reduce resource consumption as well as develop more sustainable practices and sources of irrigation. There have been several environmental impacts associated with golf course maintenance and development such as increases in chemical use and associated runoff, effect on wildlife through land clearing and occupancy but likely the most crucial would be use of local water resources (Salgot & Tapias, 2006). While golf courses have also been noted to significantly increase economic activity by creating jobs, attracting tourists, change infrastructure and increase development of real estate, there is still opposition by some to their installation usually due the issues mentioned previously (Salgot & Tapias, 2006; Briassoulis, 2007). As resource scarcity becomes more prominent, future golf courses will face even more opposition and pressure to become more sustainable in their maintenance of turfgrass.

These pressures will only grow in the future as the population increases and climate change exacerbates the issue (Scott, Rutty, & Peister, 2018). Given current trends in water consumption and population rates, we are facing a 40% water deficit by the year 2030 if increases in water use efficiency are not produced (Water Resources Group, 2009). With these data in mind, drastic reduction in resource consumption, especially in recreational facilities, must be attained. This is imperative to not only the future of the golf course industry but the sustainable future as well.

Sphagnum Peat Moss

Sphagnum peat is a widely used soil amendment in both horticultural and agronomic settings (Bigelow, Bowman, & Cassel, 2004; Bunt, 1988). The purpose of using this organic material is to allow for increased levels of water and nutrient retention due to its high porosity at 93% and a “useful” CEC (Bunt, 1988). Bunt (1988) also defines sphagnum peat moss as fiber of the stems and leaves of *Sphagnum* spp. which should be comprised of 90% organic matter on a dry weight basis. Sphagnum peat moss or commonly referred to simply as peat moss (PM) is generated in peatlands or peat bogs, the largest of which occur in the northern hemisphere in climates of low temperatures and heavy rainfall (Bunt, 1988). Peat is a highly sought-after product for amending soils in many horticulture and garden settings but is commonly used outside of horticulture to amend sand-based root zones like those found in golf course putting greens and sports fields (McCoy, 2013). Due to this popularity, it is commonly mined in a process that first drains the peatland and as it dries, the material is removed. This process of draining the bogs increases CO_2 and N_2O emissions from these carbon sinks. Once dried, the flammable material can easily catch fire. These events have occurred several times throughout this industry allowing massive quantities of CO_2 to be released back into the atmosphere, significantly contributing to global greenhouse gas emissions (Barthelmes, Couwenberg, & Joosten, 2009).

These peatlands should be less prioritized as a means to increase the water holding capacity in a greenhouse pot and more recognized as a significant sink for the world’s carbon. This is especially true in light of the growing environmental and ecological concerns relating to peat production (Turetsky, Wieder, Halsey, & Vitt, 2002). While these areas of decaying plant material may not appear to be important ecosystems, they actually offer several important ecosystem services. Locally, they play part in the regulation of flood water, provide palaeoecological archives and provide high quality drinking water from peatland catchments (Bonn, Allott, Evans, Joosten, & Stoneman, 2016). Globally, peatlands hold twice the amount of carbon compared to the entire global forest biomass pool yet cover less 3% of the Earth's surface (Bonn, Allott, Evans, Joosten, & Stoneman, 2016). Many scientists view these non-renewable peat bogs as being equally important to the Earth's climate as rainforests. It was estimated that this fraction of the planet represents 30% of global soil carbon stores (Bonn, Allott, Evans, Joosten, & Stoneman, 2016). Considering peat continues to be the predominant amendment utilized for golf course sand root zones in many parts of the world (Bigelow, Bowman, & Cassel, 2004), SCG could offer an opportunity for use of a renewable resource in many regions.

Coffee Production and Byproducts

Coffee is currently grown in over 80 countries, and is one of the largest traded commodities (Murthy & Madhava Naidu, 2012). Production and worldwide consumption of coffee has increased considerably in the recent years, with a 17% increase occurring between 2000 and 2012 alone (Campos-Vega, Loarca-Piña, Vergara-Castañeda, & Oomah, 2015). Residues from the production of coffee, including spent coffee grounds (SCG), reportedly generate more than two million tons of residue per year (Pandey, et al., 2000). In Asia, consumption of ready-to-drink coffee in bottle, packs, and cans increased remarkably in recent years (Morikawa & Saigusa, 2011), and this trend is now taking place in the U.S. The large amounts of residue generated from coffee production are significant, and have even necessitated development of waste management plans by companies including Nestlé, which has pledged to significantly reduce waste by 2020 using SCG as a source of renewable energy in more than 20 Nescafé factories (Campos-Vega, Loarca-Piña, Vergara-Castañeda, & Oomah, 2015). Currently, residues from coffee production are either discarded or collected and hauled off for use in composting, gardening, bioenergy production, and/or mushroom growth (Campos-Vega, Loarca-Piña, Vergara-Castañeda, & Oomah, 2015). One beverage company in central Texas currently generates roughly 60 m^3 per week of SCG from the production of hot and cold-brewed coffee beverages which are shipped throughout the U.S. and the world, and anticipates rapid growth over the next five years. This increased production could easily approach 80 m^3 per week from this one company alone, primarily driven by the growing popularity and demand for cold brew coffees worldwide (personal communication). Coffee grounds from this company have been utilized for incorporation into lawn compost mixes and even applied directly as lawn topdressing in commercial and home landscapes by regional landscapers.

Given the current and anticipated growth of this industry nationally and worldwide, there is considerable value in evaluating the agronomic merits/demerits of SCG for use in golf course turf applications, either in amending sand for root zones or topdressing materials. While significant anecdotal evidence has existed for years relating to the agronomic benefits of SCG on gardens and landscape plant growth, very few published data currently exist on the subject. In fact, of all 72 accessible published papers on the topic of SCG, half have been published since 2010 (Campos-Vega, Loarca-Piña, Vergara-Castañeda, & Oomah, 2015), and none can be found that relate to use in turfgrass management applications.

Spent Coffee Grounds: Physical and Chemical Properties

Chemical analysis recently conducted on SCG at Texas A&M university indicated slightly acid pH ranging from 4.8 (composted) to 5.6 (fresh), with 2.3% N, 0.05% P, 0.5% K, 0.01% Ca, 0.1% Mg 150 mg/kg Fe, 25 mg/kg Cu, 40 mg/kg Mn, 1400 mg/kg S, and 12 mg/kg B. Total C of 46% was also detected, yielding a relatively ideal 20:1 C:N ratio (similar to grass clippings) for SCG. Furthermore, coffee grounds also possess a microscopically porous nature (Figure 1.1 & 1.2), which may aid in retention of water and nutrients when used as a root zone amendment. Coffee grounds may persist in soil for a longer time period than peat moss, given their larger physical size and physical consistency. Additionally, coffee grounds have been found to contain similar concentrations of N and K relative to common organic materials such as cow manure (Kasongo, Verdoodt, Kanyankagote, Baert, & Ranst, 2011; Pandey, et al., 2000). Morikawa and Saigusa (2011) noted that topdressing applications of coffee grounds led to elevated Fe and Zn levels in rice grain due to residue acting as Fe and Zn chelating agents in soils. For turf applications, little is known regarding nutrient supplying potential, or application methods, i.e., whether grounds could be directly incorporated as a topdressing or sand amendment material, or whether it should first be composted.

Spent Coffee Grounds: Phytotoxicity

There have been several compounds in SCG that have shown phytotoxic effects on certain crops and horticultural species. Caffeine has been one of the most prominent compounds attributed for these negative effects but others such as tannins and polyphenols have been implicated as well. The physiological effect of caffeine on plants has been shown to decrease both activity and expression of rubisco (Mohanpuria & Yadav, 2009). This is a crucial enzyme in the stroma of plant chloroplasts responsible for the first step of carbon fixation in the Calvin Cycle. This enzyme is already relatively inefficient but compensates for this by being abundantly produced. If the activity and production of rubisco were inhibited, serious consequences would be observed in the plant. While several papers point to caffeine as a major culprit (Mohanpuria & Yadav, 2009; Cruz, Baptista, Cunha, Pereira, & Casal, 2012) it has also been observed that caffeine is one of the first compounds degraded in microbial communities that are capable of decomposing it (Bollen & Lu, 1961; Chalker-Scott, 2016). Another compound attributed to major adverse effects in plant development is the polyphenol chlorogenic acid, which is found in SCG (Campos-Vega, Loarca-Piña, Vergara-Castañeda, & Oomah, 2015). This acid, while proving phytotoxic, also has a function as a metal chelator and is also responsible for increasing the plant available Fe levels in soil as well as plant tissues.

Beyond the toxic compounds that remain in the spent grounds after brewing, SCG have the ability to immobilize otherwise available N in the soil. While the C:N in the SCG analyzed was 20:1, it was found that the beans are heavily lignified and the N pool consists of highly structural proteins. These components of SCG create a slow process of degradation (Kitou & Okuno, 1999; McNutt & He, 2019). So as the microbial communities work to break down the grounds they receive little N from the grounds themselves. This will cause the microbial communities to pull N from otherwise plant available sources and result in N immobilization.

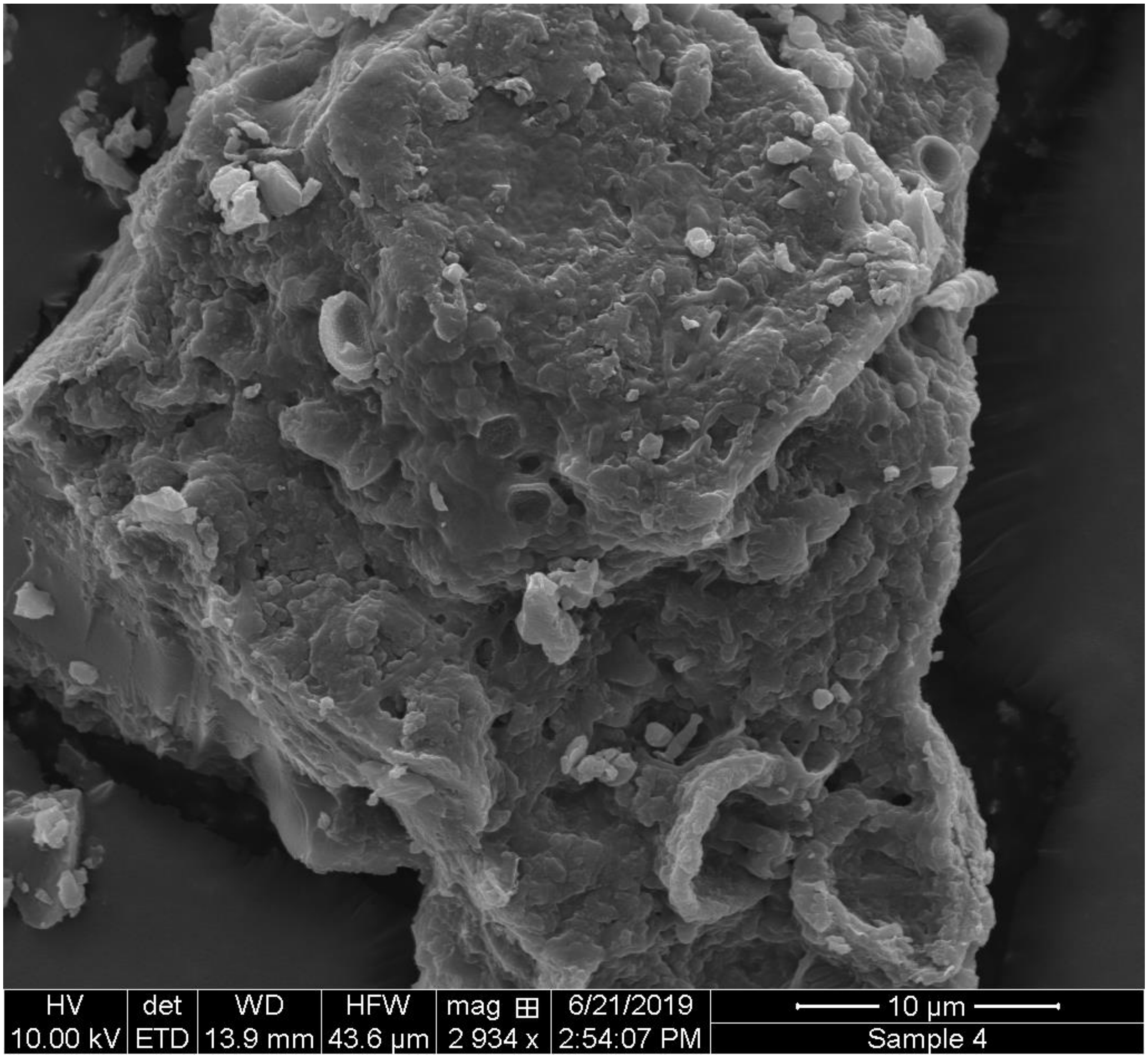

Figure 1.1: Scanning electron microscope (SEM) images taken on the FEI Quanta 600 FE-SEM at the Microscope Imaging Center (MIC), Texas A&M University. The image taken with a magnification of 2934x, shows an approximately 80-micron SCG particle from a ground sample prepared with a 6nm Pt/Pd sputter coat. SEM images taken by Aditi Pandey.

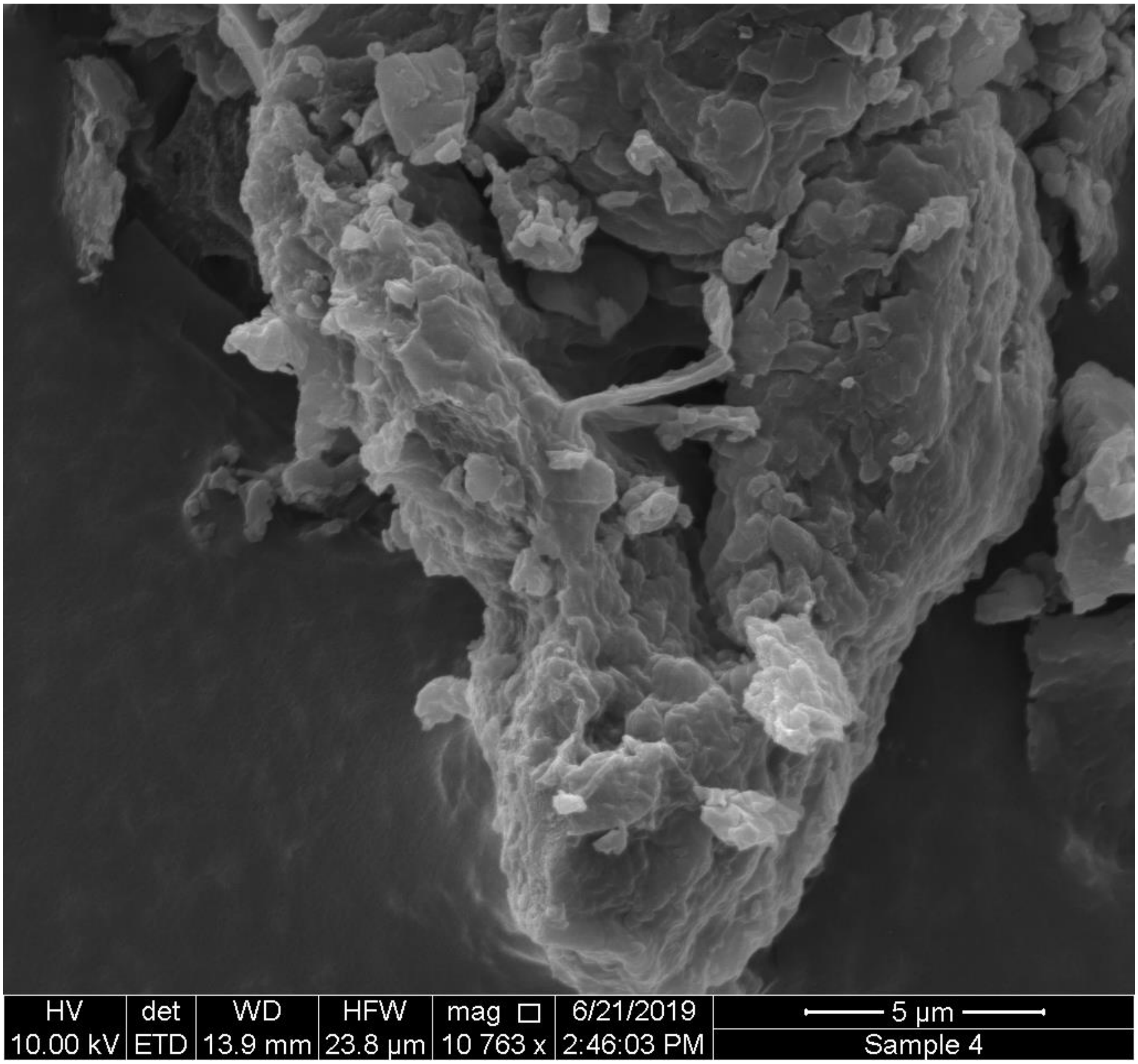

Figure 1.2: Scanning electron microscope (SEM) images taken on the FEI Quanta 600 FE-SEM at the Microscope Imaging Center (MIC), Texas A&M University. The image taken with a magnification of 10763x, shows an approximately 25-micron SCG particle from a ground sample prepared with a 6nm Pt/Pd sputter coat. SEM images taken by Aditi Pandey.

CHAPTER II

EVALUATION OF SPENT COFFEE GROUNDS AS A TOPDRESSING FERTILIZER FOR WARM-SEASON TURFGRASS LAWNS

Abstract

The growing popularity of coffee and recent rise in popularity of bottled cold-brewed coffee has resulted in greater production of spent coffee grounds (SCG). Spent coffee grounds offer many favorable agronomic properties, but also contains caffeine, tannins and phenolic compounds. There is a growing body of research examining effects of SCG on plants, but little to none of which pertains to use in turfgrass systems. Therefore, the objective of this study was to evaluate the agronomic feasibility of using SCG as a turfgrass source of nutrients. Field studies were conducted over two years to characterize performance of ‘Riley’s Super Sport’ (Celebration®) bermudagrass (*Cynodon dactylon*) to multiple nutrient source treatment regimens including direct SCG application, as well as other commercially available synthetic and natural organic fertilizers, some of which included SCG. Soil samples were obtained at the conclusion of the study to determine long-term effects of SGC on soil pH and nutrient concentrations. Our results demonstrated that although SCG possess a favorable C:N ratio, direct SCG applications did not produce responses typical of a fertilizer when applied as a topdressing. However, when combined with poultry litter, SCG-containing organic fertilizer GeoJava produced improved turf quality relative to other organic and synthetic commercial fertilizers in our study, including Milorganite, ammonium sulfate, and URI-PEL S.R.. Further, despite the acidic nature of SCG, their repeated application over multiple years did not result in any long-term changes to soil pH.

This study revealed that SCG do not act as a source of nutrients when applied alone. However, the grounds did not significantly affect the turf in a negative way. While the grounds did show transient phytotoxicity, these effects can be remedied through the addition of manure with coffee. The GeoJava treatments (containing SCG and chicken manure) were observed as maintaining a high level of turf quality over both years of the study. With the 4-2-1 fully organic product being highly competitive with fully synthetic products such as ammonium sulfate and URI-PEL S.R. this should be considered as a legitimate alternative to synthetic fertilizers that offers great color and density of turfgrass.

Introduction

Regular fertilizer inputs are often needed to provide functional and aesthetically pleasing turf quality, whether on golf courses, sports fields, lawns, or parks. Many of the fertilizers used in highly maintained turfgrass are synthetically derived, and while highly effective, if not properly applied, they can contribute to salt buildup in the soil as well as leaching or runoff of nutrients. Synthetic fertilizers also require relatively high energy inputs to produce but are commonly cheaper than their organic alternatives. This is one reason they are so popular in agronomic communities. Natural organic fertilizers can also allow for runoff and salt accumulation but with proper application, offer slow-release alternatives that can be used in commercial settings. However, these fertilizers are generally applied in higher quantities due to lower N contents (Adegbidi, Briggs, Volk, White, & Abrahamson, 2003). This could increase costs as well as require more planning due to the window required for these fertilizers to start releasing plant available nutrients. Commonly used sources of material for natural turf fertilizers include poultry waste or litter, food waste, and/or municipal biosolids (Eldridge, et al., 2009). Because of homeowners and landscapers desire to see rapid green-up following application, one potential drawback to slow release fertilizers is tendency for the slower release compared to water-soluble fertilizer sources.

The increase in coffee production worldwide offers potentially another source of material for use as an organic source of nutrients. Once coffee is roasted and brewed, the SCG remain, leaving a byproduct that offers many favorable agronomic properties, but also contains caffeine, tannins and phenolic compounds (Leifa, Pandey, & Soccol, 2000). There is a limited, but growing body of research examining effects of SCG on plants, and very little to none of this pertains to use in turfgrass systems. Spent coffee grounds have developed a favorable reputation for use on plants and soils, as for years, humans have topdressed their gardens and flower beds with leftover grounds from the morning coffee pot. In addition to offering some beneficial properties, research also suggests that spent coffee grounds (SCG) may also have toxic effects on some plants species (Fernandes, et al., 2017).

Considering their favorable chemical and physical properties, SCG may offer promise as a natural organic turfgrass fertilizer. Down-stream use of SCG as a source of nutrients could also address the environmental challenge of disposing of large quantities of coffee waste material. However, limited information currently exists relating to feasibility of SCG as a turfgrass source of nutrients. Therefore, the objective of this study was to evaluate the agronomic feasibility of using SCG as a turfgrass source of nutrients. Field studies were conducted over multiple years to characterize turf performance and soil attributes under multiple fertilization treatment programs including direct SCG, SCG-based organic fertilizer, as well as other commercially available synthetic and natural organic fertilizer sources.

Materials and Methods

Research Location and Design

This study was conducted from September 2017 through November 2019 at the Texas A&M Turfgrass Research Field Laboratory, College Station, Texas. Research plots of 7-year old established 'Riley's Super Sport' (Celebration$^{®}$) bermudagrass (*Cynodon dactylon*) were used for the study. Soils at the site were a Boonville fine sandy loam (fine, montmorillonitic, thermic, Vertic Albaqualf). The study was arranged as a randomized complete block design with three replicate plots (1.22 m x 1.22 m) per treatment. Within each block, an untreated 0.25 m wide alley divided treatment plots (Figure 2.1).

Figure 2.1: Image of the Texas A&M University fertilizer field study just prior to a clipping collection event. Trial was conducted on a 7-year-old stand of Celebration® bermudagrass.

Cultural Management

Irrigation was supplied 2 times weekly from April through October of each year. Each irrigation event supplied 1.25 cm of water totaling 2.5 cm of irrigation water per week to meet seasonal water demands for warm-season turf. To avoid over-watering, irrigation amounts were adjusted for rainfall events during the study. Briefly, 100% of the first 2.5 cm of rainfall was accounted for when determining weekly irrigation requirements, with additional rainfall beyond 2.5 cm not accounted for (i.e., considered to not be effective rainfall). Plots were mowed at 3.2 cm height of cut 1-2 times weekly during the season using a walk-behind rotary push mower with a bagger. Clippings were collected during each mowing event in order to prevent cross contamination of clippings or fertilizer treatments between adjacent plots.

Nitrogen fertilizer treatments were applied four times per growing season at 8-week intervals, at rates of 4.9 g m^{-2} from April through November. Nine different fertilizer treatments were used, which included both commercially available natural organic and synthetic, as well as spent coffee grounds (SCG) treatments (Table 2.1). The fertilizer treatments included fresh SCG and composted SCG. These grounds were obtained through Aspen Beverage, a cold brew coffee manufacturer in San Antonio, TX. The SCG were shipped to College Station via large dump trucks and processed upon arrival. Fresh SCG were prepared by taking the wet grounds and drying them less than 24 hours after delivery. This process involved taking two, 208 L trashcans and filling them with the fresh wet grounds. Once they were collected from the outdoor pile, they were placed in 23.4 L paper bags and put into a drying oven at 65 °C for 72 hours. After drying was completed, the SCG were placed back into a 55-gallon can and labelled as the “Fresh” stock. Interestingly, only one can was able to be filled after the drying was completed due to the SCG ability to shrink and swell with changes in VWC. The fresh stock was used for the fresh treatment during both years of the study. Composted SCG were prepared with the remainder of the SCG in the outdoor pile. This process allowed the grounds to be exposed to the environment for 3 months, during which time the pile was turned twice weekly. After oven drying, samples of both Fresh and Composted SCG were submitted for chemical analysis at the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory. The SCG were observed to be very hot in the center of the pile and temperatures of approximately 60°C were very common. The compost pile temperatures were determined using a 51 cm Reotemp Composting thermometer. It should be noted that at no point during the composting did the SCG pile go below "active" temperatures (38-54°C) for the duration of this study. The active temperatures are the range the Reotemp brand describes as the point where the temperature drives off or kills insects and worms and the material is degraded mainly by microorganisms. Once the 3-month period was achieved, a stock was taken from the pile and used for the future study. In the second year of the study the process was repeated to prepare a freshly composted stock.

Milorganite is a natural organic fertilizer derived from biosolids and manufactured by the Milwaukee Metropolitan Sewerage District. It acts as a slow release source of N and was fortified with iron. URI-PEL S.R. is a combination of synthetic fertilizers with 25% sulfur-coated urea which is a synthetically derived slow-release fertilizer, created from a two-step process where ammonia and carbon dioxide are reacted to create ammonium carbamate which is dehydrated to form urea. Over time, the sulfur coat wears down on the pellets releasing more urea in what is known as a controlled- release fertilizer. Ammonium sulfate is a synthetically-derived quick-release fertilizer. There are several ways to produce this synthetic compound which results in a high N and no P or K. The particular fertilizer used in this study was a 21-0-0 but also contained Iron as a supplemental nutrient.

