

MAINTENANCE OF WARM-SEASON TURFGRASSES WITH ORGANIC
AND NONSYNTHETIC PESTICIDES AND FERTILIZERS

by

MEGAN E. BABB-HARTMAN

(Under the Direction of F. Clint Waltz Jr.)

ABSTRACT

Increased interest in ecological sustainability, health, and safety has led to a need for research in the area of organic maintenance of warm-season turfgrasses. A lack of commercially-available products and knowledge of those product's behavior and efficacy severely limit professionals and homeowners in alternative management options. The vast majority of these products are manufactured by small-scale producers who cannot afford scientific research to support their advertising claims. Currently, there are no legislated statutes in the U.S. to define what is acceptable organic production and management of turfgrass unlike food commodities; however, organic-approved products labeled for turfgrasses exist. The objectives of this research were to evaluate commercially-available organic fertilizers, compost teas, herbicides, fungicides, and fungal suppressants, compare organic products against industry standards, and determine efficacy of products and potential management programs. The results indicate there is opportunity for some of these products to reduce or mitigate conventional, synthetic chemical input use.

INDEX WORDS: holistic management, nonsynthetic, organic, warm-season turfgrass

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DEDICATION

I would like to dedicate this thesis to my husband Perry for having my back no matter what, my parents Joel and Karen for fostering my curiosity, my sisters Rebecca, Cat, and Jennifer, my brother J.R, and my various teachers and mentors. Thank you for all you have done to support me through my life and giving me the tools to succeed.

Omnia vincit amor.

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CHAPTER 1

INTRODUCTION & LITERATURE REVIEW

Introduction

Lawn, turf, green, and pitch all refer to areas of managed turfgrasses, and are important components of landscapes. They serve a variety of environmental functions that include the control of soil erosion, dust, and heat dispersion, as well as provide a cushioned surface for outdoor sports and add aesthetic value to the surroundings (Heinze, 2011). In 18th century Europe, lawns were maintained by grazing