GeoJava, GeoJava Bridge Product, Sigma Agriscience Organic, Sigma Agriscience Bridge Product were all produced by SigmaAgriscience in Boling, TX. The GeoJava fertilizers were created using SCG from Aspen Beverage combined with Sigma 7-2-1 Bio. The GeoJava 4-2-1 fertilizer is an organic 4-2-1 fertilizer that is 50% SCG and 50% Sigma 7-2-1 Bio which is composed of composted poultry manure and feather meal. The GeoJava Bridge Product has a N-P_2O_5-K_2O of 12-2-6 and is 50% GeoJava Organic and 50% Sigma Agriscience Bridge Product.

Evaluation of Growth Responses to Fertilizer Treatments

Following mid-summer fertilizer treatment applications, clipping studies were conducted during both 2018 and 2019 in order to characterize shoot growth responses to each source of nutrient treatments over six weeks following application. Prior to clipping collections, alleys between blocks were mowed to a slightly lower, 2.5 cm height of cut to remove the clippings outside of plot borders. As a result, the effective area (1.02 m^2) of turf mowed within each plot during each clipping collection event was slightly less than the overall plot area (1.49 m^2) (Figure 2.1).

For clipping events, the bagger was removed and a HDX 3.79 L elastic top strainer bag was secured to the exit port of the mower. The elastic strainer bags allowed the clippings to be easily captured and directly transferred to the drying oven, where they were oven dried for 3 days at 65°C before weighing.

Table 2.1: Description of fertilizers used in the evaluation and comparison of SCG as a topdressing fertilizer for warm-season turfgrass lawns.

Fertilizer Treatment	**Manufacturer**	**Analysis (N-P-K)**	**Additional Nutrients**	**Description**
Untreated	-	-	-	-
Fresh SCG	Aspen Beverage	2.3-0.1-0.5	Ca(0.2%), Mg(0.1%), Na(0.1%), Zn(18ppm), Fe(409ppm)	Fresh SCG that have been dried one day after receiving date to reduce degradation effects and microbial activity.
Composted SCG	Aspen Beverage	2.9-0.1-0.5	Ca(0.2%), Mg(0.1%), Zn(20ppm), Fe(750ppm)	From same stock as fresh SCG but allowed to compost over a three month period
Geojava 4-2-1	Sigma AgriScience	4-2-1	Ca(5.0%), Fe(0.2%)	Composed of 50% SCG and 50% composted poultry manure and feather meal
Geojava Bridge 12-2-6	Sigma AgriScience	12-2-6	S(4.0%), Mg(5.0%), Fe(0.3%)	Consists of 25% SCG and 50% chicken litter and 25% Sigma 7-2-1 Bio and inoculated with *Glomus aggregatum, Glomus Mosseae, Glomus etunicatum, and Glomus intraradices* at 0.04 propagules/g
Milorganite	Milwaukee Metropolitan Sewerage District	6-2-0	Ca(1.2%), Total Fe(2.5%), Cl Max.(1.0%)	Pelletized processed biosolids from Milwaukee
Sigma 12-2-6	Sigma AgriScience	12-2-6	S(4.0%), Fe(0.3%)	Derived from composted poultry manure as well as synthetic fertilizers and inoculated with *Glomus aggregatum, Glomus Mosseae, Glomus etunicatum, and Glomus intraradices* at 0.04 propagules/g
Sigma 4-2-2	Sigma AgriScience	4-2-2	Ca(9.0%), Fe(0.2%)	Derived from composted poultry manure and feather meal and inoculated with *Glomus aggregatum, Glomus Mosseae, Glomus etunicatum, and Glomus intraradices* at 0.04 propagules/g
Ammonium Sulfate	American Plant Food Corp.	21-0-0	S(24%)	Synthetic high nitrogen fertilizer
URI-PEL S.R. 25% Sulfur Coated Urea	American Plant Food Corp.	21-7-14	S(5.00%), Cu(0.05%), Fe(3.00%), Mn(0.05%), Mo(0.0005%), Zn(0.05%)	Synthetic fertilizer with 25% of pellets accounting sulfur coated urea

Evaluation of Seasonal Turf Performance

Turfgrass performance during the study was evaluated through a number of parameters, including visual turf quality ratings, normalized difference vegetation index (NDVI), percent green cover based on digital images, and volumetric water content. The NDVI readings were taken once a week using a Fieldscout TCM 500 NDVI Turf Color Meter (Spectrum Technologies, Plainfield, IL). These readings were averaged from 3 different areas of representative turfgrass within one plot. Digital images were obtained using a Canon SX170 IS camera using a 1/13 shutter speed, F4.5 aperture and an ISO of 100. All images were taken using a lightbox with dimensions: 60.96 x 50.8 x 55.88 cm, using 4, 800 lumen fluorescent bulbs mounted at the top of each corner. SigmaScan Pro (Systat, San Jose, CA) sowftware was then used to determine percent green cover using a macro from the University of Arkansas named “Turf Analysis” (Karcher & Richardson, 2005). Dark Green Color Index (DGCI) of each image was obtained from the output of the turf analysis macro using the following equation (Karcher & Richardson, 2003):

$$\frac{[\frac{Hue - 60}{60 + (1 - Saturation) + (1 - Brightness)}]}{3}$$

This equation was used given the outputs of the “turf analysis” macro run in the SigmaScan Pro (Systat, San Jose, CA) software. This output produced the hue, saturation, and brightness from each picture which in turn was used to calculate the DGCI with the above equation.

Turf quality (TQ) was taken as a subjective measurement where a rating is given from 1 to 9 with 5 being the least acceptable level of TQ (Bilgili & Acikgoz, 2005). In this scale, 9 is the highest level of TQ while 1 is the lowest level. Rating was done by the same investigator for the entirety of the study and was taken around the same time of the day at each observation once a week. The volumetric water content was determined as the average of two readings taken at the 0-5 cm depth within each plot using a Dynamax TH_2O portable soil moisture meter using a Theta Probe ML3 (Dynamax, Houston, TX). Soil volumetric water content readings were taken weekly on the day prior to irrigation.

Soil Chemical Analysis

At the conclusion of the study (October 2019), two soil cores (15 cm deep x 5 cm in diameter) were removed from each field plot using an AMS 2"x6" (5.08cm x 15.24cm) soil core sampler (AMS, American Falls, ID). The upper 2.5 cm thatch/mat layer of each core was discarded before combining and thoroughly mixing cores from each plot. Representative samples for the upper 15 cm of each plot were then submitted to the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory for chemical analysis.

Analysis of Data

At the conclusion of the experiment, data was subjected to analysis of variance using the general linear model univariate test procedures (SPSS version 21.0; IBM Corporation, Armonk, NY) to determine statistical significance of the results. Where applicable, data were grouped according to rating season (Spring = March through May; Summer = June through August; Fall = September through November) to test effects of season on treatment responses. Mean separation procedures were performed using Fisher's Least Significant Difference at the $P \leq 0.05$ level.

Results

Preliminary chemical analyses indicated many favorable properties of spent coffee grounds, including a 2.4% N content, 23:1 C:N ratio, slightly acidic pH of 5.6, and presence of many essential macro and micronutrients including S, Mg, Zn, Fe, and Cu (Table 2.2, Flores, 2019). The highly porous nature of coffee beans may also presumably aid in soil water retention.

The ANOVA showed a significant treatment effect both years for all parameters except soil VWC and DGCI during 2018 (Table 2.3). All parameters except percent green cover and VWC showed a year x treatment interaction and therefore data have been presented separately by year. The ANOVA detected no significant treatment main effects or interactions for VWC. The ANOVA also showed significant treatment main effects in both years and a significant treatment x season interaction in 2019 for both TQ and NDVI. The ANOVA showed significant main effects of treatments on percent green cover, when pooled across years. The ANOVA also showed no significant treatment by season or treatment main effects for DGCI during 2018, however there was a significant treatment main effect on DGCI detected for 2019. The ANOVA for clipping dry mass data showed a significant treatment by year interaction, so data were again presented separately by year (Table 2.4). For both years of the study, ANOVA detected significant treatment main effects on clipping dry mass.

Table 2.2: This data represent the chemical analysis of spent coffee grounds sent to the Texas A&M Agrilife Extension Soil, Water and Forage Testing Laboratory before the begging of the study. This data shows the macro and micronutrients observed in the "fresh" SCG.

pH	EC umhos/cm	N %	P %	K %	Ca %	Mg %	Na %	Zn mg/kg
5.6	1260	2.3	0.1	0.5	0.2	0.1	0.1	15.2

Fe mg/kg	Cu mg/kg	Mn mg/kg	S mg/kg	B mg/kg	Total Carbon %	C:N Ratio
151	27	45	1445	11.5	46	20:1

Table 2.3: Analysis of variance for various turf performance parameters. This study was designed to look at the effects of different sources of nutrients and compare them to SCG as a topdressing. Data are split by year where significant Year x Treatment interactions were detected. Data were grouped according to rating season (Spring = March through May; Summer = June through August; Fall = September through November) to test effects of season on treatment responses.

Source	VWC	NDVI		TQ		%GC	DGCI	
		2018	2019	2018	2019		2018	2019
Treatment (T)	NS	**	***	***	***	**	NS	*
Season (S)	***	***	***	***	***	***	***	***
T x S	NS	NS	**	NS	***	NS	NS	NS

*, **, *** indicate statistical significance at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, respectively.

VWC – Volumetric Water Content
NDVI – Normalized Difference Vegetation Index
TQ – Turf Quality
%GC – Percent Green Cover
DGCI – Dark Green Color Index

Table 2.4: Analysis of variance for clipping dry mass data obtained during the mid-summer six-week clipping collection periods each year during the Texas A&M fertilizer field study. Year x treatment interactions were significant, so data are presented separately by year.

	Clipping Dry Mass	
Source	2018	2019
Treatment (T)	***	***
Week (W)	***	***
T x W	NS	NS

***Significant at P ≤ 0.001

Turf Quality

Based on ANOVA, there were highly significant treatment main effects detected for turf quality (TQ) in both 2018 and 2019, as well as a highly significant treatment x season interaction in 2019 (Table 2.3). In 2018, when averaging across all rating dates and seasons, mean TQ among treatments ranged from 5.5 to 6.6, with composted SCG showing the lowest ratings (5.5 out of 9) and GeoJava 4-2-1 (6.7 out of 9) showing the highest TQ (Figure 2.2). Overall TQ of GeoJava 4-2-1, Sigma 12-2-6, Sigma 4-2-2, and ammonium sulfate were all significantly greater than untreated control plots. Also, neither fresh nor composted SCG produced TQ that was significantly different from the untreated plots.

In 2019, a treatment x season interaction was detected for TQ (Figure 2.3). During spring, TQ among treatments ranged from 6.8 to 7.3. GeoJava 12-2-6 produced the highest spring TQ (7.3 out of 9), while the untreated controls had the lowest (6.8 out of 9). However, treatments did not statistically differ from one another or from the untreated control during spring. During summer months, TQ ranged from 6.7 to 7.6 among treatments, with Sigma 12-2-6 having the highest TQ (7.6 out of 9) and the untreated control again showing the lowest (6.7 out of 9). During summer, all treatments except for Fresh and Composted SCG, and GeoJava 4-2-1 showed statistically greater TQ than the untreated control. During the fall, TQ ranged from 5.8 to 7.6, with ammonium sulfate producing the highest levels of TQ (7.6 out of 9) and composted SCG yielding the lowest (5.8 out of 9). All treatments except for fresh and composted SCG had significantly higher levels of TQ than the untreated control. While the LSD bars do not allow for comparison between seasons, there was a general trend of untreated and SCG treatments showing initially higher TQ in the spring but declining throughout the summer and fall seasons. The remainder of the treatments stay relatively static or slightly improved over the season.

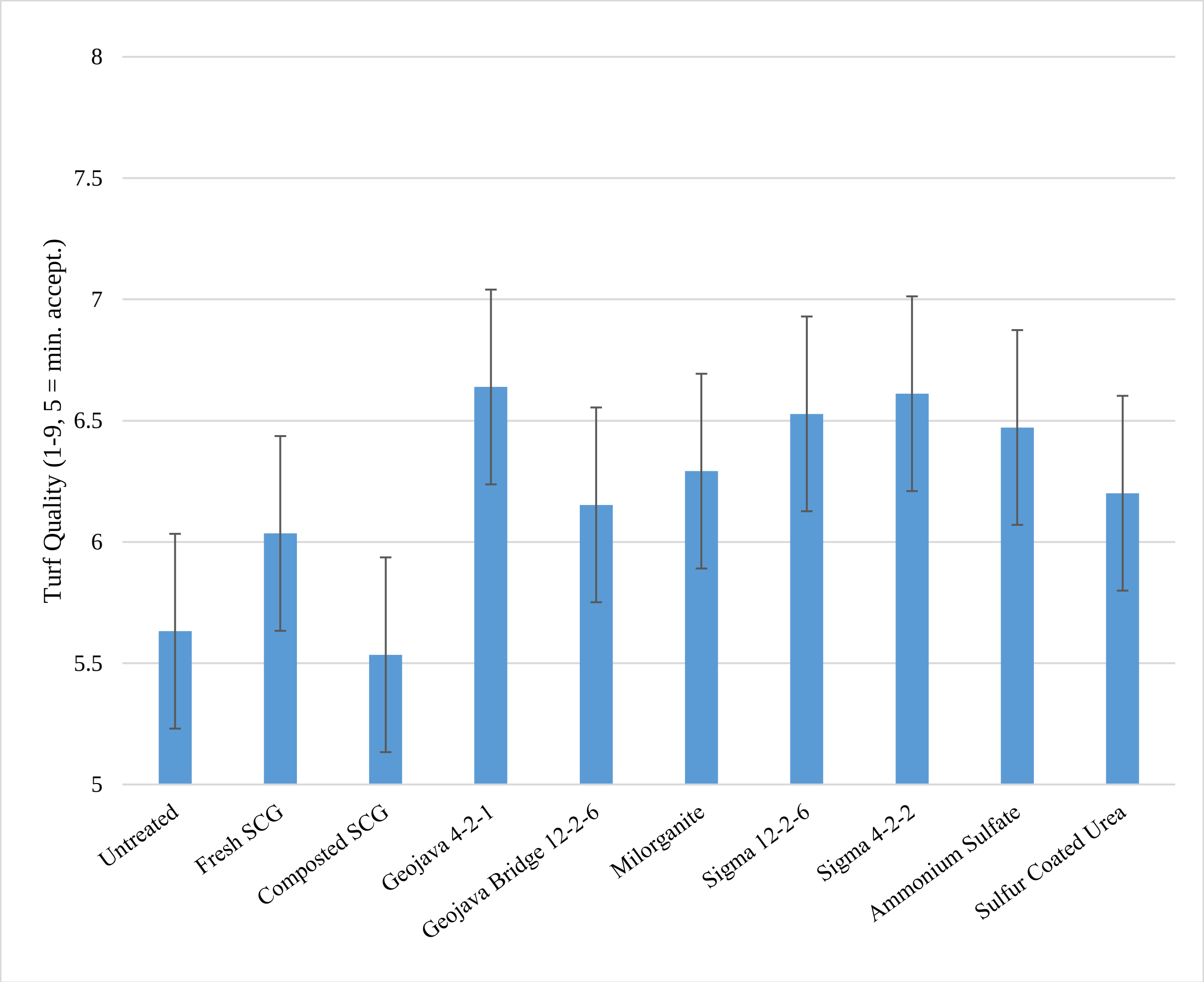

Figure 2.2: Fertilizer treatment main effect on Turf Quality during 2018 in the SCG fertilizer field study. Data are pooled across all rating dates. Error bars denote Fisher's LSD (0.05).

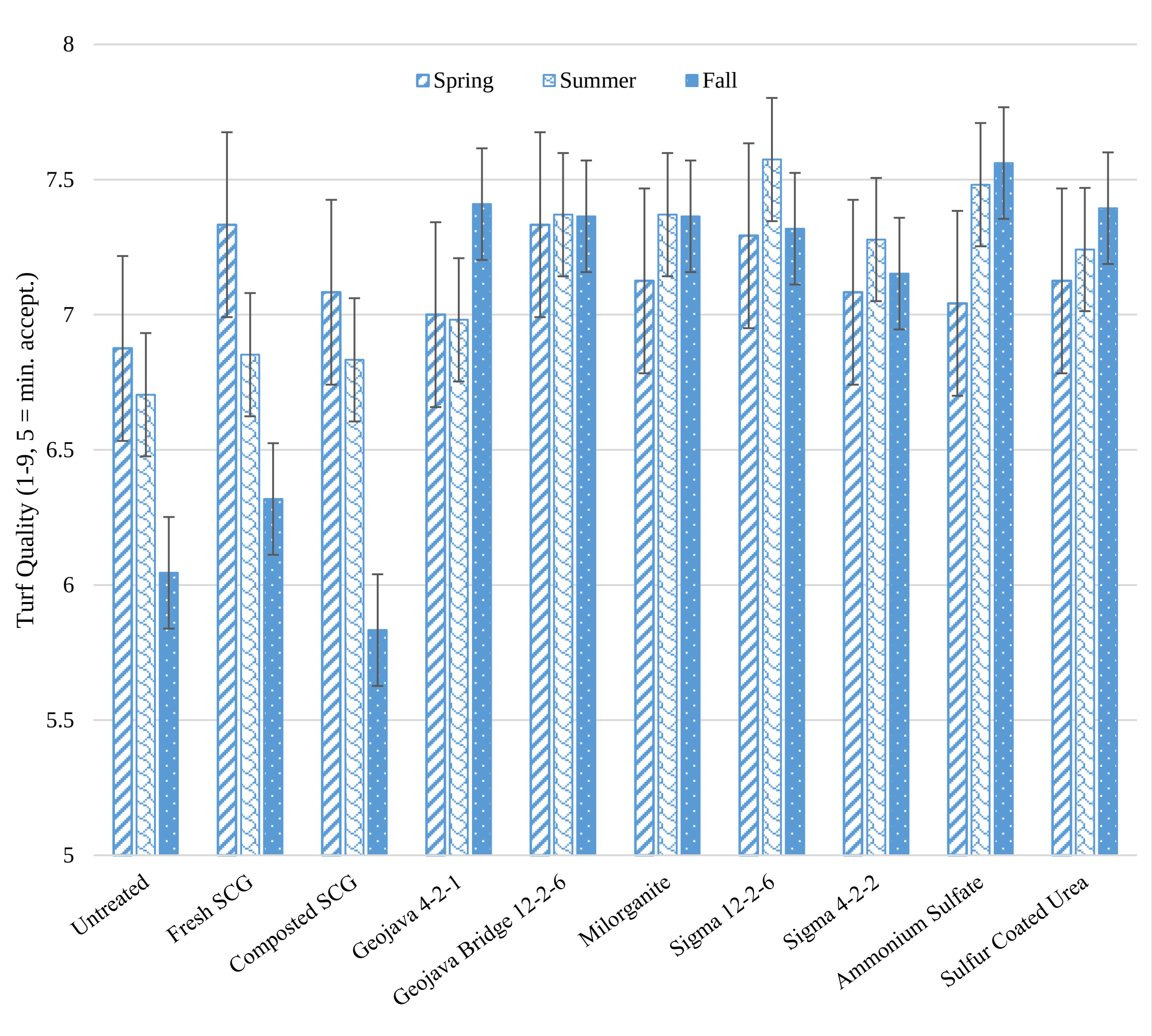

Figure 2.3: Fertilizer Treatment x Season interaction on Turf Quality during 2019 in the SCG fertilizer field study. Where, Spring = March-May, Summer= June-Aug, Fall= Sept-Nov ratings. Error bars denote Fisher's LSD (0.05), and are for comparing among treatments within a given season.

Percent Green Cover

The ANOVA showed no significant treatment x year interaction for percent green cover; therefore, data were pooled across 2018 and 2019 years (Figure 2.4). When averaging across all years and rating dates, percent green cover ranged from 72 to 81%, with the highest percent green cover occurring with Sigma 4-2-2 (81%) and the lowest being URI-PEL S.R. (72%). Although no treatments statistically differed from the untreated controls, Sigma 4-2-2, GeoJava 4-2-1, and Sigma 12-2-6 all showed significantly higher percent green cover (81, 78, and 77% green cover, respectively) compared to the URI-PEL S.R. treatment (72%).

Dark Green Color Index

There was a significant treatment by year interaction for DGCI, so data were split by year. In 2018, there were no significant treatment main effects or interactions for DGCI, however, in 2019, there were significant treatment main effects detected (Table 2.3). The DGCI data from 2019 ranged from 0.47 to 0.53, with URI-PEL S.R. showing the highest (0.53) and the untreated control showing the lowest DGCI (0.47) (Figure 2.5). When considering all treatments and rating dates in 2019, only the URI-PEL S.R. treatment significantly differed from the untreated control.

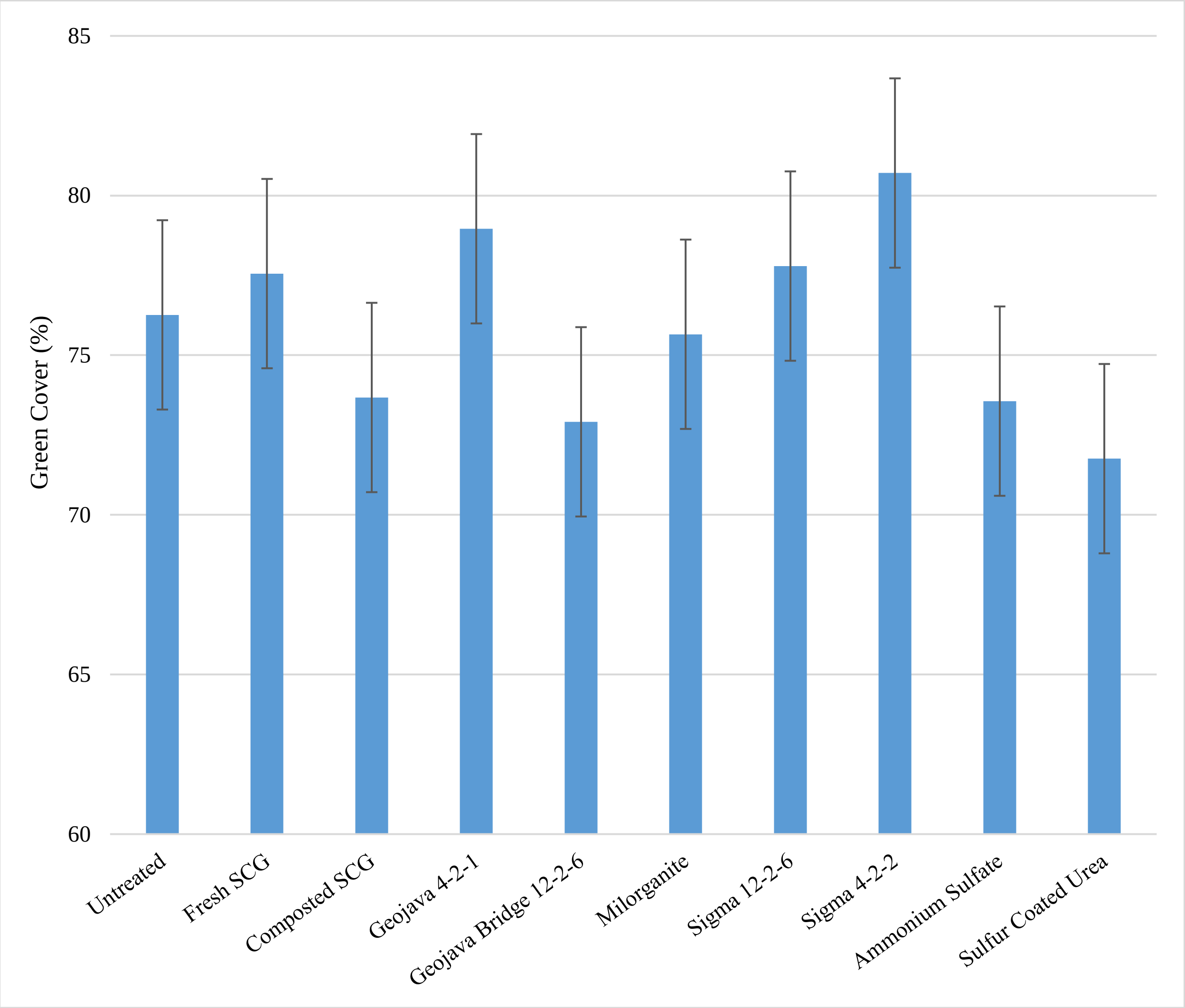

Figure 2.4: Fertilizer treatment main effect on Percent Green Cover during the SCG fertilizer field study. Data are pooled across all 2018 and 2019 rating dates. Error bars denote Fisher’s LSD (0.05).

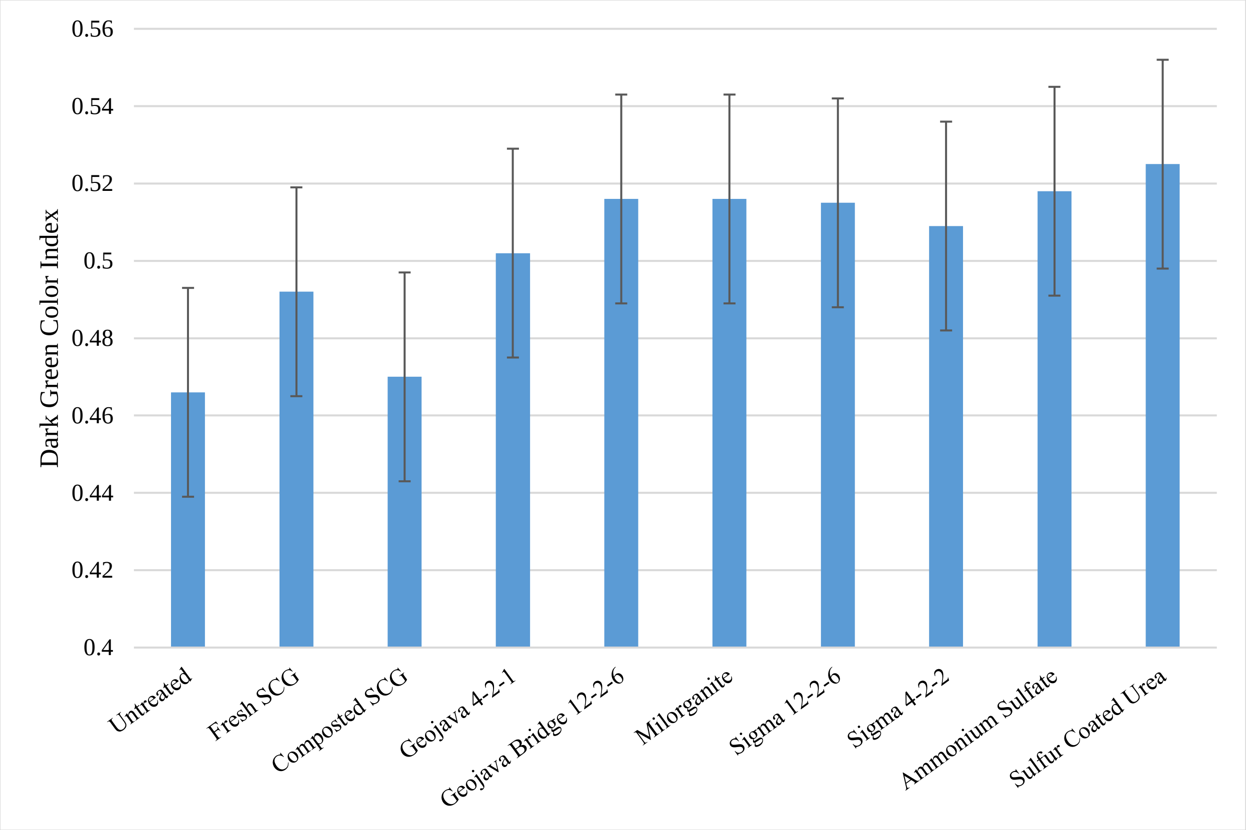

Figure 2.5: Main effect of fertilizer treatment on Dark Green Color Index (DGCI) during 2019 in the SCG fertilizer field study. Data have been pooled across all 2019 rating dates. Error bars denote Fisher's LSD (0.05).

Normalized Difference Vegetation Index

The ANOVA showed a significant treatment x year interaction for NDVI, so data were split by year (Table 2.3). There was a significant main effect of fertilizer treatment on NDVI in 2018 and 2019. In 2018, NDVI ranged from 0.66 to 0.70, with Sigma 4-2-2 showing the highest (0.70) and composted SCG showing the lowest NDVI (0.66) (Figure 2.6). While no treatments statistically differed from the untreated control plots, Sigma 12-2-6, GeoJava 4-2-1, and Sigma 4-2-2 all showed significantly greater NDVI (0.7, 0.69, 0.69, respectively) compared to the composted SCG treatment (0.66).

In 2019, there was a significant treatment x season interaction on NDVI (Figure 2.7). During spring months, NDVI ranged from 0.62 to 0.65, with Sigma 12-2-6 showing the highest (0.65) and both Ammonium Sulfate and URI-PEL S.R. showing the lowest (0.62) NDVI for the season. For spring, no treatments statistically different from one another or from the untreated controls. During summer months, NDVI ranged from 0.67 to 0.69, with Sigma 12-2-6 and Sigma 4-2-2 showing the highest (0.69) and untreated controls yielding the lowest (0.67) NDVI. During summer, there were again no statistical differences between any treated or untreated plots, however, summer NDVI were greater than those for spring. The NDVI readings for fall ranged from 0.64 to 0.70, with Sigma 12-2-6 once again providing the highest overall NDVI (0.70) and composted SCG generating the lowest average NDVI (0.64). For fall, all treatments provided significantly higher NDVI relative to the untreated control, fresh SCG, and composted SCG (which did not differ from one another). Finally, all treatments except for fresh SCG, and composted SCG yielded higher NDVI during fall than in other seasons.

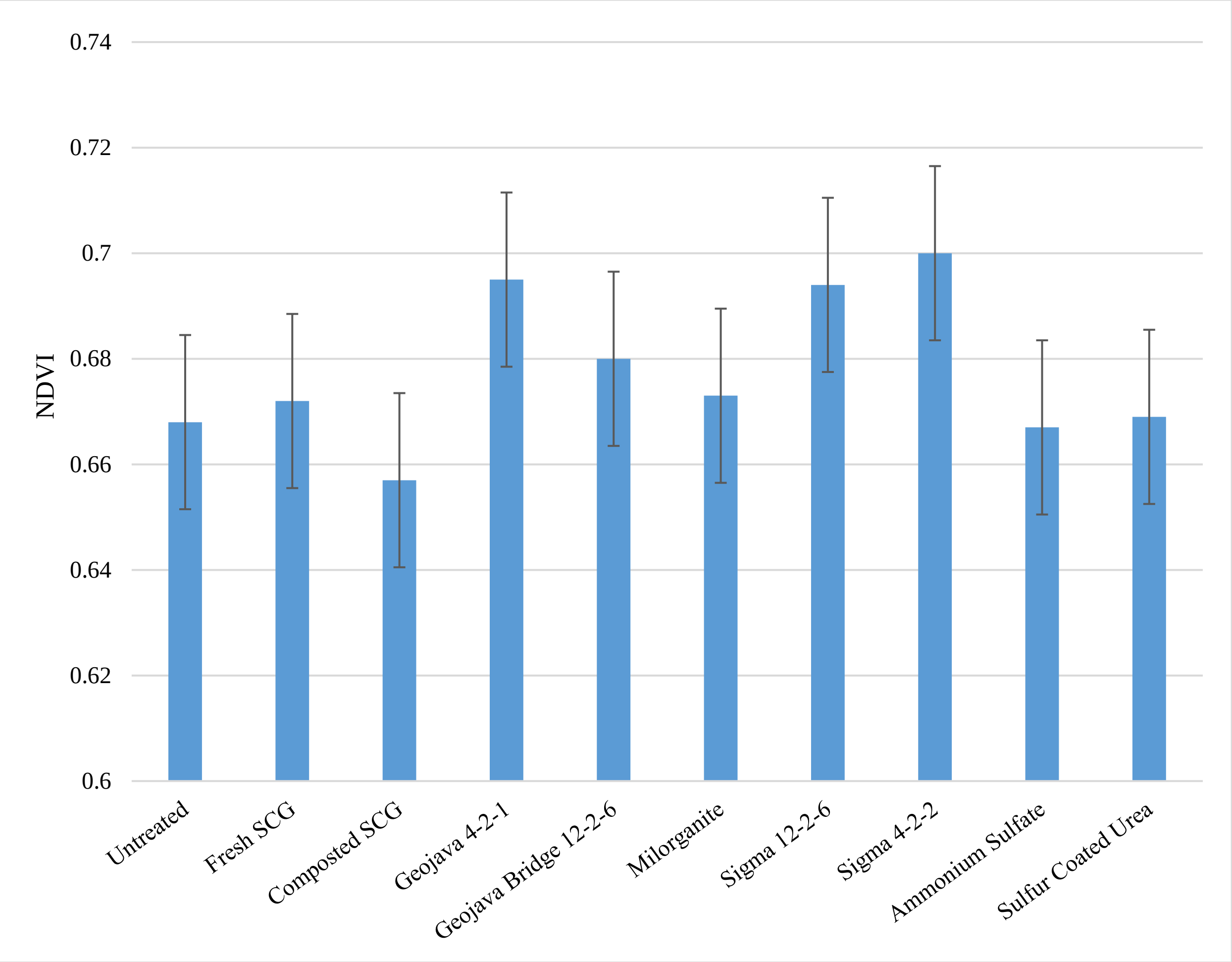

Figure 2.6: Main effect of fertilizer treatment on Normalized Difference Vegetation Index during 2018 in the SCG fertilizer field study. Data have been pooled across all 2018 rating dates. Error bars denote Fisher's LSD (0.05).

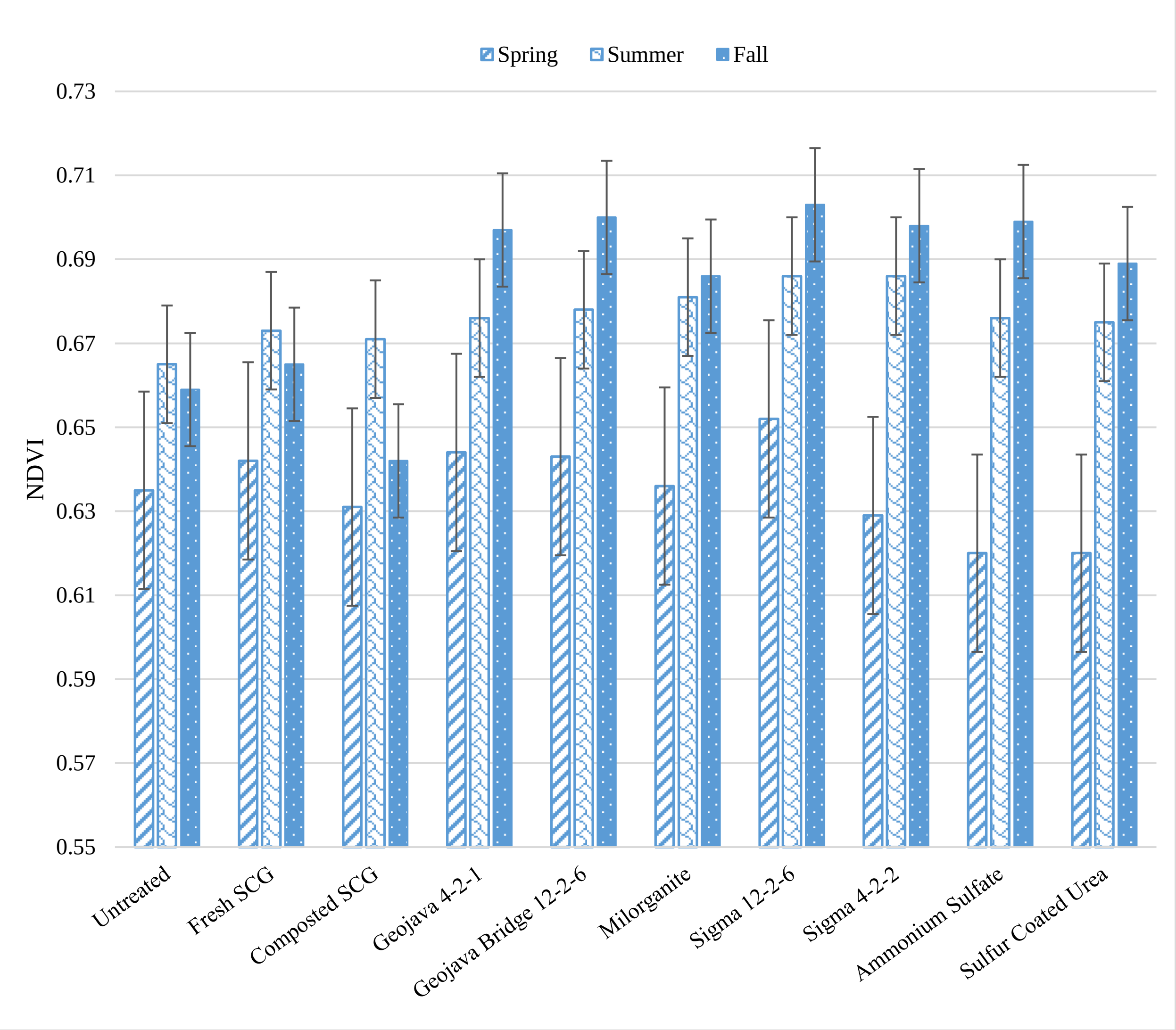

Figure 2.7: Fertilizer treatment x season interaction on Normalized Difference Vegetation Index during 2019 in the SCG fertilizer field study. Where, Spring = March-May, Summer= June-Aug, Fall= Sept-Nov ratings. Error bars denote Fisher's LSD (0.05), and are for comparing fertilizer treatments within a given season.

Clipping Biomass Production Rates

A significant treatment x year interaction occurred for clipping biomass data, so data were split into the 2018 and 2019 years (Table 2.4). In both years, there were significant treatment main effects (Figure 2.8). In 2018, clipping biomass production ranged from 2.7 to 4.8 g plot^{-1} day^{-1}, with ammonium sulfate producing the highest (4.8 g per plot per day) and untreated control plots producing the lowest (2.7 g plot^{-1} day^{-1}) amount of clippings. Also during 2018, GeoJava 4-2-1, GeoJava Bridge, Milorganite, ammonium sulfate, and URI-PEL S.R. all had significantly higher rates of clipping production than the untreated control. Also, SCG treatments showed similarly low levels of clipping production as untreated control plots. In 2019, shoot growth rates were higher overall, with clipping biomass production ranging from 3.3 to 8.6 g plot^{-1} day^{-1}. GeoJava Bridge produced the highest clipping biomass (8.6 g plot^{-1} day^{-1}) while the untreated controls were again the least productive (3.3 g plot^{-1} day^{-1}). During 2019, all treatments except for the composted and fresh SCG treatments had significantly greater clipping biomass production than untreated control plots.

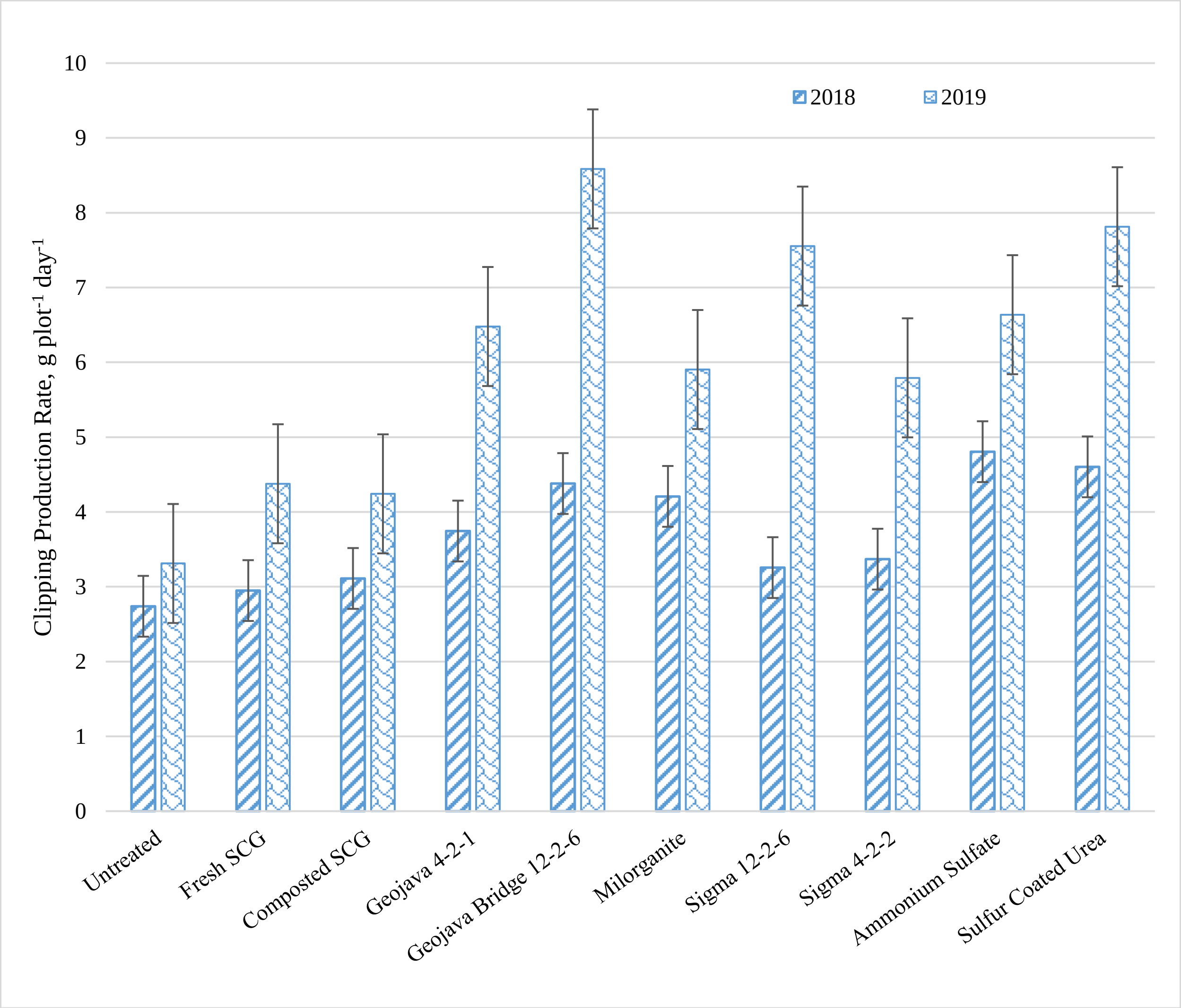

Figure 2.8: Fertilizer main effect on Clipping Production Rate for 2018 and 2019 during the SCG fertilizer field study. Data have been pooled across collection week. Error bars denote Fisher's LSD (0.05), and are for comparing means within a given year.

End-of-Study Soil Chemical Analyses

With the exception of soil K and S concentrations, ANOVA for soil chemical analyses data including pH, electrical conductivity, sodium adsorption ratio, and the major macro- and micro-nutrients within the 0-15 cm soil depth revealed no significant differences due to nutrient source treatments by the end of the two-year study (Table 2.5). End-of-study soil K ranged from 62 to 105 mg kg^{-1}, with Sigma 4-2-2 yielding the highest soil K concentration (105.3 mg/kg) and ammonium sulfate the lowest (62.0 mg/kg K) (Figure 2.9). While there were no significant differences compared to untreated plots, composted SCG, GeoJava Bridge, Sigma 4-2-2, and URI-PEL S.R. each had higher final soil K levels compared to ammonium sulfate. The reason for this is that all other nutrient sources supplied K where the ammonium sulfate did not.

Soil S data also showed highly significant differences, with treatments ranging from 18 to 90 mg/kg S (Figure 2.10). With regard to soil S, no treatments other than ammonium sulfate were significantly different from the untreated control or from one another. This is due to ammonium sulfate contributing S to the soil and the other fertilizers comparatively had little to none. The next highest soil S levels were associated with URI-PEL S.R. (36 mg/kg S).

Table 2.5: Analysis of variance for end-of-study soil pH, elemental nutrient concentrations, EC, SAR, and SSP. Soil samples were obtained at the 0-15 cm depth during October 2019 at the conclusion of the study.

Source	pH	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu	EC	SAR	SSP
Treatment	NS	NS	*	NS	NS	***	NS	NS	NS	NS	NS	NS	NS	NS

*, *** indicate statistical significance at $P \leq 0.05$ and $P \leq 0.001$, respectively.

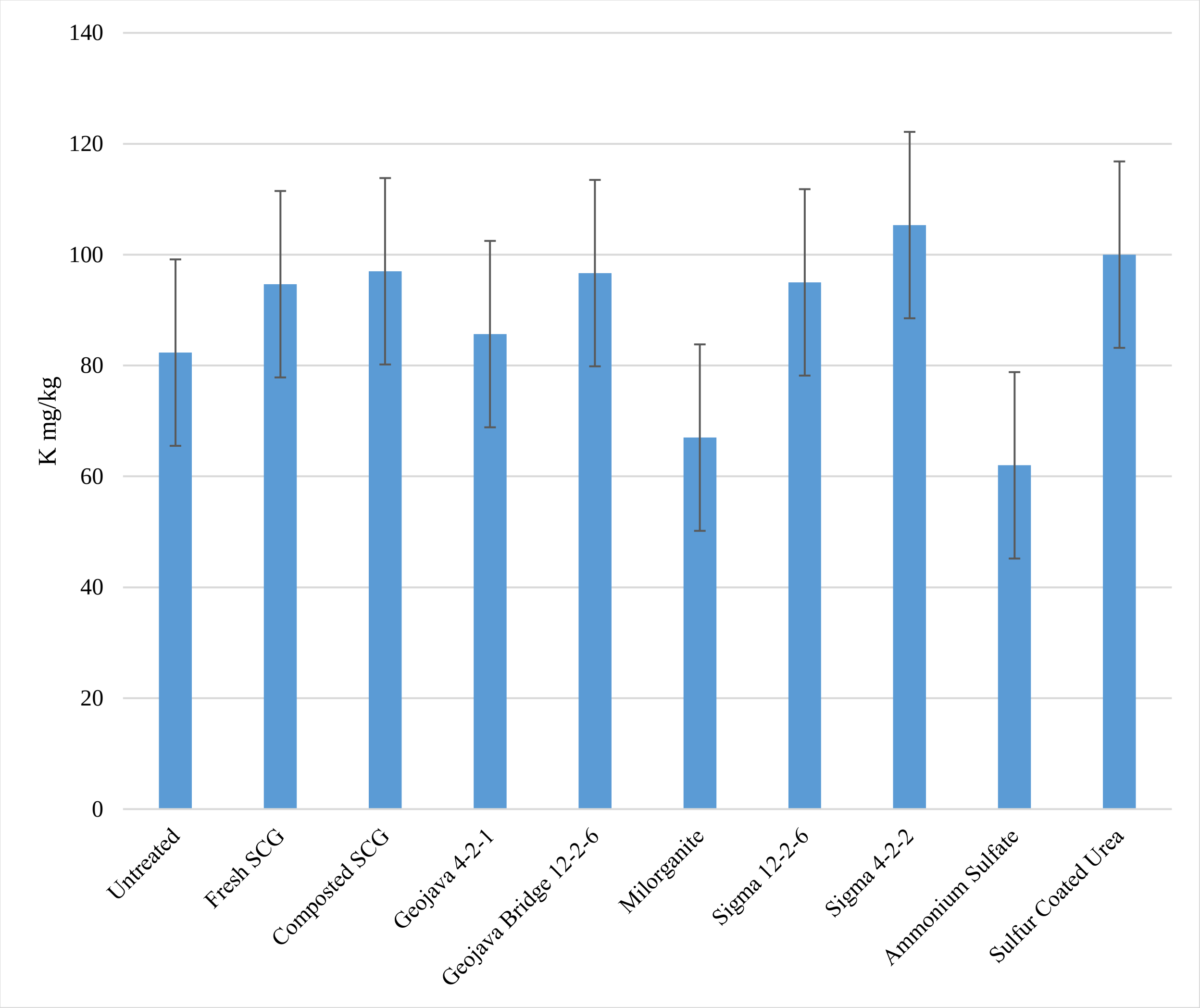

Figure 2.9: Main effect of fertilizer treatment on end-of-study soil potassium concentrations in the SCG fertilizer field study. Soil samples were obtained at the 0-15 cm depth during October 2019 at the conclusion of the study. Error bars denote Fishers LSD (0.05).

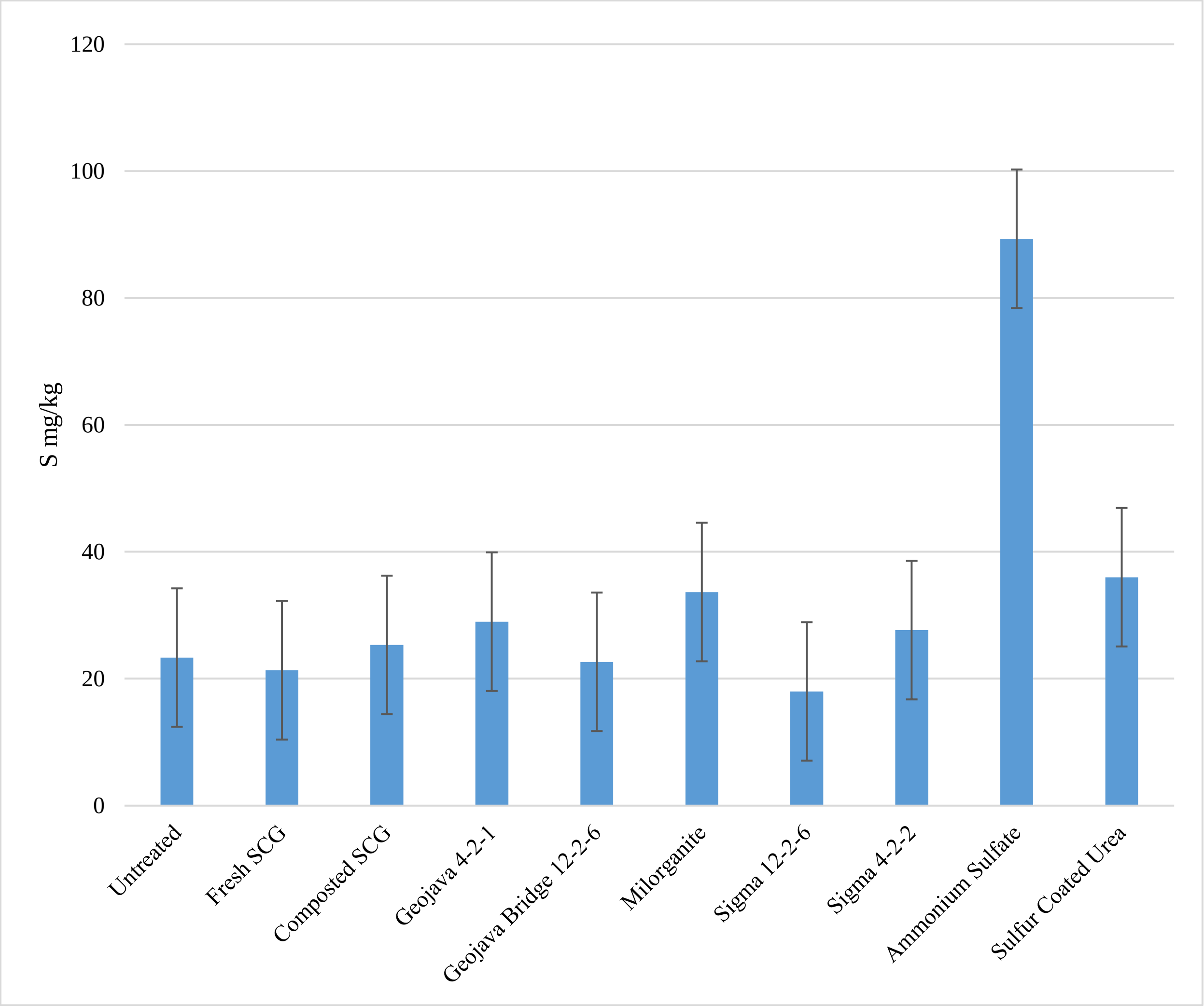

Figure 2.10: Main effect of fertilizer treatment on end-of-study soil sulfur concentrations in the Texas A&M SCG fertilizer field study. Soil samples were obtained at the 0-15 cm depth during October 2019 at the conclusion of the study. Error bars denote Fishers LSD (0.05).

Discussion

The premise of this study was to determine whether SCG, composted or fresh might be used as a standalone topdressing fertilizer. In 2018 and 2019 there were no statistical differences in TQ, Percent Green Cover, DGCI, NDVI, or Clipping Biomass between either SCG treatment compared to the untreated control plots. This is supported by several studies that observed phytotoxic effects when SCG were used in cropping systems but with effects that were both rate and species specific (Fujii & Takeshi, 2007; Hardgrove & Livesley, 2016; Kitou & Yoshida, 1997). While no negative effects were observed in turfgrass on native soil, they trended lower for turf quality especially during the 2019 year (Figure 2.3). It may be that bermudagrass has a higher tolerance for any phytotoxic compounds remaining within the SCG or the bi-weekly irrigation events help flush the compounds out of the root zone. The slow rate of decomposition could also be a reason that little to no negative effects were observed.

It should also be noted that the composted grounds trended lower in NDVI, DGCI, percent green cover, and turf quality when compared to the fresh SCG treatment (Figures 2.2 to 2.7). This contradicts some of the literature that showed composting the SCG can mitigate deleterious effects and while these effects may be statistically insignificant, they oppose previous observations (Cervera-Mata, et al., 2018). This may be due to the fact that the composted and fresh grounds were of relatively similar NPK but applied at the same rate. This application rate however, should have allowed the composted material a higher rate of N because at the time of analysis the composted SCG showed a 0.6% higher rate of N compared to the fresh SCG. It is possible that the composted grounds lost their readily available N before the application in the compost pile and the remaining N was highly lignified and structural N (Kitou & Okuno, 1999).

If this is the case, the composted grounds could more effectively immobilize any otherwise available nitrogen in the soil.

Again, these data show that SCG alone do not act as a fertilizer but in the first year of the study GeoJava 4-2-1 showed significantly higher turf quality than the control plots (Figure 2.2). This fertilizer contains 50% composted chicken manure and feather meal, as well as 50% SCG and appears to act as a slow release fertilizer (Table 2.1). It is found in the literature that SCG have the ability to improve soil fertility when combined with a fertilizer (Yamane, et al., 2014). Beyond this, an innate ability to bind compounds such as heavy metals in the soil was seen (Kim, et al., 2014), increase CEC and water holding capacity of a soil (Kasongo, Verdoodt, Kanyankagote, Baert, & Ranst, 2011) and bind pesticide residues which prevents the leaching of these chemicals (Fenoll, et al., 2014). Along with its retention properties SCG were found to increase the mobility of Fe in a soil (Morikawa & Saigusa, 2011) and reduce the ammonification and nitrification rates (Bollen & Lu, 1961). These observations combined with the literature allow the assumption that the grounds in tandem with other fertilizers have some capability to extend the beneficial period observed after fertilizer application by preventing highly soluble nutrients such as NO_{3-} from rapidly leaching out of the soil profile and making other nutrients more available due to their release of metal chelators. This idea is further strengthened in the next chapter when using SCG as a soil amendment.

Conclusions

SCG did not act as a source of nutrients when applied alone, but when combined with another source of nutrients they retained and possibly increased other nutrients that were previously unavailable in the soil. The GeoJava treatments were observed to promote a high level of turf quality over both years of the study, with the 4-2-1 fully organic product being highly competitive with fully synthetic products such as ammonium sulfate and URI-PEL S.R.. No changes in soil pH or soil nutrients were observed compared to the untreated control plots over multiple years of SCG application. Based on these observations, SCG may offer promise as a component for production of synthetic/bridge or organic fertilizers.

CHAPTER III

USE OF SPENT COFFEE GROUNDS AS AN AMENDMENT IN SAND-BASED ROOTZONES

Abstract

The growing popularity of coffee and recent rise in popularity of bottled cold-brewed coffee has resulted in greater production of spent coffee grounds (SCG). Spent coffee grounds offer many desirable agronomic properties, but also contain caffeine, tannins and phenolic compounds. There is a growing body of research examining effects of SCG on plants, but little to none of which pertains to use in turfgrass systems. Given the current widespread use and environmental concerns with peat moss production, there is growing interest in finding substitute organic amendments for use in turfgrass sand-based root zones, and SCG may offer a viable alternative. Therefore, the objectives of this project were to evaluate the feasibility of using SCG as a turfgrass sand root zone amendment compared to peat moss amended sands during a fertilizer use efficiency and dry down study. Our results demonstrated that SCG incorporation promoted a number of favorable responses. Although a small amount of transient bermudagrass chlorosis was noted in the initial weeks following incorporation, these effects soon disappeared. Spent coffee grounds incorporation generally improved both water and nutrient retention properties when compared to peat moss as well as sand alone. The SCG showed comparable-to-improved levels of extractable soil water during dry-down, and higher levels of tissue N at the end of the study, suggesting effects on enhanced retention of N in the root zone. Considering the observed responses in this greenhouse study, it would appear that SCG has the potential of becoming an alternative amendment for peat moss in sand-based root zones. However, further

research is needed to better understand the chemical, biological, and/or physical mechanisms relating to the observed responses.

Introduction

Currently, many golf course and sports turfgrass playing fields are built on sand-based root zones. The most common and well tested root zone is the United States Golf Association (USGA) spec root zone, which consists of a 30 cm sand layer over top a 10 cm pea gravel layer. In addition to other physical properties, specific particle size properties must be achieved in order for the system to properly function (United States Golf Asscociation, 2018). The USGA root zone construction guidelines also allow for various organic or inorganic amendments to be used for improving physical/chemical properties of the root zone, the most commonly used organic amendment is sphagnum peat moss (Bigelow, Bowman, & Cassel, 2004).

Peat moss significantly increases the water holding capacity of a USGA recommended sand and has been used successfully for many years (Bigelow, Bowman, & Cassel, 2004); however, peat is a declining natural resource. Peat moss is obtained by draining and mining peatlands, largely in northern Canada. Peatlands are important because they are significant carbon sinks and destroying them allows for the release of soil carbon back to the atmosphere (Turetsky, Wieder, Halsey, & Vitt, 2002).

It has been observed that SCG can have somewhat deleterious effects on growth of some plant species and such responses are often rate-dependent (Hardgrove & Livesley, 2016; Kitou & Yoshida, 1997). Kitou and Yoshida (1997) suggested that plant growth inhibition may be due to a combination of factors, including nitrogen immobilization in the rhizosphere, multiplication of plant pathogenic fungi, and/or release of phytotoxins derived from fresh organic matter. There are also several phytotoxic compounds associated with SCG that may directly affect plant growth, including chlorogenic acid (Pandey, et al., 2000) as well as caffeine, tannins, and polyphenols (Yamane, et al., 2014). However, it has also been observed in some species that negative phytotoxic effects from incorporation of SCG may be ameliorated through addition of other sources of fertility (Hardgrove & Livesley, 2016; Yamane, et al., 2014).

Given the unique physical/chemical properties of SCG, there may be opportunities for its use as a sand root zone amendment in turfgrass systems. Although the C:N ratio of SCG is comparable to that of other organic materials (Kitou & Okuno, 1999), its decomposition rate may be slower than other organic materials due to the primary N component being structural protein-N, which is not easily decomposed (Kitou & Okuno, 1999). Higher proportions of structural protein-N in organic materials would likely result in increased N immobilization following addition to soil, and may require additional sources of N to be co-applied for maximum benefit. For example, when SCG were incorporated into a soil with manure, plant inhibitory effects were diminished (Yamane, et al., 2014). A negative correlation was also observed between plant residues content of cellulose and hemicellulose and its rate of degradation (Kitou & Yoshida, 1994). With the cellulose and hemicellulose content of SCG observed at 45.3%, w/w, dry weight (Mussatto, Carneiro, Silva, Roberto, & Teixeira, 2011), it is probable this is acting to reduce the rate of decomposition as these compounds are not easily broken down. SCG have also been shown to increase the water holding capacity of soil (Ballesteros, Teixeira, & Mussatto, 2014), bind toxic heavy metals (Kim, et al., 2014), and bind pesticide residues as well as moderate soil temperature (Chalker-Scott, 2016)

Therefore, the objectives of this greenhouse study were to evaluate potential for spent coffee grounds to be used as a sand root zone soil amendment. More specifically, we aimed to:

1. Evaluate nutrient retention properties and ‘Tifway’ bermudagrass grown atop unamended, peat moss-amended, or SCG-amended USGA root zones over 6-weeks following soluble nitrogen fertilizer application.
2. Determine effects of amendment treatments on extractable soil water and days to wilt during multiple week dry-down periods.
3. Evaluate recuperative characteristics of turfgrass following re-watering after dry-down in relation to the various amendment treatments.

Materials and Methods

Research Location and Design

This study was conducted in a greenhouse at Texas A&M University, College Station, TX. The fertilizer use efficiency portion of this study was conducted from 8 October to 13 November 2018 and repeated from 8 August 2019 to 24 September 2019. The dry down and recovery phase of the study ran from 13 December 2018 to 18 January 2019, and was repeated 17 October through 21 December 2019. The study was arranged as a randomized complete block design with three replicate lysimeters per treatment. A lysimeter consisted of a 40 cm tall segment of 15 cm diameter PVC pipe with an end cap glued to the bottom. The end cap had a 0.6 cm hole drilled in the center to allow water drainage from the bottom. In the bottom of the lysimeter column was 10 cm pea gravel. Overlying the gravel was 30 cm of one of the root zone mixtures discussed below. The columns were planted with Tifway bermudagrass (*Cynodon dactylon x C. traansvalensis* Burt. Davy) sod plugs that had been washed free of soil. Water used for irrigation used during all phases of the study was generated from an onsite reverse osmosis system. Throughout both studies, the greenhouse was set to maintain 29/21℃ (day/night) temperatures.

Root Zone Sand Physical Properties

The sand used in the mixtures met USGA recommendation for particle size distribution (ref) . Physical analysis of this sand showed it to consist of 10% very coarse (1 to 2 mm), 42% coarse (0.5 to 1 mm), 35% medium (0.25 to 0.5 mm), 10% fine (0.1 to 0.25 mm), and 1.5% very fine (0.05 to 0.1 mm) diameter sand particles (Table 3.1; Figure 3.1).

Prior to filling columns, various root zone amendment treatments were created. Sand root zone amendment treatment names and rates are described by Table 3.2. The label of 10 and 20% by volume refers to the premixed volumes so they are not 10 and 20% by resultant volume after mixing. The 10 and 20% volumes are based on industry construction of sand based root zones for putting greens. In this field a 10% rate is not 10% but rather 10 parts sand to 1 part of a given amendment (Table 3.2). These rates are still labeled as 10 and 20% for convenience and comparability to industry construction. The "mass" treatments are defined as the mass of peat moss that was used to create the 10% amendment rate. SCG are much more dense than peat moss and the same masses were compared in order to describe the effect simply adding more organic matter to the sands had on the measured data. Spent coffee grounds were obtained from Aspen Beverage, San Antonio, TX, prior to the initiation of the study, and had been previously used to extract cold-brew coffee. Prior to their use in the experiment, coffee grounds had been oven dried for 3 days at 65°C and were thereafter stored at 23°C for use in greenhouse studies. On drying, the SCG shrunk in size by approximately 50%.

Table 3.1: Particle size distribution of the sand used in the 2018 and 2019 root zone amendment studies.

Sieve #	**Sieve (mm)**	**Empty Sieves (g)**	**Sieves w/sand (g)**	**Sand (g)**	**Mass Fraction**	**Mass Finer**	**SAND**
10.0	2.0	434.4	435.0	0.6	0.0	1.0	99.4
18.0	1.0	404.1	414.7	10.7	0.1	0.9	88.8
35.0	0.5	332.0	374.1	42.1	0.4	0.5	46.8
45.0	0.4	320.5	344.6	24.2	0.2	0.2	22.7
50.0	0.3	322.8	328.5	5.8	0.1	0.2	17.0
60.0	0.3	319.2	324.4	5.2	0.1	0.1	11.8
80.0	0.2	309.6	314.6	4.9	0.0	0.1	6.8
100.0	0.1	301.0	303.5	2.4	0.0	0.0	4.4
120.0	0.1	300.0	301.6	1.7	0.0	0.0	2.7
140.0	0.1	287.9	289.2	1.3	0.0	0.0	1.4
200.0	0.1	305.1	306.0	0.9	0.0	0.0	0.5
Plate		354.5	355.0	0.5	0.0		
Total				100.3	0.9		

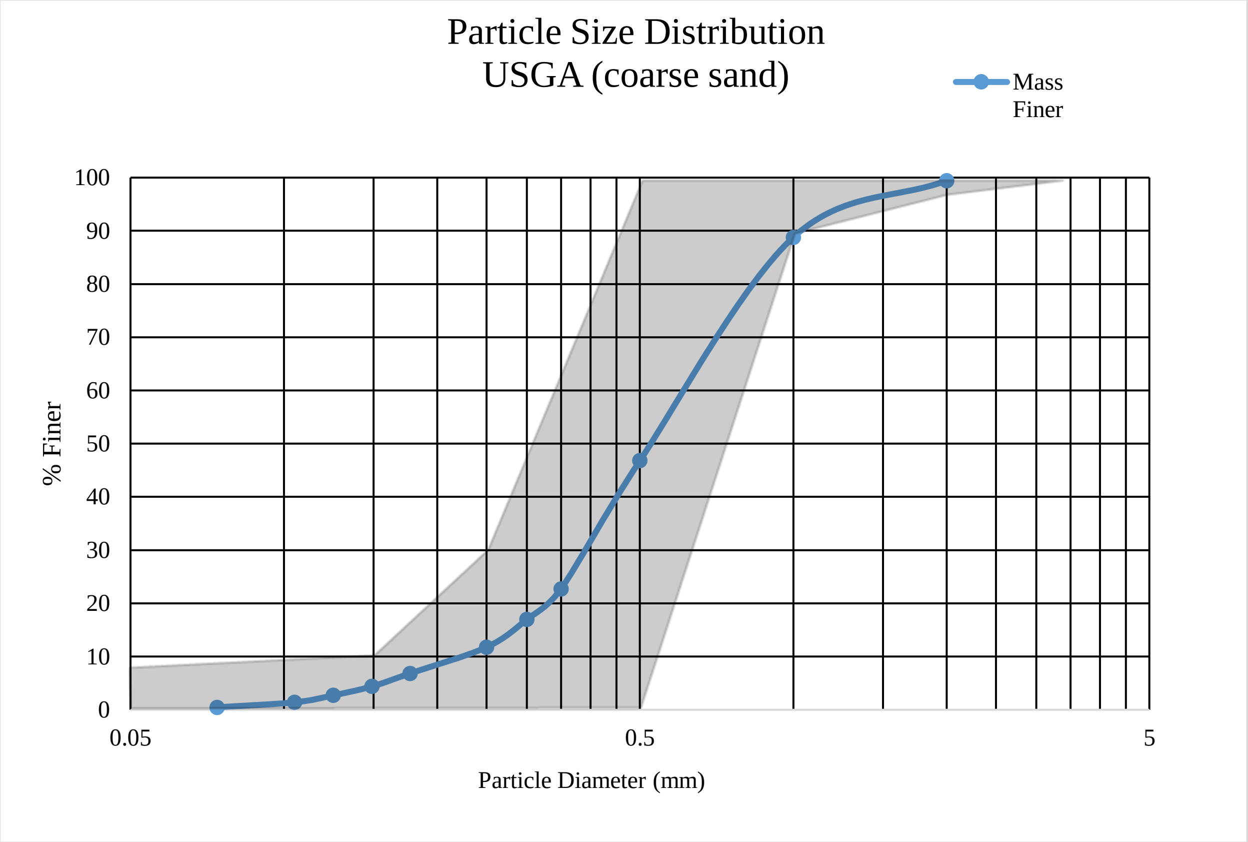

Figure 3.1: Fraction Finer graph of the coarse USGA spec sand used for the sand root zone amendment greenhouse studies in 2018 and 2019 at Texas A&M University.

Table 3.2: This table represents the basis of amendment rates for each treatment on V:V basis. These volumes estimated based on the density of each treatment.

Treatment	V_{sand}:$V_{treatment}$	Density (g/cm^3)	Mass added to mix (g)
SCG Coarse 10%	10:1	.36	172.90
SCG Coarse 20%	10:2	.36	345.79
SCG Coarse Mass	Added on a mass basis according to peat moss 10% rate	.36	79.41
SCG Fine 10%	10:1	.30	143.53
SCG Fine 20%	10:2	.30	287.06
SCG Fine Mass	Added on a mass basis according to peat moss 10% rate	.30	79.41
Peat Moss 10%	10:1	.16	79.41
Peat Moss 20%	10:2	.16	158.81
Sand		1.70	9100

Establishment Phase

On top of the root zone mixtures in the lysimeters, washed bermudagrass sod plugs were established in the greenhouse over a 4 week period prior to initiating experiments. Pots were initially fertilized using a 13-13-13 N-P_2O_5-K_2O complete fertilizer (American Plant Food Corp., Galena Park, TX) at an N rate of 4.9 g m^{-2} and top-watered daily to supply 1.5 cm irrigation per day using an Erlenmeyer flask. Also, during this time, grasses were trimmed with scissors to a height of 1.3 cm on four to seven-day intervals and clippings were not returned to the columns.

Fertilizer Use Efficiency Phase

Once the four-week establishment period was complete, all lysimeters were brought to water holding capacity by fully submerging in a large container of water for 10 minutes and then removed and allowed to drain for 8 hours. At this time, the water retention capacity of each experimental unit was measured and recorded. The weight measured was the weight of the entire column after saturation and no soil or gravel were subtracted from the mass recorded. Each experimental unit was then fertilized using ammonium nitrate (21-0-0) at an N rate of 4.9 g m^{-2}, and then was watered in with 0.3 cm irrigation. Lysimeters were thereafter weighed and re-watered three times weekly. During watering events, each lysimeter was irrigated back to above its water retention capacity mass by supplying an additional 15% to the mass difference between the mass at water retention capacity and the current mass to assure return to capacity and provide some leaching of nutrients, especially soluble sources such as N.

Clipping Collections

During the 6 week evaluation of fertilizer use efficiency, experimental units were trimmed weekly to a height of 1.3 cm and the clippings were collected. Clippings were oven dried at 65 °C for three days before weighing. At the conclusion of the study, cumulative clipping biomass was determined for each treatment.

Turf Performance Evaluations

All turf performance data were collected once weekly prior to watering events so that drought stress, if any could be observed. Turf Quality (TQ) was evaluated using a 1-9 scale, with a rating of 5 representing the minimum level of acceptability (Karcher & Richardson, 2005; Reicher & Throssell, 1997). In this scale, 9 is the highest level of TQ while 1 is the lowest level. The NDVI readings were taken using a Fieldscout TCM 500 Turf Color Meter (Spectrum Technologies, Plainfield, IL). Digital images were obtained using a Canon SX170 IS camera using a 1/6 shutter speed, F4.5 aperture and an ISO of 100. Images were taken by interfacing the camera with a lightbox constructed from a 19-liter bucket with two brackets inside that held two battery-powered portable LED bulbs. Images were analyzed for percentage green cover using SigmaScan Pro (Systat, San Jose, CA) digital image analysis software using hue and saturation settings of 45 to 120 and 0 to 100, respectively (Karcher & Richardson, 2003; Karcher & Richardson, 2005; Richardson, Karcher, & Purcell, 2001). Dark Green Color Index (DGCI) of each image was also obtained from the output of the "turf analysis" macro using the equation (Karcher & Richardson, 2003):

$$\frac{[\frac{Hue - 60}{60 + (1 - Saturation) + (1 - Brightness)}]}{3}$$

This equation was used given the outputs of the "turf analysis" macro run in the SigmaScan Pro (Systat, San Jose, CA) software. This output produced the hue, saturation, and brightness from each picture which in turn was used to calculate the DGCI with the above equation.

Dry-Down and Recovery Phase

To initiate the dry-down phase of the study, lysimeters were saturated by fully submerging in a large container of water for 10 minutes, and then allowed to drain to water retention capacity over 8 hours. After this, no water was added until leaf wilt was noted across ≥50% of its canopy. During the dry-down phase, turf quality was evaluated weekly using the same methodology described previously. Soil VWC for the 0-20 cm depth was also measured weekly using a Fieldscout TDR 300 (Spectrum Technologies, Plainfield, IL).

Total Extractable Water Determination

During the dry-down period, lysimeters were weighed two to three times weekly until ≥50% wilt was noted to determine water loss over the period. Total extractable water was then calculated as the amount of water loss occurring between water retention capacity (8-hours after saturating and allowing drainage) and wilting point for each lysimeter.

End of Study- Recovery and Shoot Tissue Analysis

Once all columns had expressed wilt, lysimeters were uniformly trimmed to 1.3 cm height and well-watered for 3 weeks to allow recovery. After the 3-week recovery period, lysimeters were evaluated for turf quality, trimmed to 1.3 cm, with leaf tissues collected. Leaf tissues were oven dried at 65 °C for 72 hours, and submitted to the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory for chemical analysis and determination of nitrogen content.

Analysis of Data

At the conclusion of the experiment, data were subjected to ANOVA using the general linear model univariate test procedures (SPSS version 21.0; IBM Corporation, Armonk, NY) to determine statistical significance of the results. Mean separation of means were performed using Fisher's Least Significant Difference at the $P \leq 0.05$ level.

Results

Fertilizer Use Efficiency Phase

The ANOVA for the fertilizer use efficiency phase showed a significant treatment x year interaction for all parameters. Therefore, data were presented separately by year. With the exception of 2019 cumulative clippings, statistically significant treatment main effects were detected for all parameters (Table 3.3). With the exception of 2018 NDVI and 2019 clipping biomass, there were also significant treatment x date interactions for all parameters. Because cumulative clipping biomass was the sum of all clippings collected for each lysimeter during the fertilizer use efficiency phase, there was no date factor associated with this parameter.

Table 3.3: Analysis of variance for parameters measured in the fertilizer use efficiency phase of the SCG sand root zone amendment study. Where year x treatment interactions were significant, data have been split by year.

	TQ		% GC		DGCI		NDVI		Clipping Biomass		Cumulative Clipping Biomass	
Source	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Treatment	***	***	***	***	***	***	***	***	***	***	***	NS
Date	***	***	***	***	***	***	***	***	***	***		
TRT x Date	***	***	***	**	***	***	NS	***	***	NS		

, * indicate statistical significance at $P \leq 0.01$ and $P \leq 0.001$, respectively.

Turf Quality

There were significant treatment x date interaction for TQ both years of the study (Table 3.3). In 2018, the coarse 10% treatment was the only amendment to maintain a significantly higher turf quality across all dates compared to the untreated sand-only lysimeters. It should also be noted that in both the coarse 20% and fine 20% treatments, TQ showed a steady improvement throughout the study period (Figure 3.2). By the 1 November rating date, both of these SCG treatments had attained significantly higher levels of TQ than the untreated control. Conversely, peat moss treatments showed a gradual decline in TQ over the course of the 2018 study. TQ of peat moss at the 20% rate was initially relatively high compared to other treatments (8.5 out of 9), but by the end of the study had declined to a rating of 7, similar to that of the untreated sand pots. Peat moss at the 10% rate showed TQ similar to that of the sand-only control through most of the study, but by 7 November, had declined to minimally acceptable levels.

In 2019, fine 20% SCG treatments showed the highest level of TQ over the duration of the study, and had significantly higher TQ from 4 September through the remainder of the study compared to untreated sand-only pots (Figure 3.2). In general, most treatments showed an initial increase in TQ from the first date followed by a slight to moderate decrease during the middle half of the study, depending on treatment. All coarse treatments showed this trend except for coarse 20%, which was statistically lower than the untreated control on the 21 and 28 August rating dates. Despite showing lower TQ on these two rating dates, coarse 20% held acceptable levels of TQ throughout the experiment. After the 4 September rating date, the coarse 20% treatment rose to a higher average turf quality for the remaining dates compared to the untreated pots but TQ levels were not statistically different. Both peat moss treatments followed the same general trend with peat moss at the 20% rate following very closely to the straight sand-only control pots. The 10% peat moss treatment responded similarly to 2018, as a steep decline in TQ was observed after several weeks of observation.

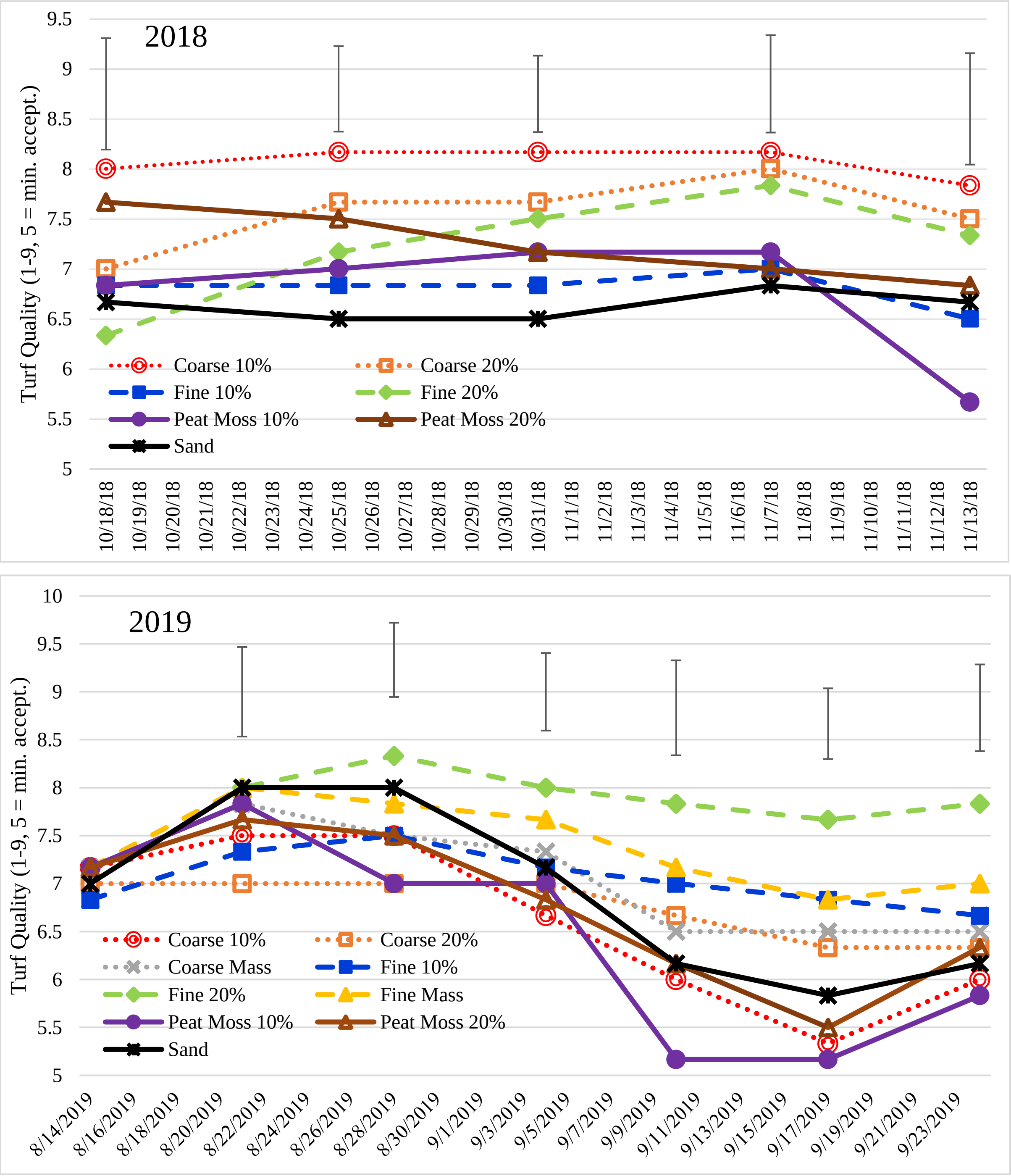

Figure 3.2: Turf Quality by date as affected by root zone amendment during the six-week fertilizer use efficiency phase of the 2018 (upper) and 2019 (lower) greenhouse studies. Error bars denote Fisher's LSD (0.05).

Percent Green Cover

The ANOVA showed a treatment x date interaction for Percent Green Cover (GC) both years of the study (Table 3.3). In 2018, there was a general trend of increasing GC between 8 and 25 October, after which GC declined for most treatments (Figure 3.3). The exceptions to this trend were both coarse SCG treatments. The coarse SCG 10% and 20% rates showed slight increases in the beginning and declined after 25 October, similar to the other treatments. After the 21 October data collection, all treatments continued to decline while coarse SCG treatments began to increase GC. Percent GC of the fine SCG treatments responded differently than coarse treatments. While the fine treatments did follow the general trend, they appeared to hold better GC later into the study compared to the untreated and peat moss treatments after the initial drop in GC during late October. It should also be noted that peat moss at the 10% rate held the lowest GC for 3 of 5 sampling dates and was significantly lower than sand-only controls on the 10/31 rating date.

In 2019, an overall decline was observed across all treatments as the study progressed into the late summer, with a rise in GC occurring after date 17 September rating date. Contrary to the prior year, the 20% rate of fine SCG held the highest level of GC and was significantly higher than the control on 21 August and during the final three September rating dates. The other SCG treatments generally held higher GC than control pots, but were not statistically different from one another. Percent GC of both peat moss treatments trended lower than that of straight sand controls across all dates, but were only significantly lower at the 20% rate on 4 September. The peat moss 20% treatment trended the lowest for GC among all treatments, and had significantly lower GC than the fine 20% treatment on all rating dates.

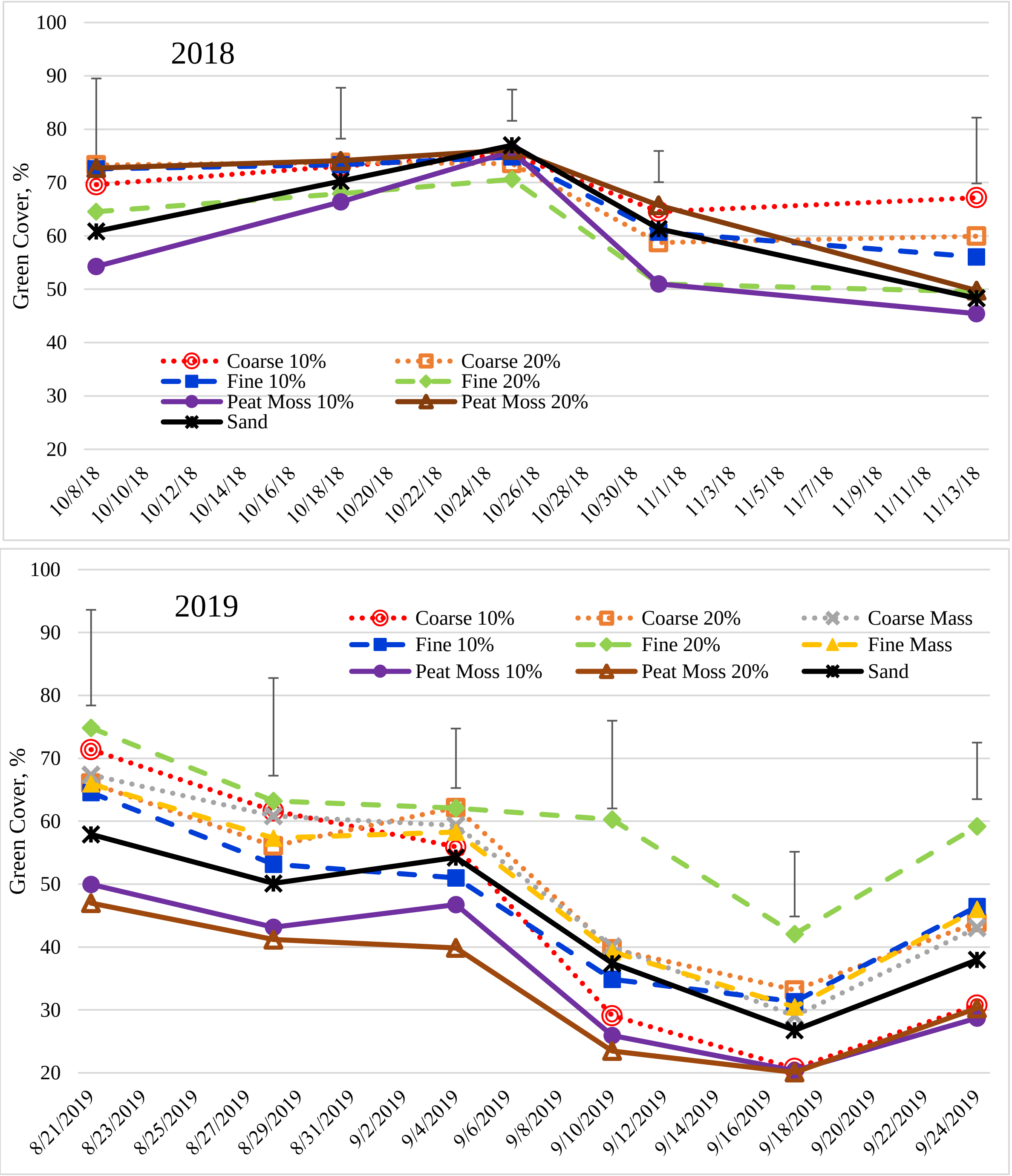

Figure 3.3: Percent green cover as affected by root zone amendment treatments during the six-week fertilizer use efficiency phase of the 2018 (upper) and 2019 (lower) greenhouse studies. Error bars denote Fisher’s LSD (0.05).

DGCI

Dark Green Color Index (DGCI) showed a significant treatment x date interaction in both years of the study (Table 3.3). In 2018, both coarse treatments as well as fine 10% decreased from their initial DGCI levels through 31 October, but in contrast to other treatments, then increased on the final rating date (Figure 3.4). The remaining treatments (peat moss, control and fine SCG 20%) increased in DGCI across the initial four rating dates, but then declined below the aforementioned SCG treatments on the final rating date. The fine 10% SCG treatment showed significantly lower DGCI levels compared to the control on the 18 and 25 October rating dates. The fine 10% treatment trended toward the lowest DGCI levels on all dates except for the final rating date, where peat moss 20% declined to the lowest levels of DCGI observed during the study.

In 2019, there were statistical differences detected on only two of six rating dates, the first and last dates of the study (Figure 3.4). During this study, DGCI for all treatments followed the same general trend, peaking at 28 August and 17 September 2019. On the first rating date (21 August), both of the coarse treatments were significantly below the DGCI of the straight sand treatments. On the final rating date (24 September), all treatments other than coarse SCG at the 10% rate and peat moss at the 10% rate were statistically significantly higher than the untreated control pots.

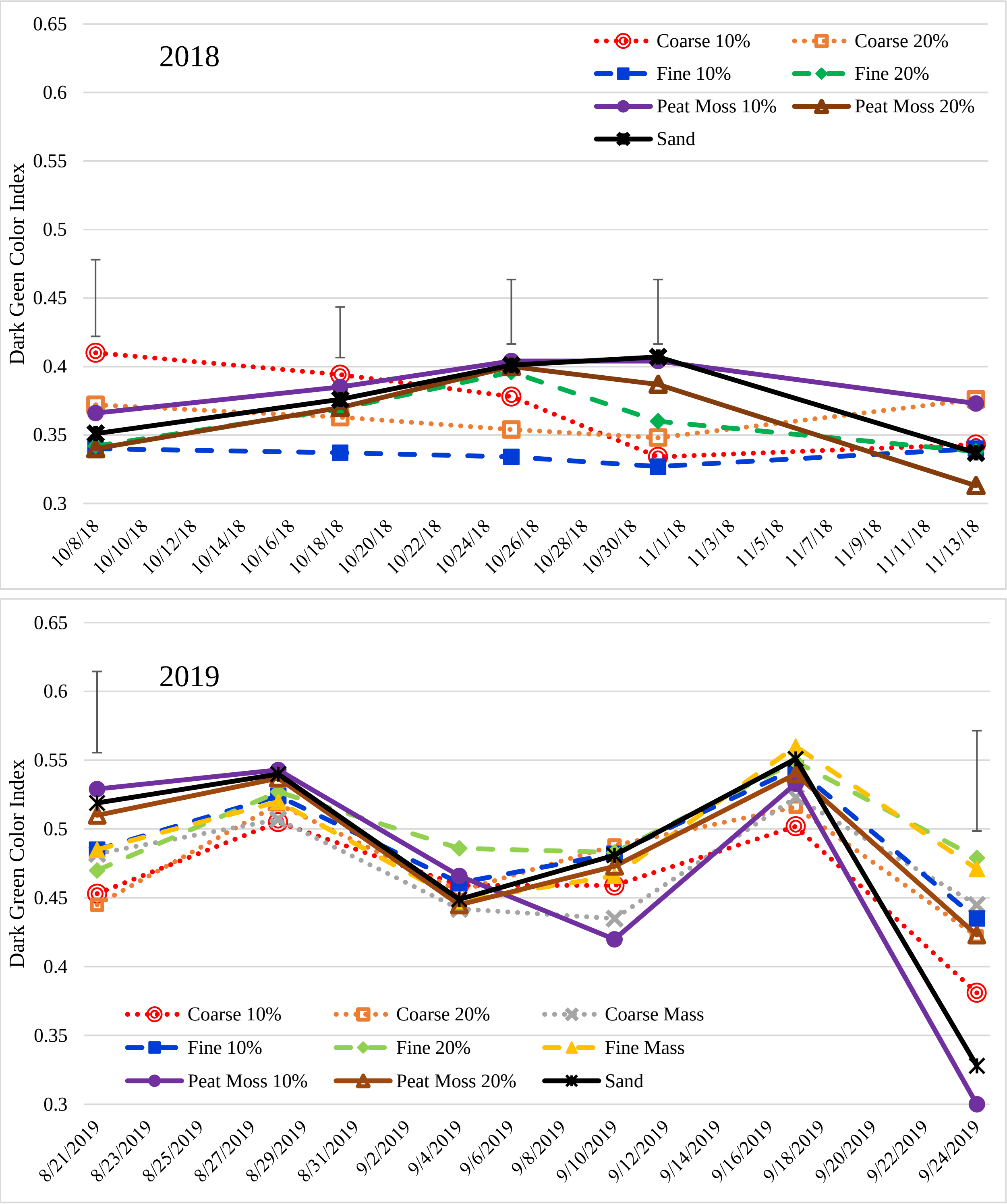

Figure 3.4: Dark Green Color Index by date as affected by root zone amendment treatments during the six-week fertilizer use efficiency phase for the 2018 (upper) and 2019 (lower) greenhouse studies. Error bars denote Fisher's LSD (0.05).

Normalized Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) showed highly significant treatment main effects during both 2018 and 2019 but only showed a treatment x date interaction during 2019 (Table 3.3). In 2019, when pooling across all rating dates, coarse 10% SCG treatments showed higher NDVI than most other treatments, although they were not significantly greater than the sand-only control treatment (Figure 3.5). No treatments were significantly greater than the sand-only control, however, peat moss 10% showed significantly lower levels of NDVI compared to the control as well as all other treatments.

In 2019, the fine 20% SCG treatment maintained the highest NDVI over the entire study (Figure 3.6). This treatment had significantly higher levels of NDVI compared to the control and all other treatments on the final four rating dates, from 4 September through the end of the study. The remainder of the treatments showed few statistical differences from one another, and followed the same general trend, with a slight peak on 21 August followed by gradual decline through 17 September. On the final rating date, NDVI slightly increased for many treatments.

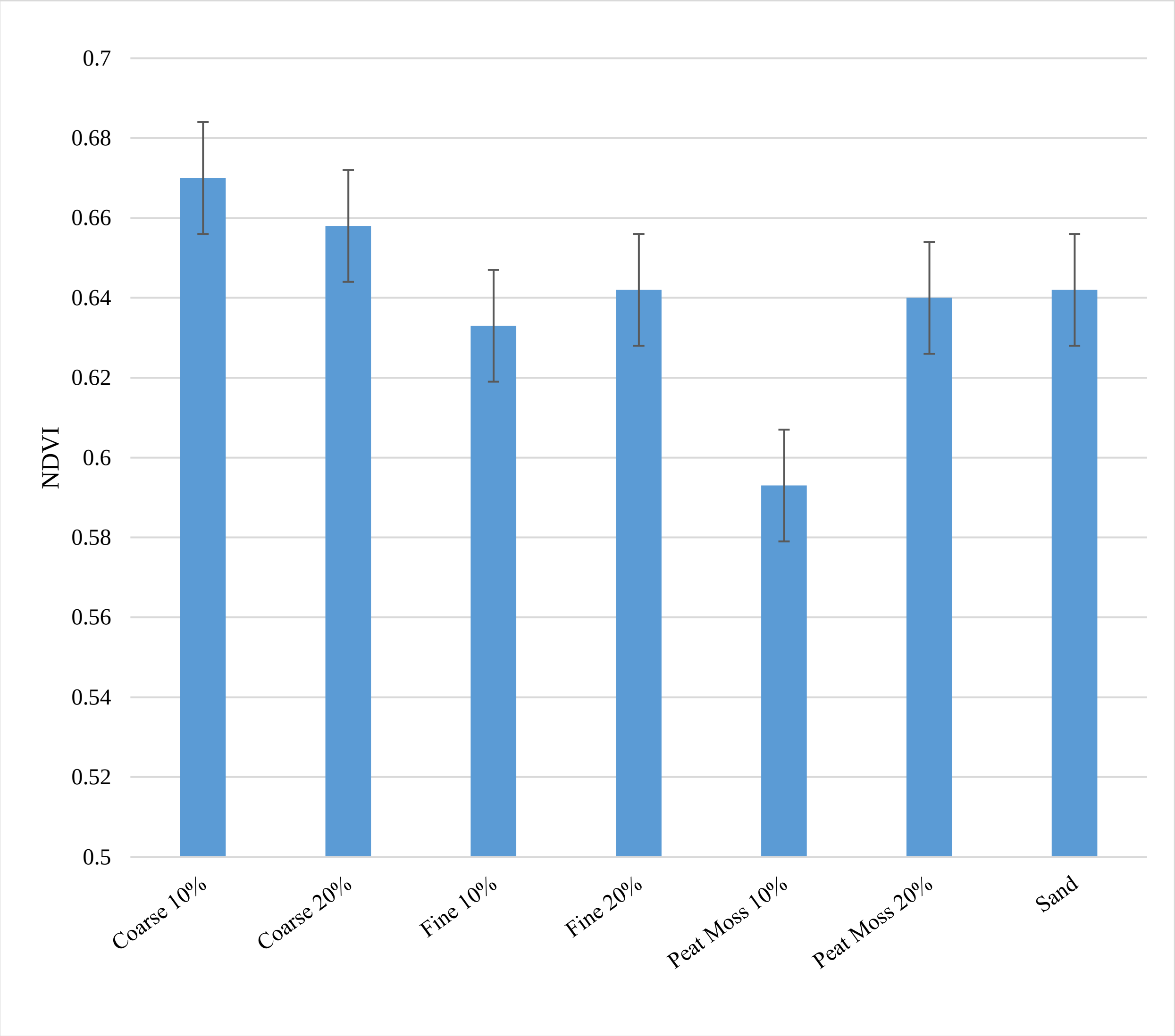

Figure 3.5: Main effect of root zone amendment on Normalized Difference Vegetation Index during the six-week fertilizer use efficiency phase of the 2018 greenhouse study. Data are pooled across rating dates. Error bars denote Fisher's LSD (0.05).

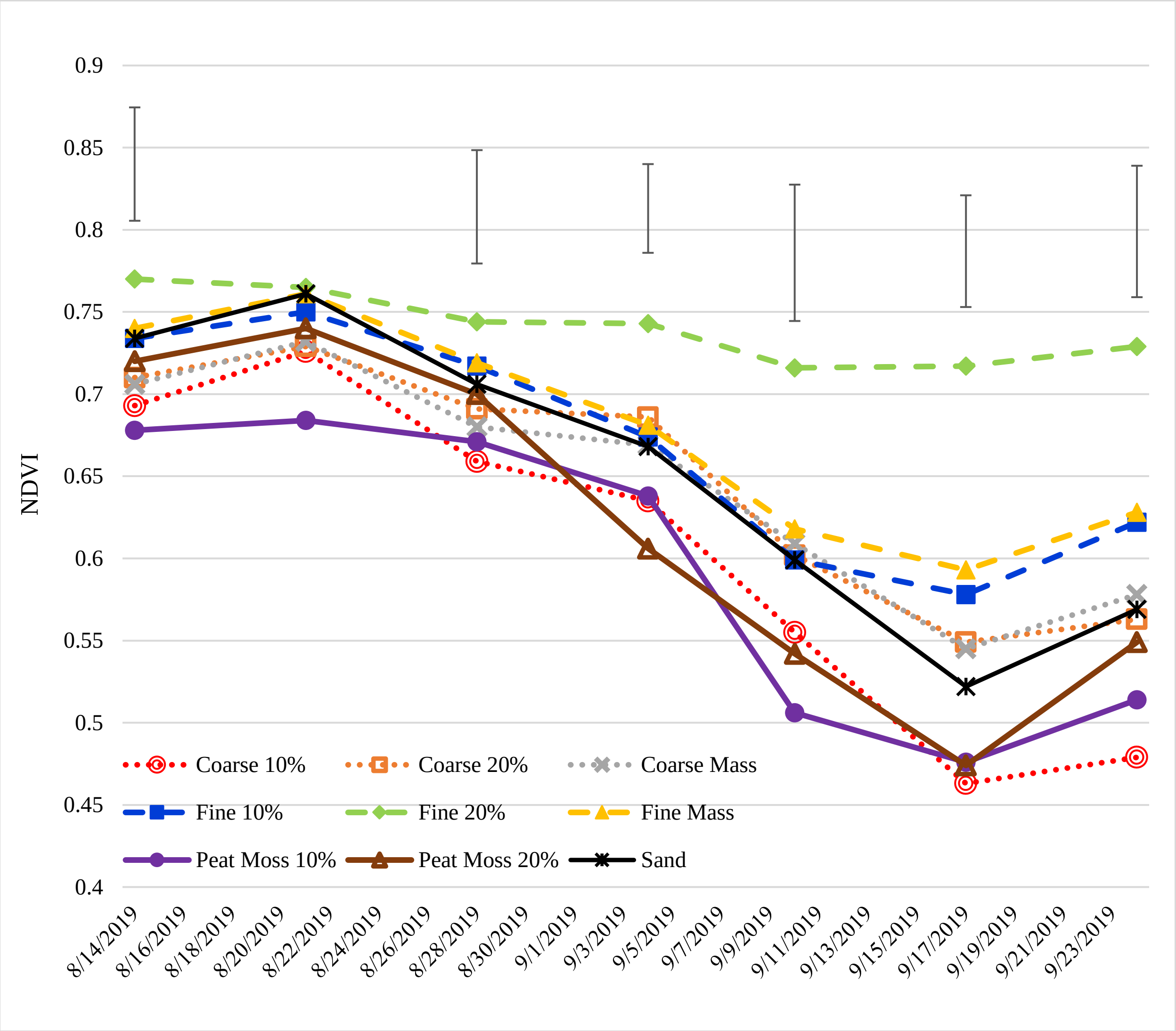

Figure 3.6: Normalized Difference Vegetation Index by date as affected by root zone amendment during the six-week fertilizer use efficiency phase of the 2019 greenhouse study. Error bars denote Fisher's LSD (0.05).

Clipping Biomass Production

Clippings were collected over a six-week period during the well-watered fertilizer use efficiency phase, as a means of determining relative fertilizer use efficiency. The ANOVA showed highly significant treatment main effects in both years of the study, but treatment x date effects were only seen in 2018 (Table 3.3). During 2018, a general trend was observed where clipping production for all treatments declined between 8 October and 18 October, but then peaked on the 25 October collection date (Figure 3.7). With the exception of the initial collection date, coarse SCG treatments and fine SCG at the 20% rate had the highest rate of clipping production across all collection dates. From 25 October through 13 November, these treatments led to significantly higher rates of clipping production compared to the untreated control pots as well as the peat moss treatments. At no point in the study did the peat moss treatments statistically differ from the sand-only controls, but they did show the lowest clipping production across the final four collection dates between 18 October and 13 November.

For 2019, ANOVA showed no treatment x date interaction, so data were pooled across collection dates (Table 3.3). Overall clipping production ranged from 180 to 110 mg d^{-1}, with peat moss 20% yielding the highest and coarse SCG 20% yielding the least clipping production (Figure 3.8). However, contrary to 2018, in 2019 no treatments statistically different from the untreated sand-only controls. The peat moss treatment was statistically different than the coarse SCG at the 10 and 20% rates as well as fine SCG at the 10% and mass rates.

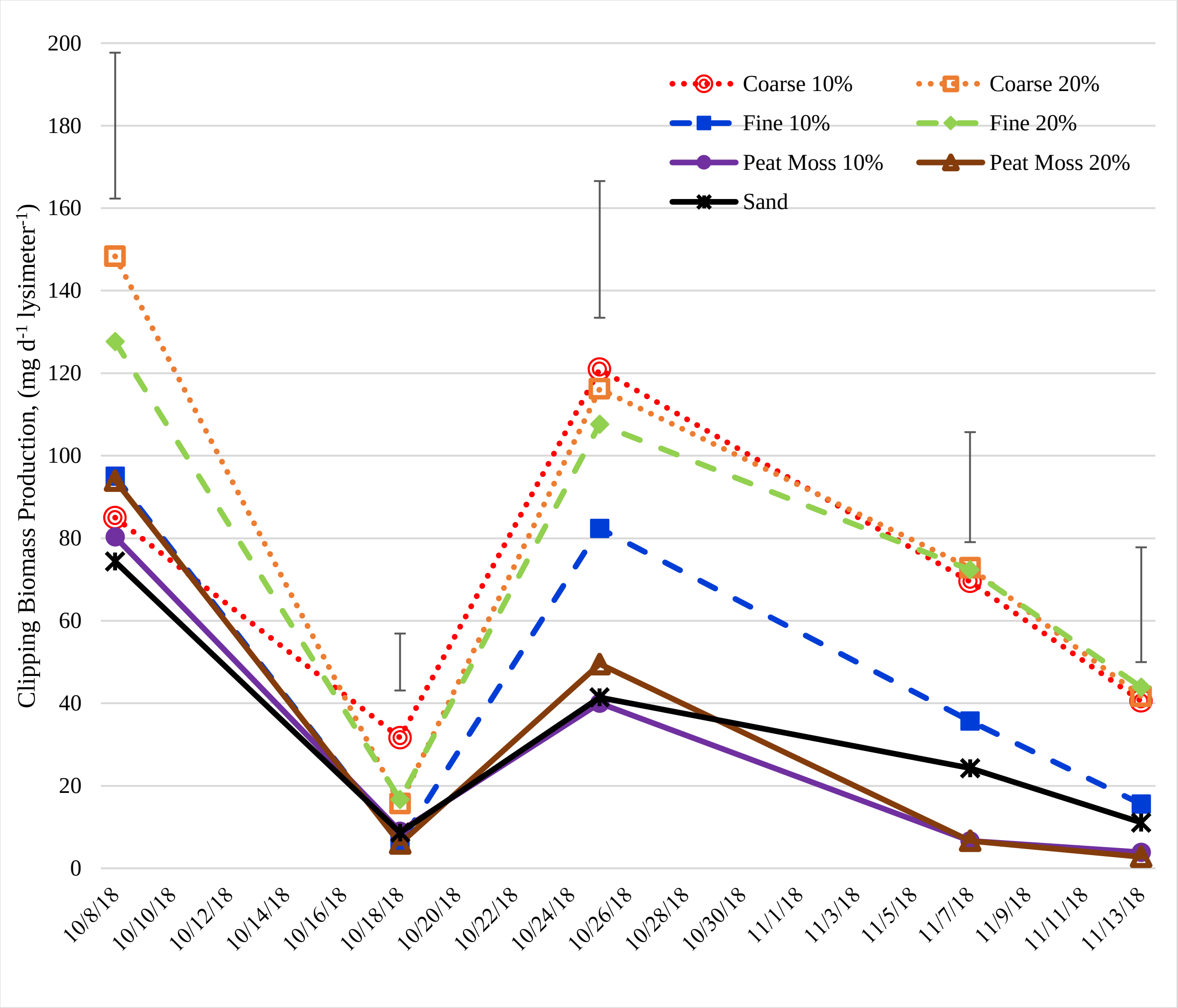

Figure 3.7: Effects of root zone amendment on daily clipping biomass production rate during the 2018 root zone amendment study. Error bars denote Fisher's LSD (0.05).

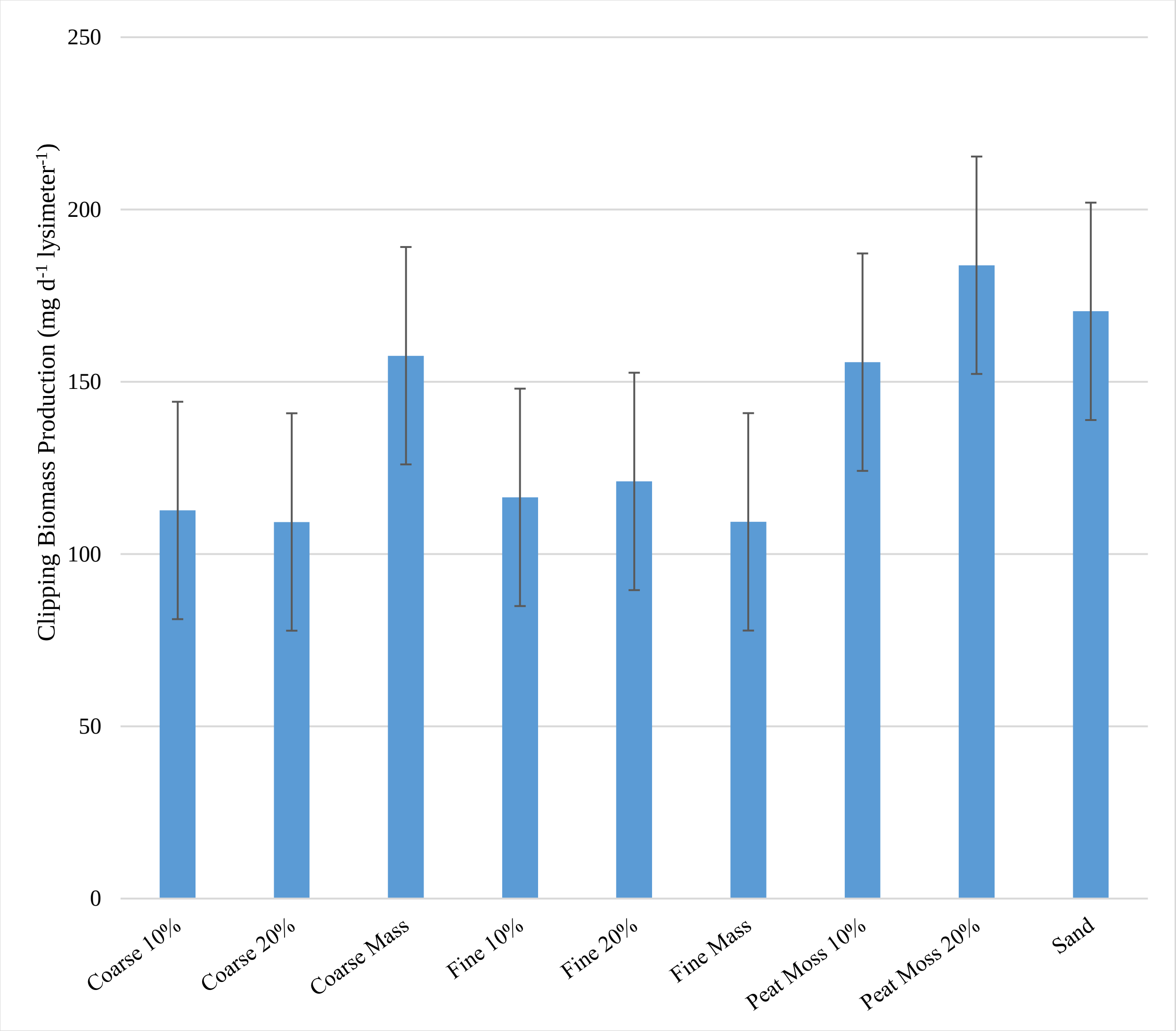

Figure 3.8: Root zone amendment main effect on daily clipping biomass production during the 2019 study. Data are pooled across clipping dates. Error bars denote Fisher's LSD.

Cumulative Clipping Biomass

As a means of assessing fertilizer use efficiency, cumulative clipping biomass (dry mass) was also determined for both years of the study. The ANOVA showed no significant effect of year on cumulative clippings, so data were pooled across both years of the study (Table 3.3). The ANOVA also showed a significant treatment effect on cumulative clippings, with total clipping production over the six-week period ranging from 1.2 to 3.2 g, depending on treatment (Figure 3.9). The coarse SCG 20% treatment produced the greatest amount of total clippings (3.2 g), with peat moss 10% producing the least (1.2 g) over the six-week period. The coarse treatments at both 10 and 20% amendment rates, as well as the fine treatment at the 20% rate yielded significantly greater cumulative clipping production relative to the sand-only control and peat moss treatments.

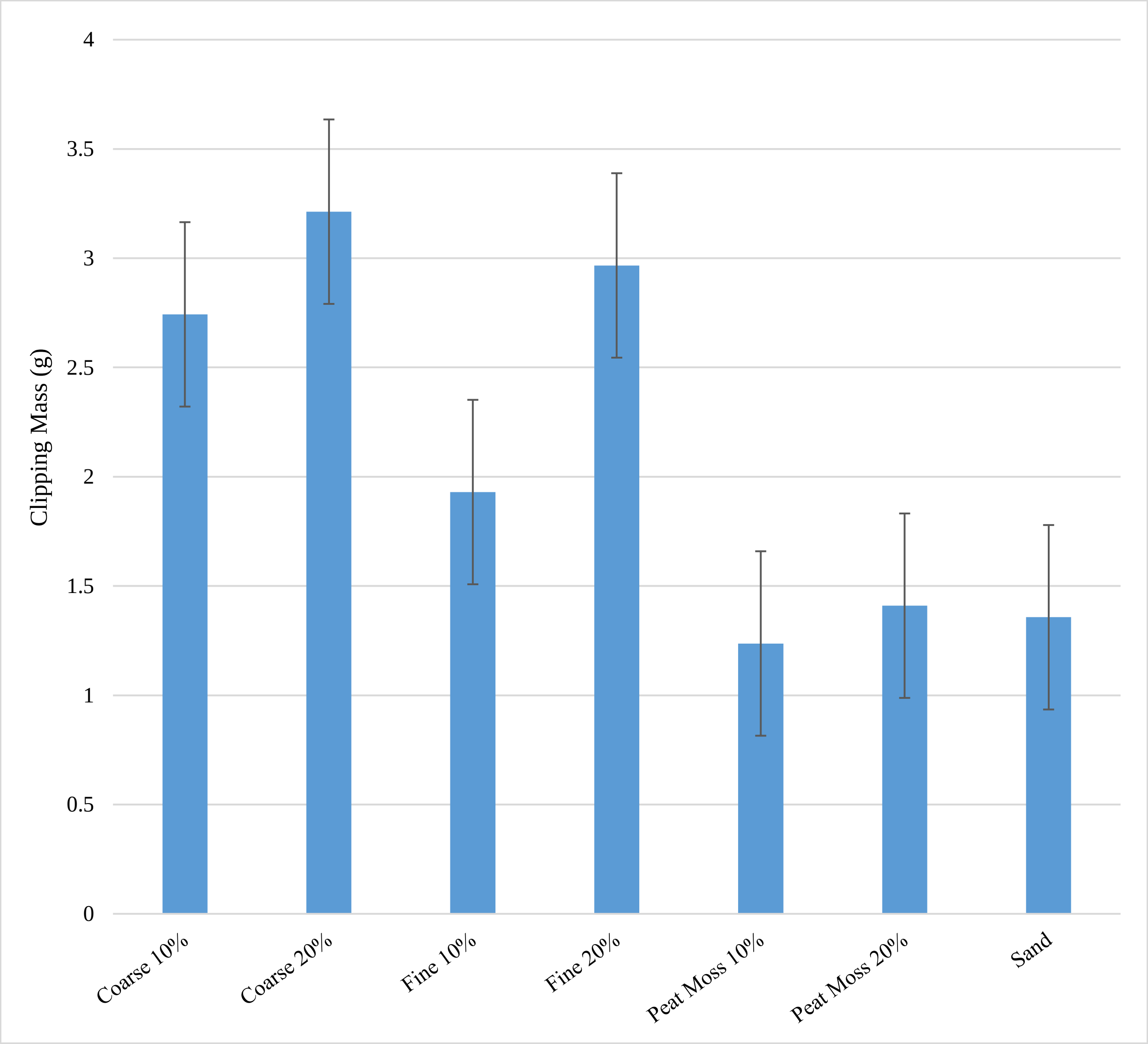

Figure 3.9: Cumulative clipping ciomass production for the 2018 root zone amendment greenhouse study. Data are summed over all clipping dates. Error bars denote Fisher's LSD.

Table 3.4: Analysis of variance for parameters evaluated during the dry-down phase of the greenhouse soil amendment study. Where Year x Treatment interactions were significant, data are presented separately by year.

	Volumetric Water Content		Total Extractable Soil Water		Days to Wilt	Final Turf Quality		Leaf Tissue %N	
Source	Yr 1	Yr 2	Yr 1	Yr 2		Yr 1	Yr 2	Yr 1	Yr 2
Treatment (T)	***	***	***	*	***	***	***	***	TBD
Date (D)	***	***							
T x D	NS	***							

*, *** indicate statistical significance at $P \leq 0.05$ and $P \leq 0.001$, respectively.

Dry-Down and Recovery Phase

Volumetric Water Content

The ANOVA showed a year x treatment interaction for VWC (0-20 cm depth), so data are presented separately by year (Table 3.4). There was a treatment main effect on VWC in 2018, but treatment x date interaction for 2019. Mean VWC, pooled across 2018 dry-down rating dates, ranged from 13 to 19%, with the highest soil VWC associated with peat moss 20% treatment (18%) and the lowest with straight sand control treatments (13%) (Figure 3.10). Peat moss 20% treatments showed significantly higher VWC across the 2018 year compared to all other treatments except fine and coarse SCG treatments at the 20% rate. Compared sand-only control, the coarse 20% SCG, fine 10 and 20% SCG, and peat moss 20% treatments held significantly higher VWC during 2018.

For 2019, peat moss 20% maintained the highest VWC across all dates except the initial rating date (Figure 3.11). Conversely, the unamended, sand-only columns maintained the lowest VWC during the majority of rating dates, and was the first to fall below 2% VWC. It should be noted that soil VWC readings were continued until ≥50% wilt was noted within the turf canopy for a given experimental unit, and although SCG treatments appeared to maintain similar or slightly lower VWC than their peat moss counterparts for a given rating date, measurements were continued later into the dry-down period for SCG treatments due to later appearance of leaf wilt. This appears to suggest that the critical soil VWC for wilt, or wilting point, is lower when SCG is used as compared with peat moss amendment.

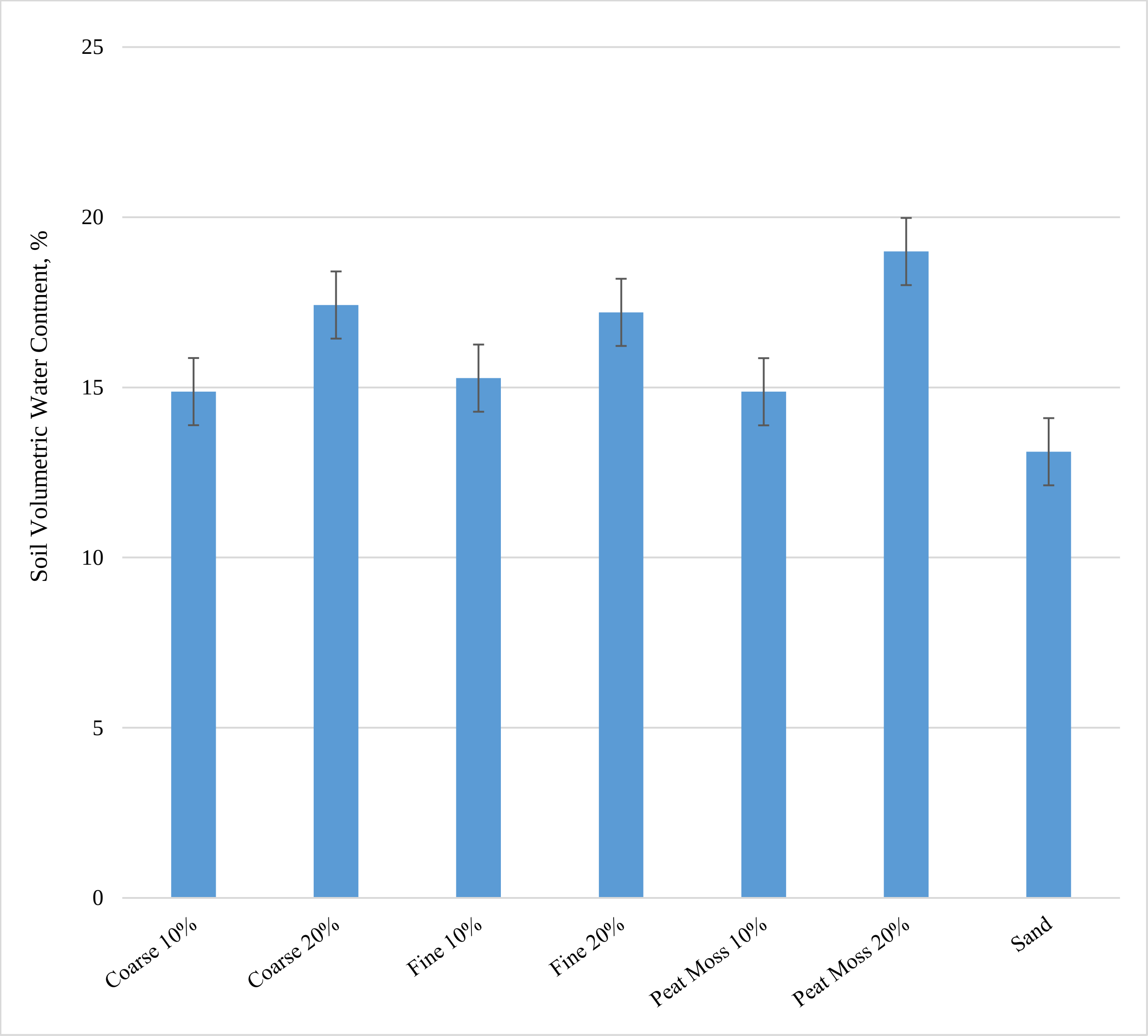

Figure 3.10: Main effect of root zone amendment on Soil Volumetric Water Content at the 0-20 cm depth during the dry-down phase of the 2018 greenhouse study. Data are pooled across measurement dates during the dry down study phase. Error bars denote Fisher's LSD (0.05).

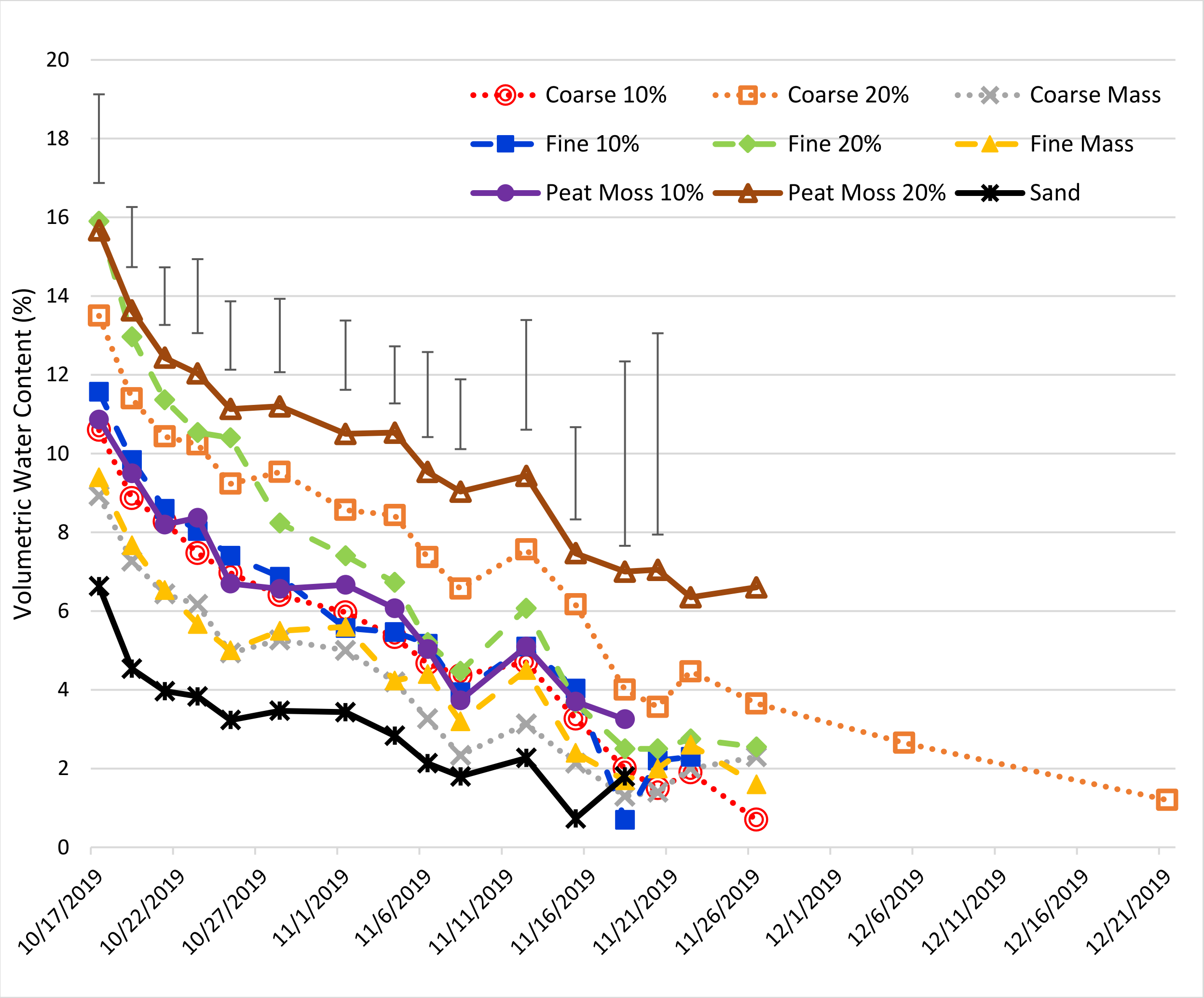

Figure 3.11: Soil Volumetric Water Content at 0-20 cm depth by date as affected by root zone amendment during the 2019 greenhouse study. Readings were taken until ≥50% wilt was noted within the canopy of a given experimental unit. Error bars denote Fisher's LSD (0.05).

Total Extractable Soil Water

The ANOVA showed a significant treatment x year interaction for Total Extractable Soil Water (TESW), so data are presented separately by year (Table 3.4). There were also significant treatment main effects on TESW within each year. For 2018, TESW (determined in this experiment as the amount of water (g) held between water storage capacity and 50% of the blades reaching the permanent wilting point) ranged from 850 to 1700 g (Figure 3.12), with nearly 2x greater TESW associated with fine 20% SCG (1392 g) as compared with sand-only controls (855 g). In addition, the fine 20% SCG treatment showed significantly higher levels of TESW compared to fine 10% SCG treatment, peat moss 10% and the sand-only columns. The TESW was also found to be significantly greater for both coarse SCG treatments (10 and 20%), fine SCG 20%, and peat moss 20%, compared to sand-only controls.

For 2019, TESW trended lower than in 2018, likely due to the study being conducted during the late summer, as opposed to fall months. TESW for 2019 ranged from 800 to 1400 g. Trends were similar to 2018, with a few exceptions. coarse SCG 20% held the greatest TESW (1400 g) during 2019, and was the only treatment to show significantly greater TESW compared to the sand-only controls. Coarse and fine SCG 20% treatments also trended higher than sand-only controls and both peat moss treatments, however, differences were not significant. The least TESW was once again associated with sand-only columns.

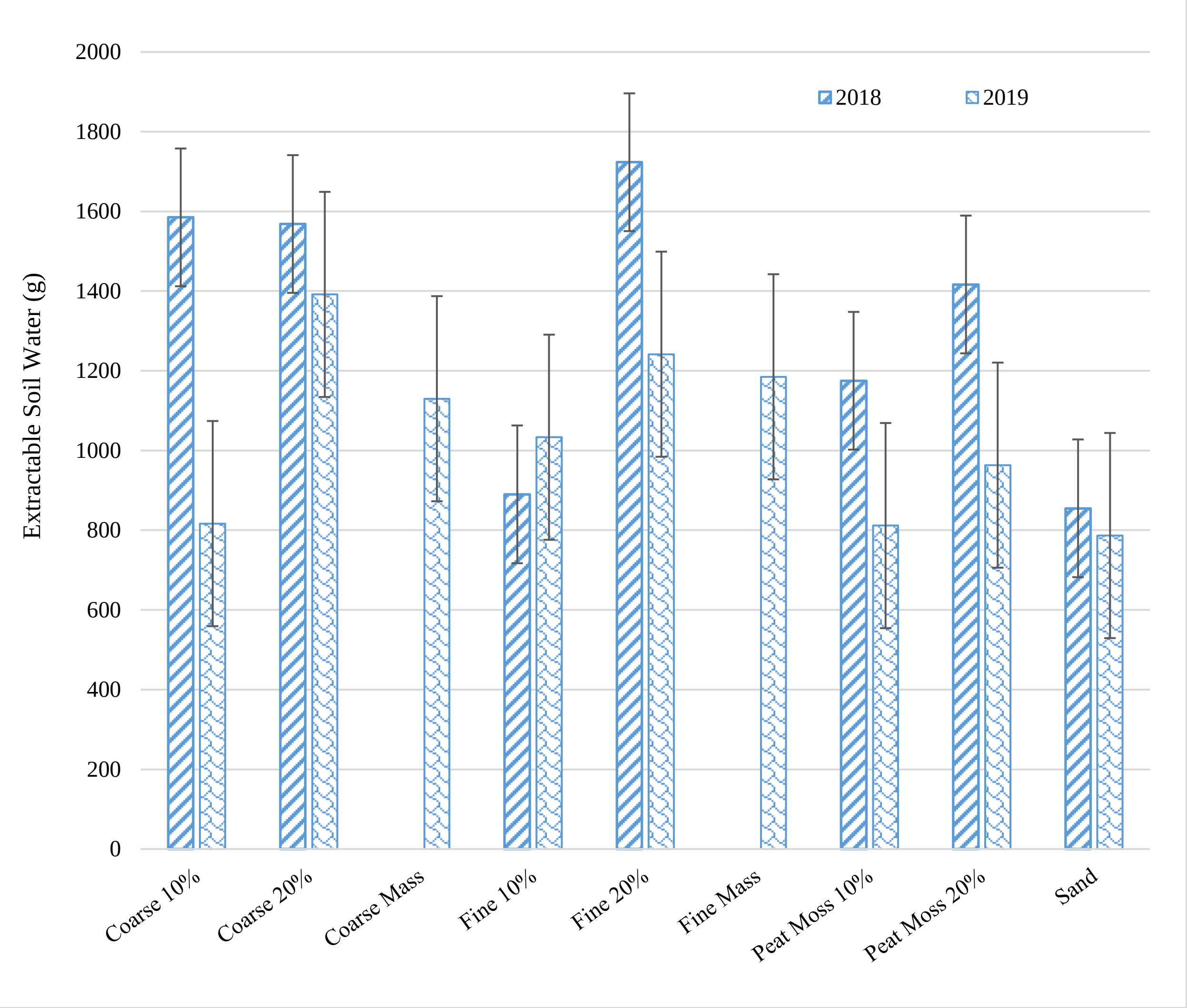

Figure 3.12: Total Extractable Soil Water as affected by root zone amendment for the 2018 and 2018 dry-down periods. Total Extractable Soil Water was determined as starting (field capacity) lysimeter mass – wilt point lysimeter mass. Error bars denote Fisher's LSD (0.05), and are for comparing within a given year.

Days to Wilt

The ANOVA showed no treatment by year interaction for Days to Wilt, so data were pooled across both years of the study (Table 3.4). Across all treatments and years, Days to Wilt ranged from 28 to 48 days (Figure 3.13). The greatest number of days to wilt was observed in the coarse 20% treatment (48 days), which showed a statistically longer period of time before 50% of the turfgrass reached the permanent wilting point. Coarse 20% was observed as having statistically more days before the majority of the grass was wilted compared to all treatments except for peat moss 20% (39 days). The lowest number of days to wilt occurred with the sand-only control treatment (28 days). In addition, the coarse and fine SCG 20%, fine mass, and peat moss 20% treatments all showed significantly greater number of days to wilt than the sand-only controls.

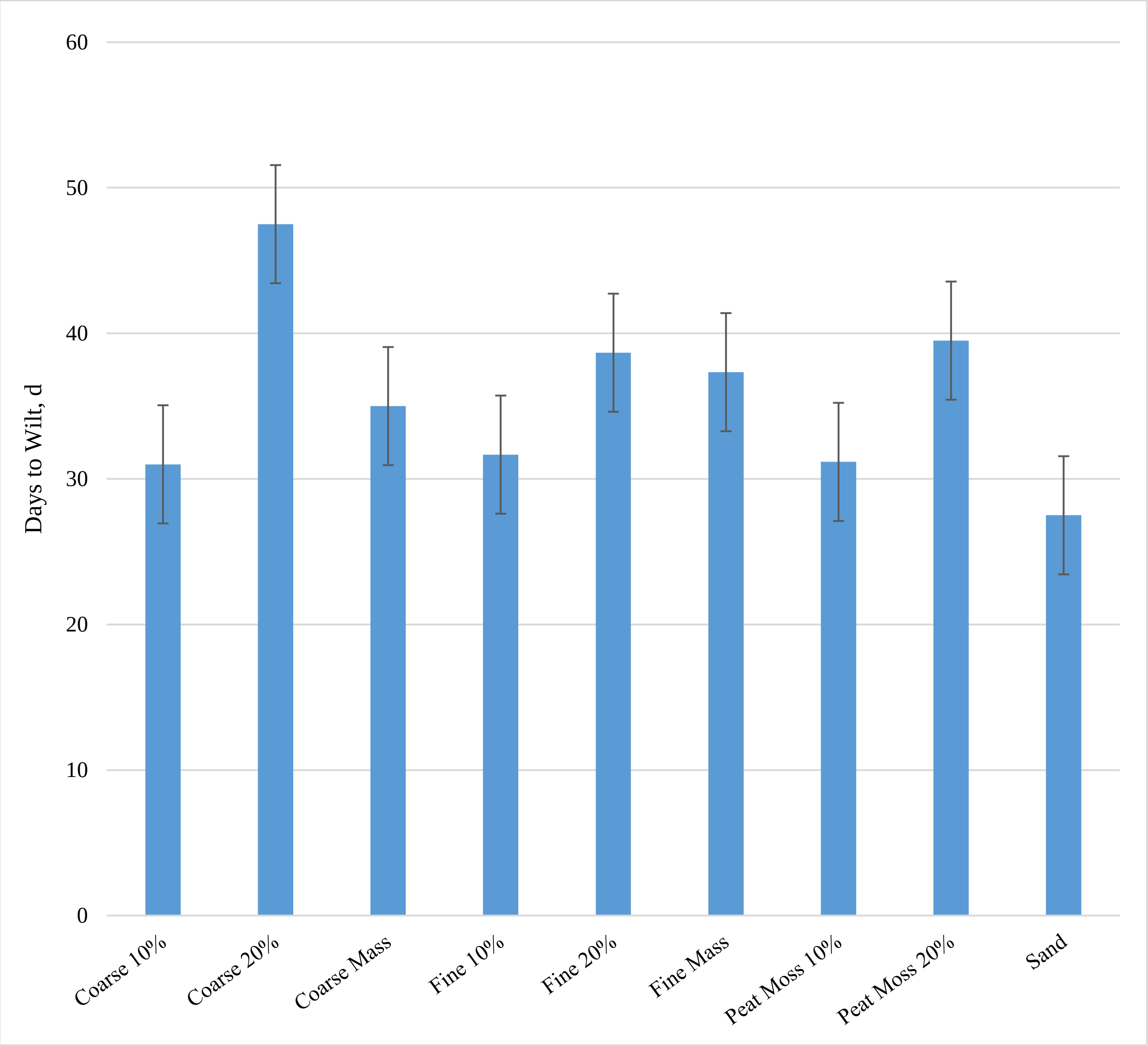

Figure 3.13: Days to Wilt as affected by root zone amendment. With the exception of Coarse Mass and Fine Mass treatments, data are pooled over 2018 and 2019 studies. Coarse Mass and Fine Mass treatments are for the 2019 study only. Error bars denote Fisher's LSD (0.05).

Leaf Tissue Nitrogen

The ANOVA showed a significant treatment main effect for leaf tissue N, taken at the conclusion of the 2018 study nearly 16 weeks after fertilization (Table 3.4). Data from the 2019 study are not yet available. Leaf tissue N, as determined from leaf tissue harvested 3 weeks after re-watering post-dry-down, ranged from 1.1 to 2.2% N (Figure 3.14). The highest leaf tissue N contents (2.2%) were associated with coarse SCG 20%, while the lowest were associated with peat moss at the 20% rate (1.1%). The coarse 20% treatment had statistically greater leaf tissue N than all other treatments, nearly double that of peat moss treatments and sand-only controls. Interestingly, all other SCG treatments also showed significantly higher leaf tissue N compared to both peat moss and sand-only control treatments. Finally, leaf tissue N did not differ between peat moss and sand-only control treatments.

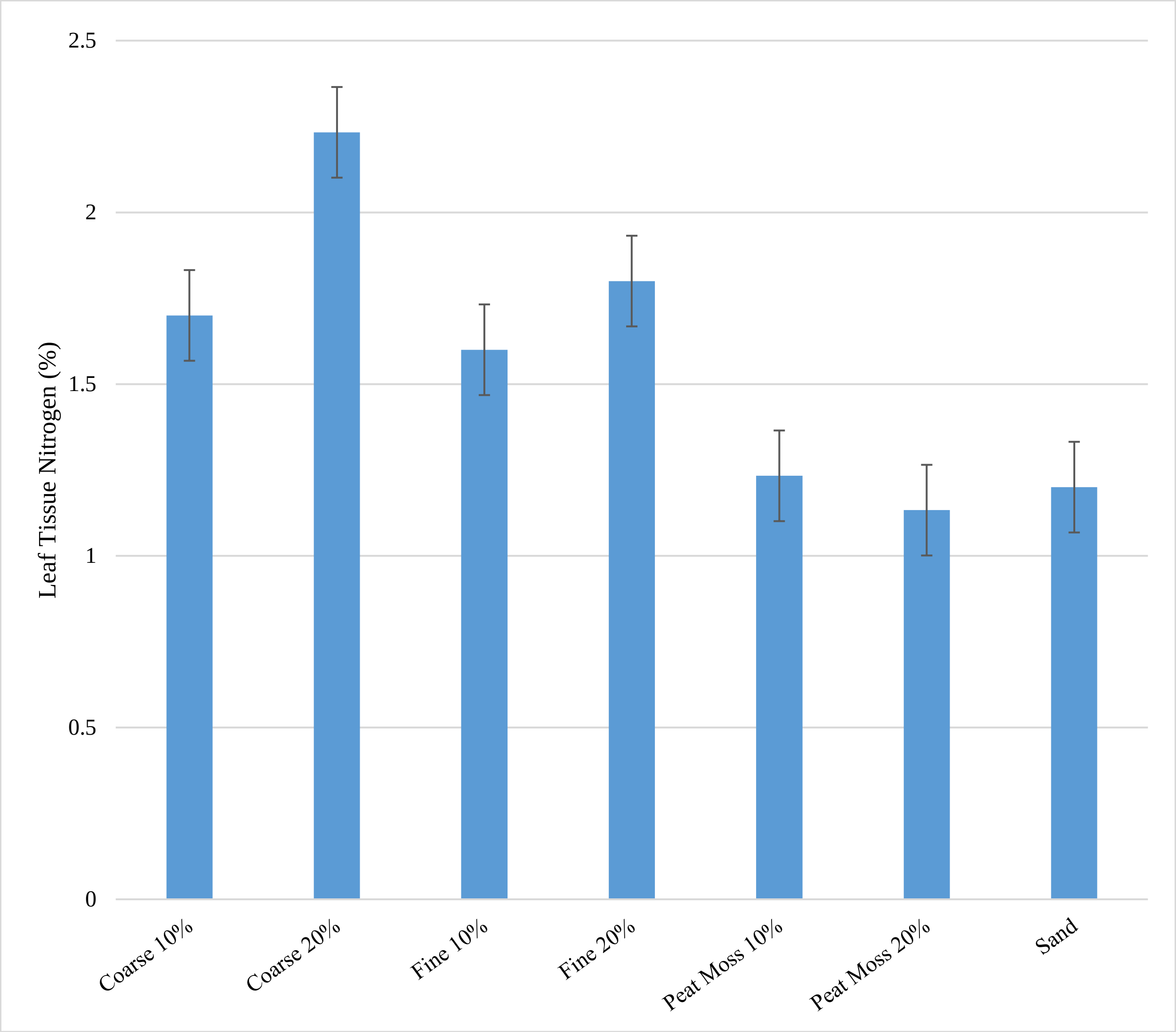

Figure 3.14: Leaf Tissue Percent Nitrogen following dry-down and recovery phase of the 2018 greenhouse study. Clippings analyzed were for the final clipping event, which occurred 2 weeks after re-watering of lysimeters following the dry-down period. Error bars denote Fisher's LSD (0.05).

Post Dry Down Recovery- Turf Quality

ANOVA showed a significant treatment x year interaction and resulted in the post dry down recovery TQ being split into the 2018 and 2019 years. In 2018 all SCG treatments were observed as having significantly higher TQ than the unamended sand control or either of the peat moss treatments (Figure 3.15.). The TQ range fell from 8.5 to 3.8 with coarse SCG at the 20% rate holding the highest level of TQ and the unamended control maintaining the lowest level of TQ. These data were collected 129 Days after the last fertilization event and show the all SCG treatments except fine 10% as having a very high TQ. The fine 10% treatment did not have unacceptable quality but was significantly lower than both coarse treatments. The peat moss treated sands did not show a significantly different level of TQ compared to the unamended sand control and both peat moss and sand treatments showed unacceptable levels of TQ after dry down recovery.

In 2019, somewhat similar results were observed. The range of TQ in this year fell from 8.5 to 1.3 with fine SCG at the 20% rate holding the highest level of TQ and peat moss at the 10% rate having the lowest level of TQ (Figure 3.15). The data show once again the peat moss treatments as not statistically different from the unamended control sand and all of these fall below acceptable levels of TQ after dry down recovery. In this year’s study the course treatment did not hold the same level of TQ as the previous year but no SCG treatment fell below acceptable levels though coarse mass and fine 10% did come close. Again all SCG treatments were significantly higher in TQ than the control and peat moss treatments.

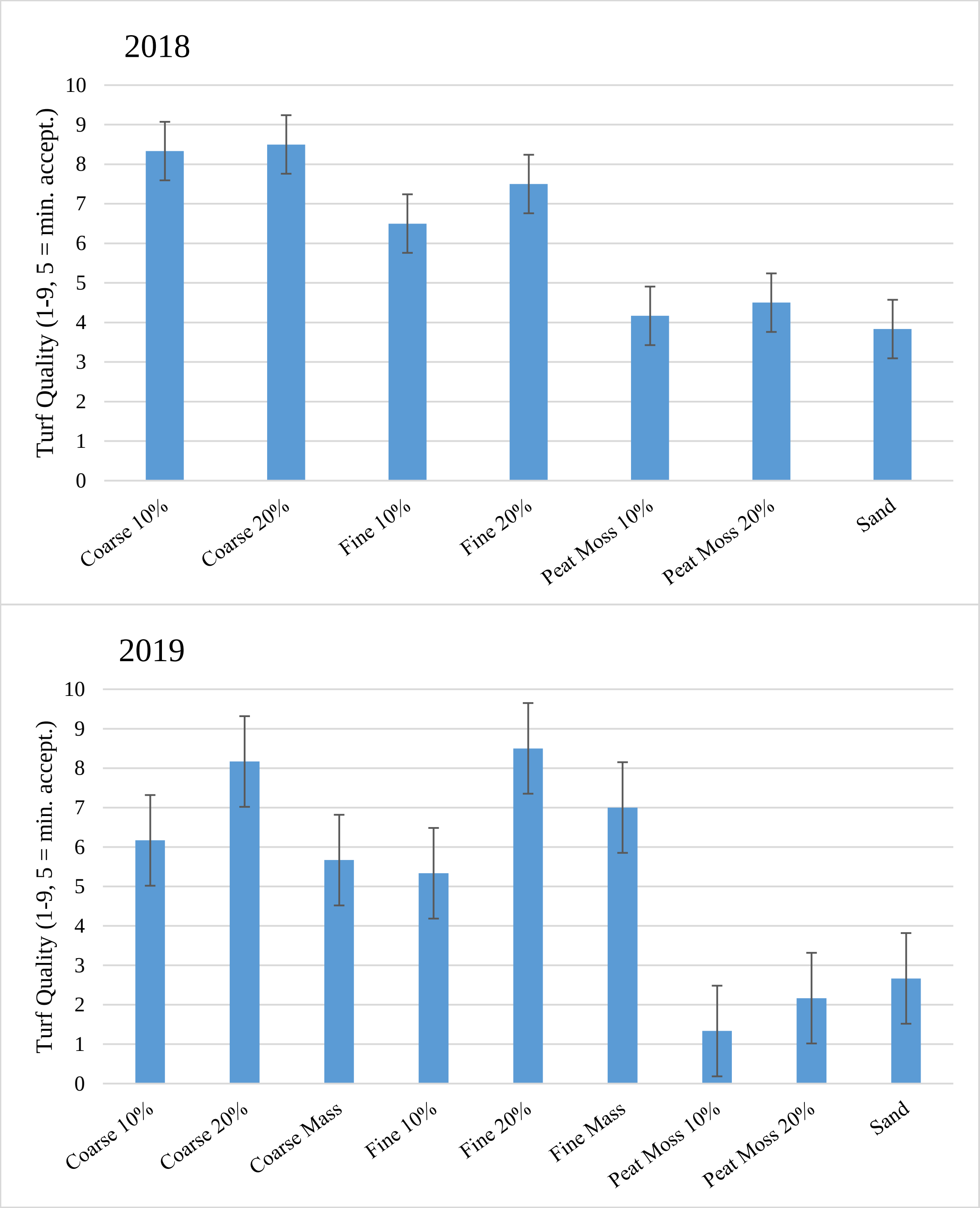

Figure 3.15: Turf Quality by date as affected by root zone amendment after the Dry Down and Recovery phase of the 2018 (upper) and 2019 (lower) greenhouse studies. Error bars denote Fisher’s LSD (0.05).

Discussion

To our knowledge, this is the first study to report on use of SCG for amending sand-based turfgrass root zones. In general, responses of SCG were comparable, and at times superior to that of sphagnum peat moss, both with regard to aiding in fertilizer use efficiency as well as water retention. Although the literature has shown that coffee grounds have the potential to inhibit or suppress growth in some plant species (Hardgrove & Livesley, 2016; Leifa, Pandey, & Soccol, 2000), bermudagrass turf quality of all treatments in our study were always at or above acceptable quality. However, it should be noted that we did observe minor amounts of temporary chlorosis occurring in areas of the turf canopy in plants grown on SCG-amended sands in both studies, and this was noted primarily during the establishment phase, or early in the fertilizer use efficiency phase. However, this was never substantial enough to affect the growth, NDVI, turf quality, percent green cover ratings of bermudagrass. In the well-watered portion of the study, somewhat greater amounts of chlorosis were observed during 2019 compared to 2018. Other than conducting the studies at slightly different times of the year (2018 = Oct/Nov; 2019= Aug/Sept.), this may have been a function of a lengthier establishment period leading up to the 2018 study, which was needed due to failure of the initial washed sod plugs used and re-sodding of columns. While the washed sod that was eventually used in 2018 was ultimately given 4 weeks to establish, the lysimeters had received 2-3 weeks of watering prior to that time. While we cannot fully know, we speculate that either 1) the additional watering during establishment in 2018 resulted in greater leaching of soluble phytotoxic compounds form SCG prior to the experiment or 2) net immobilization of available soil N may occur during the initial weeks to months following SCG sand amendment, either of which could have could have contributed to the more favorable SCG responses observed in 2018. While specific compounds have such as caffeine (Cruz, Baptista, Cunha, Pereira, & Casal, 2012), have been noted as being detrimental to plant health they are also water soluble and the majority is likely removed at the time of brewing so it is likely that less soluble compounds are the culprit of the negative effects observed. Yamane et al. (2014), reported that nitrate nitrogen was immobilized by SCG-amended soils until around 4-months after application, which supports the observed results. This loss of plant inhibitory effects by SCG after an initial period of weeks or months may help to explain the differences in observed chlorosis between 2018 and 2019 TQ.

Interestingly, TQ effects due to SCG particle size varied by year in this study. While coarse grounds produced similar to slightly superior quality to fine grounds at both 10 and 20% amendment rates in 2018, fine grounds showed similar or better responses than coarse grounds in 2019. While we cannot fully explain this response, we speculate that fine SCG, with a higher surface area and smaller ground size (0.5 to 1 mm) may reduce the period in which phytotoxic effects occur by means of leaching or possibly microbial activity that would remove any toxic compounds. The mechanism of this period is still unknown but it is probable that there are multiple mechanisms working simultaneously. Spent coffee grounds immobilize N by having a low plant available N and a very slow rate of decomposition, effectively behaving as a compound that possesses a high C:N ratio, even though the actual ratio (20:1) is quite favorable, and similar to other organic materials (Kitou & Okuno, 1999). No bleaching or purpling of the leaf blades were observed indicating that the turfgrass was not deficient in S or P respectively. This could occur due to the immobilization of N which could affect otherwise mobile nutrients. This, combined with the potential for toxic compounds in SCG such as caffeine, chlorogenic acid, and phenolic compounds (Kim, et al., 2014) illustrates that negative effects can be observed but these effects are transient.

In this study, SCG showed a comparable or improved ability to retain water over extended periods, when compared to the amendment sphagnum peat moss. Interestingly the SCG treatments showed slightly lower VWC at than their peat moss counterparts at their respective rates. However, bermudagrass grown on SCG-amended sands did not display wilt until reaching noticeably lower VWC compared to peat moss-amended sands. This data, along with the extractable soil water data demonstrate that peat moss may hold similar to slightly greater amounts of water compared to SCG, however, it appears to hold less plant available water, which is evidenced in the fewer days, and the higher VWC at which bermudagrass wilt occurred. The peat moss showed signs of wilt at a higher VWC compared to the SCG at their respective rates. This observation is consistent with other reports that show SCG offering higher water holding capacity than other organic materials (Ballesteros, Teixeira, & Mussatto, 2014; Kasongo, Verdoodt, Kanyankagote, Baert, & Ranst, 2011).

Probably the most intriguing finding in this study was the ability of sands amended with SCG to support significantly higher levels of N within leaf tissues, as measured 4 months following fertilization. While TQ and other canopy-based measurements did not appear to respond rapidly to the 4.9 g N m^{-2} addition of ammonium sulfate, differences among treatments as long as 4 months following the fertilization event were dramatic. To illustrate this, Figure 3.16 depicts all of the treatments at the initiation of the fertilizer use efficiency study in 2018. Figure 3.17 depicts the same columns 4 months later. The columns went from uniform TQ to drastically different in this time. Figure 3.18 and 3.19 show a more profile and enlarged view of the different treatments after seen in figure 3.17. These photos make it easier to illustrate the point that all SCG treatments produced more growth and density of turfgrass compared to the peat moss or sand controls.

Figure 3.20 shows the sod plugs during the grow in phase of 2019. They are not yet as far along as figure 3.16, which was the previous year but they still show that the plugs are uniform and no initial differences were observed. Figure 3.21 shows these same columns after the dry down study with similar results as the previous year (Figure 3.17). Again, photos were taken up close to allow easier comparison between treatments (Figures 3.22 to 3.24).

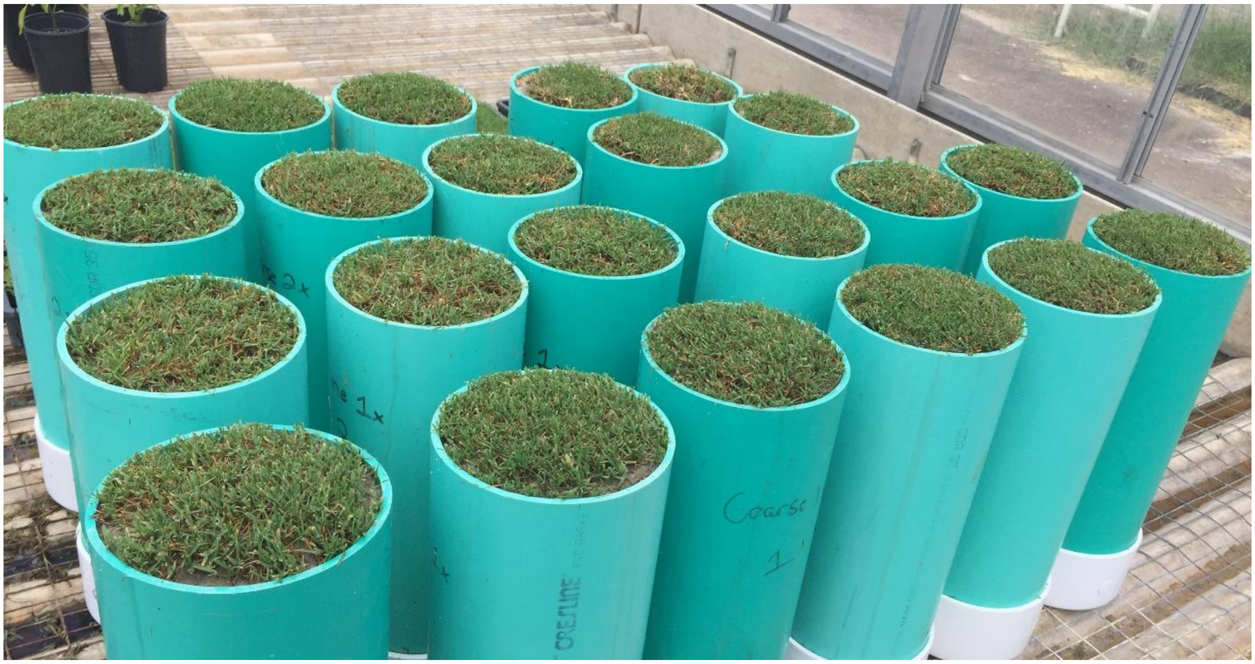

Figure 3.16: Image of treatments at the initiation of the 2018 sand root zone amendment greenhouse study at Texas A&M. Washed 'Tifway' bermudagrass sod was established into lysimeters composed of USGA spec root zones.

Figure 3.17: Image of treatments at the conclusion of the sand root zone amendment study in 2018. Image was taken 4 months after N fertilization event following fertilizer use efficiency and dry-down/recovery phases. Treatments are as follows from left to right (three replicates): Coarse SCG 20%, Peat Moss 20%, Fine SCG 20%, 1 Extra straight sand Column, Sand-only Control, Peat Moss 10%, Fine SCG 10%, Coarse SCG 10%.

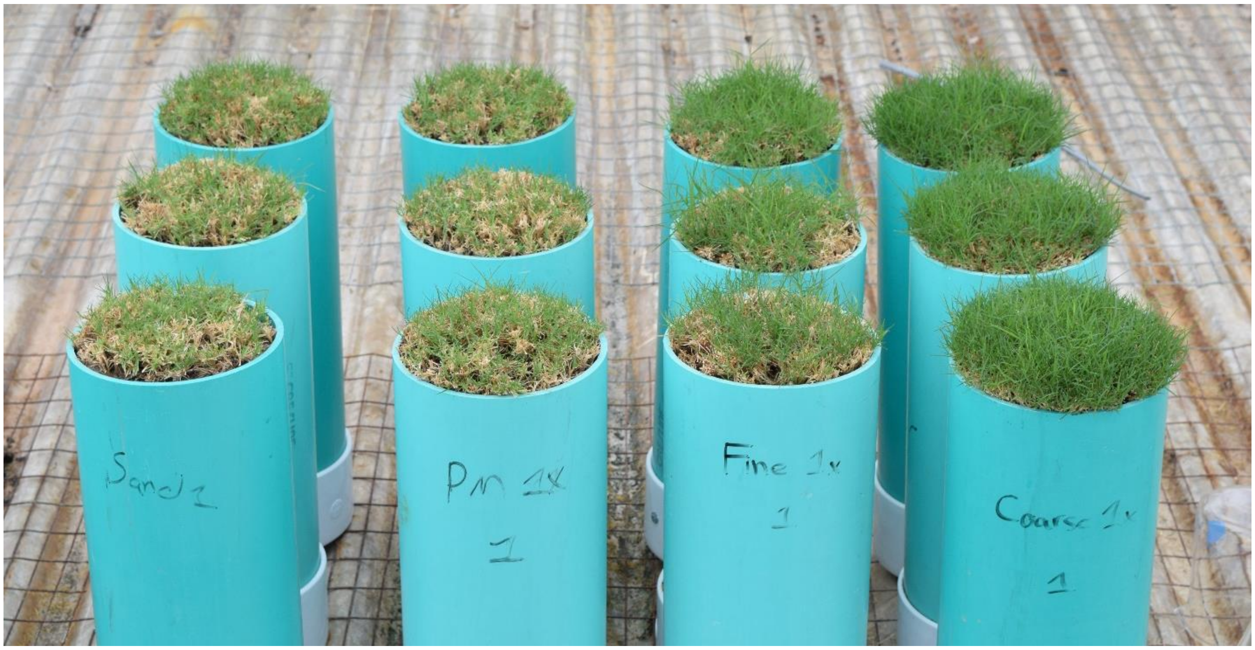

Figure 3.18: A closer view of the 2018 lysimeters after the dry-down study and recovery phase with the following treatments from left to right: Sand, Peat Moss 10%, Fine SCG 10%, Coarse SCG 10%.

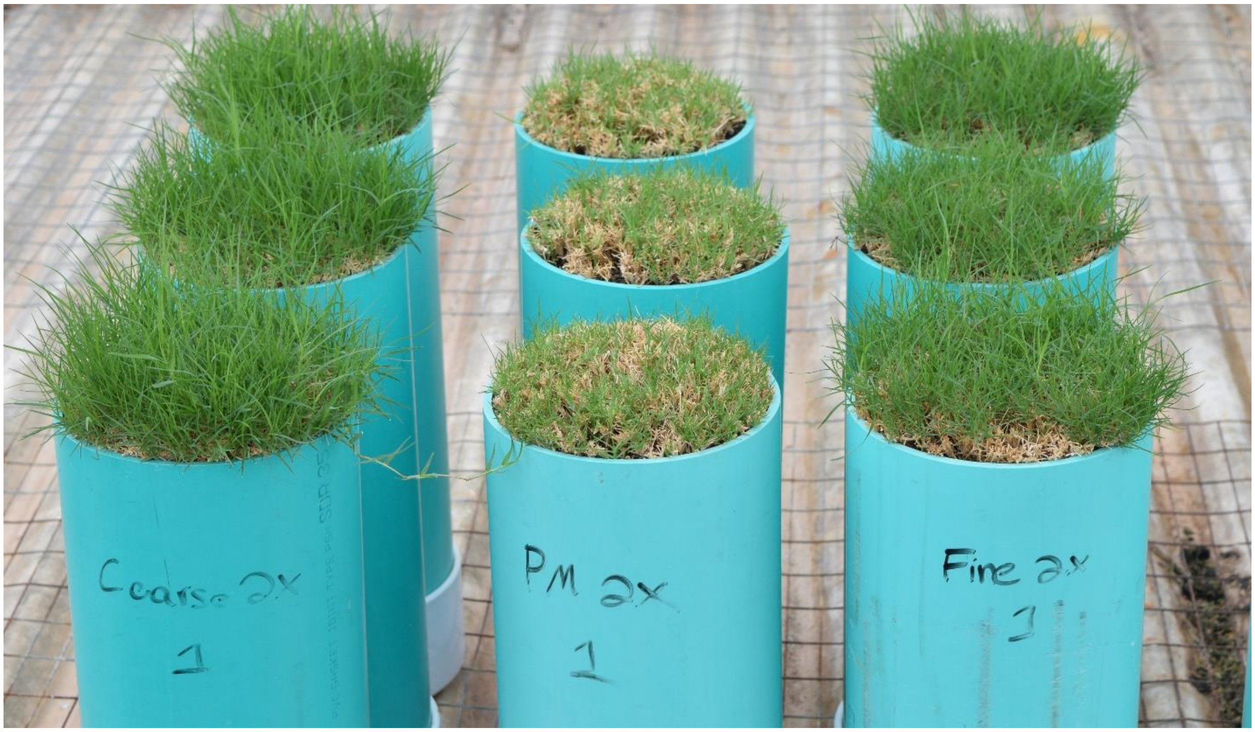

Figure 3.19: A closer view of the 2018 lysimeters after the dry-down study and recovery phase with the following treatments from left to right: Coarse SCG 20%, Peat Moss 20%, Fine SCG 20%

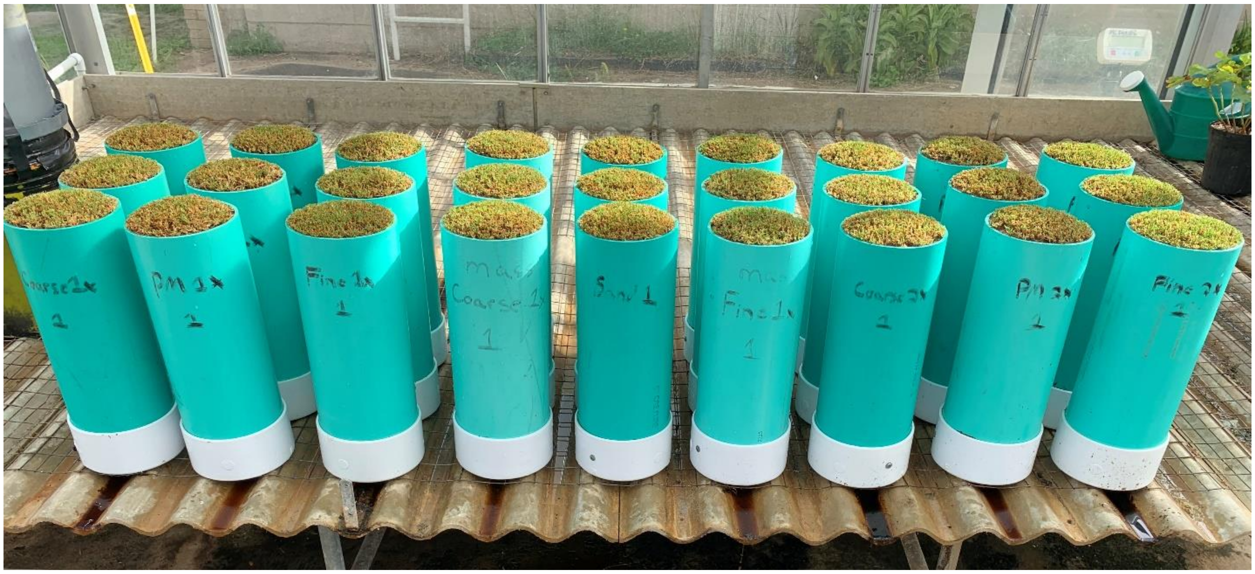

Figure 3.20: This image depicts all lysimeters at the beginning of the establishment phase of the 2019 study.

Figure 3.21: Image of treatments at the conclusion of the sand root zone amendment study in 2019. Image was taken 4 months after N fertilization event following fertilizer use efficiency and dry-down/recovery phases. Treatments are as follows from left to right (three replicates): Coarse SCG 10%, Peat Moss 10%, Fine SCG 10%, Coarse SCG Mass, Sand-Only Control, Fine SCG Mass, Coarse SCG 20%, Peat Moss 20%, Fine SCG 20%.

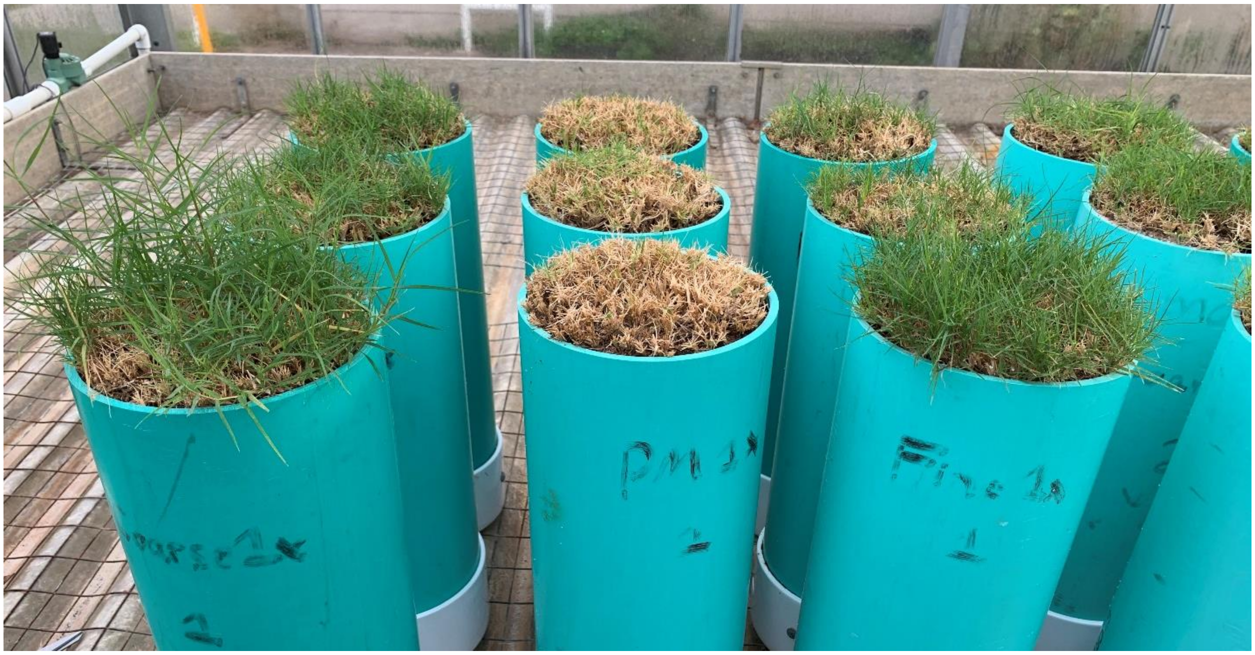

Figure 3.22: A closer view of the 2019 lysimeters after the dry-down study and recovery phase with the following treatments from left to right: Coarse SCG 10%, Peat Moss 10%, Fine SCG 10%

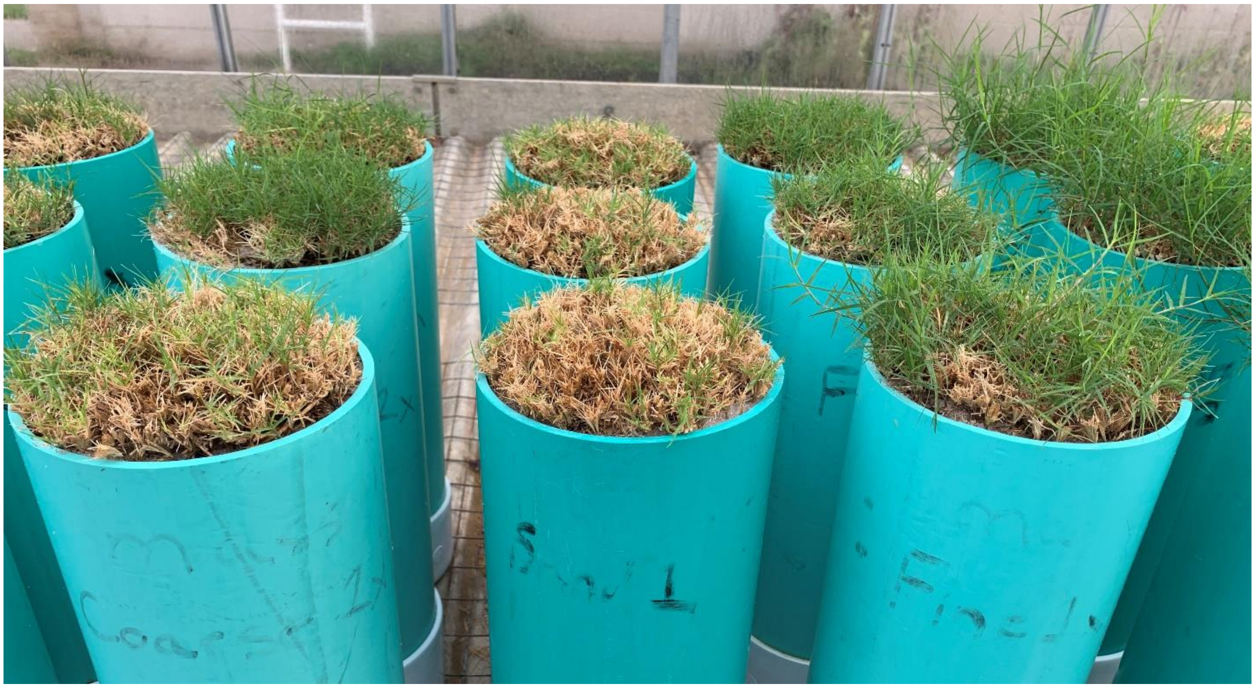

Figure 3.23: A closer view of the 2019 lysimeters after the dry-down study and recovery phase with the following treatments from left to right: Coarse SCG Mass, Sand, Fine SCG Mass.

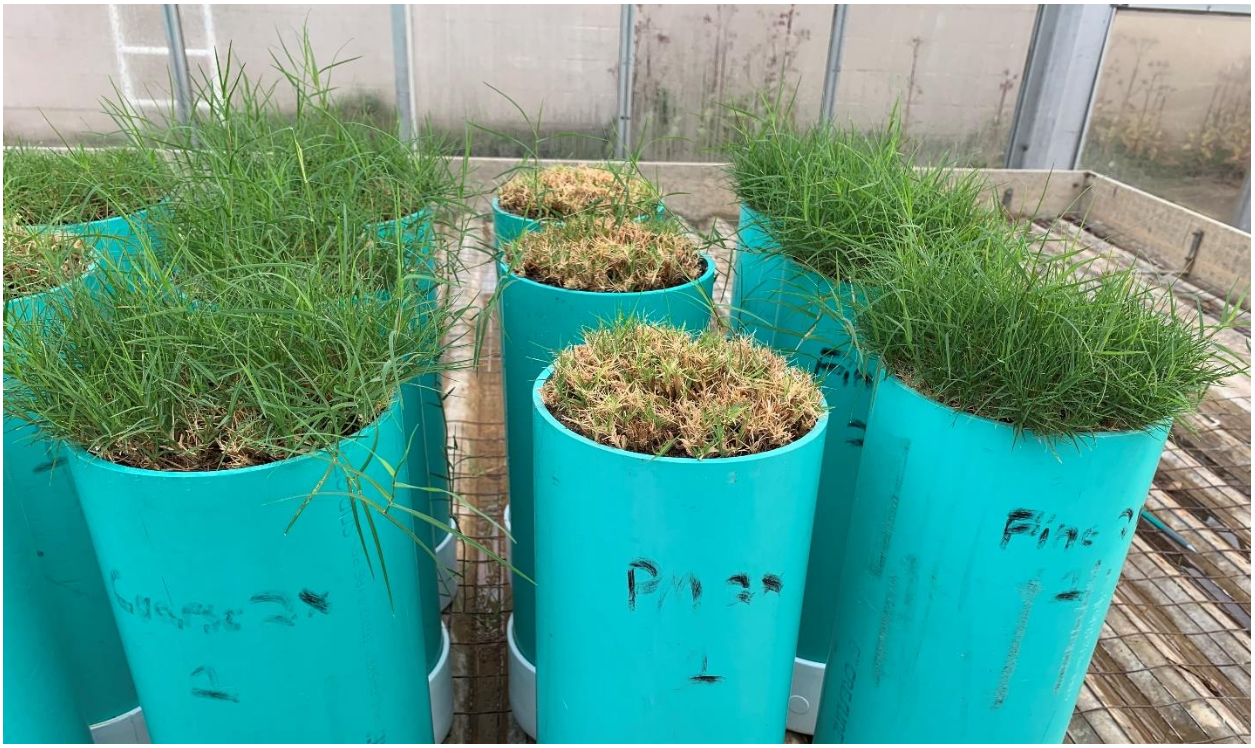

Figure 3.24: A closer view of the 2019 lysimeters after the dry-down study and recovery phase with the following treatments from left to right: Coarse SCG 20%, Peat Moss 20%, Fine SCG 20%.

The SCG-amended sand treatments demonstrated superior recovery attributes following dry-down both years and continued to grow vigorously after being re-watered, despite this being 4 months after the last fertilization. Minimal to no growth was seen in the other treatments and when clippings were harvested, N content in the SCG treatments was nearly double that of the peat moss and sand-only treatments.

It has been observed that SCG increase the CEC of soils (Kasongo, Verdoodt, Kanyankagote, Baert, & Ranst, 2011) which would make it possible to reduce leaching of highly soluble nutrients such as NH_{4+} and potentially exchangeable K (Kasongo, Verdoodt, Kanyankagote, Baert, & Ranst, 2011). The spent grounds have also been observed to keep nutrients in the rootzone by reducing the rates of both ammonification and nitrification (Bollen & Lu, 1961; Emmanuel, et al., 2017). Bollen & Lu (1961) alluded to the oil content remaining in the SCG as having the ability to retard the microbial communities. In any case these processes would allow the nutrients (especially the soluble nutrients) to remain in the rootzone for an extended period before they are broken down and become soluble.

Another possibility is that SCG may interact with or enhance activity of the soil microbial community. The rates of soil respiration have increased with the incorporation of SCG indicating that the grounds do have the ability to stimulate soil activity among soil microbial communities (Cervera-Mata, et al., 2019). While the increase of soil respiration is not necessarily a good result due to the likely hood of N immobilization by the active microbial community it could allow for the promotion of beneficial microbes. In the literature SCG were seen as being attractive habitat and food source for a variety of fungal species. These fungal hyphae incorporate the SCG and soil particles forming aggregates that improve soil structure (Cervera-Mata, et al., 2019). This type of aggregation can occur over time and while this study was not long enough to observe these effects, one interesting observation was made when the columns were taken apart. After disassembly of the lysimeters the roots of the bermudagrass were seen growing though the coarse SCG and were not able to be removed from the tissue without damaging or losing root mass (Figure 3.25). Due to this interaction, no root measurements (volume or mass) could be recorded.

It is likely that both microbial and chemical interactions are occurring simultaneously; where the SCG create a beneficial environment in the rhizosphere with its ability to bind organic and synthetic compounds as well as maintain high a level of extractable soil water. Whatever the case may be, N was obviously more available to all coffee ground treatments than to the control or peat moss columns (Figures 3.14, 3.17 and 3.21).

Lastly, despite parallel field studies that suggest virtually no N release following years of surface applications, we cannot rule out the possibility that mineralization of SCG may occur when amended into soils. The literature shows conflicting observations where some studies show slight increases in soil N levels (Cervera-Mata, et al., 2018; Kasongo, Verdoodt, Kanyankagote, Baert, & Ranst, 2011), while others show that N mineralization is negligible from SCG (Hardgrove & Livesley, 2016). However, a small level of mineralization could explain the enhanced growth responses observed, especially later on in the study period.

Summary and Conclusions

The structural and chemical properties of SCG do not make them a good source of nutrients but they could make an excellent soil amendment to increase CEC and water holding capacity. The drawback of using them in this way is primarily the window of phytotoxicity that was observed in both years but this was only temporary as seen at the end of each study. While N immobilization was discussed in this paper as well as the literature it is likely not the reason for the detrimental effects observed in this study. With the data from the tissue N (Figure 3.14), it is clear that there is plenty of plant available N at the end of the dry down some 4 months after the first fertilization event. Assuming the break down of SCG does cause N immobilization the 4.9 g N m^{-2} applied during the grow in and at the beginning of the well-watered phase should mitigate these effects. WhiThe ability to create some sort of beneficial environment in the rhizosphere is a critical find that could lead to less inputs of both water and chemicals such as fertilizers and pesticides on lawns, sports fields and golf courses that could be amended with SCG. The coarse treatments did very well for the most part in this study and as the coffee grounds received contained 72% coarse grounds (1-2 mm) in the “fresh” stock, this is likely a close representation of what unprocessed SCG may look like if SCG were used fresh from a brewing plant.

There remains much to be explored in future research, namely the microbial communities that establish themselves after the rootzones have been established. Host mediated microbiome engineering (HMME) would be an excellent start to observe beneficial microbes that could inhabit the SCG biome. Another important aspect for future research would be finding exactly which phytotoxic compounds that are responsible for the stress response observed in this study and throughout the literature. If these compounds or effects can be remedied, the ability of SCG to replace sphagnum peat moss as a major soil amendment worldwide would be undeniable. It would be advisable to develop a study similar to this one in which the leachate of the columns is collected and analyzed over an extended period of time to capture the "window" of phytotoxicity observed and what compounds are being lost during this time. The mechanism of these observations needs to be further studied but the consequences may be crucial in creating a sustainable future.

Figure 3.25: Image of 'Tifway' bermudagrass roots after the completion of the dry down recovery phase of the 2018 sand root zone amendment greenhouse study at Texas A&M. Washed bermudagrass sod was established into lysimeters composed of USGA spec root zones, where the turf roots can be seen growing into the coarse SCG.

CHAPTER IV

CONCLUSIONS

SCG did not act as a source of nutrients when applied alone, but when combined with another source of nutrients they retained and possibly increased other nutrients that were previously unavailable in the soil. The GeoJava treatments were observed to promote a high level of turf quality over both years of the study, with the 4-2-1 fully organic product being highly competitive with fully synthetic products such as ammonium sulfate and URI-PEL S.R.. No changes in soil pH or soil nutrients were observed compared to the untreated control plots over multiple years of SCG application. Based on these observations, SCG may offer promise as a component for production of synthetic/bridge or organic fertilizers.

While the structural and chemical properties of SCG do not make them a good source of nutrients, they could make an excellent soil amendment to increase CEC and water holding capacity. The drawback of using them in this way is primarily the window of phytotoxicity that was observed in both years but this was only temporary as seen at the end of each study. While N immobilization was discussed in this paper as well as the literature, it is likely not the reason for the detrimental effects observed in this study. With the data from the tissue N (Figure 3.14), it is clear that there is plenty of plant available N at the end of the dry down some 4 months after the first fertilization event. Assuming the break down of SCG does cause N immobilization the 4.9 g N m^{-2} applied during the grow in and at the beginning of the well-watered phase should mitigate these effects. The ability of SCG to create some sort of beneficial environment in the rhizosphere is a critical find that could lead to fewer inputs of both water and chemicals such as fertilizers and pesticides on lawns, sports fields and golf courses that were amended with SCG. The coarse treatments did very well for the most part in this study and as the coffee grounds received contained 72% coarse grounds (1-2 mm) in the “fresh” stock, this is likely a close representation of what unprocessed SCG may look like if SCG were used fresh from a brewing plant.

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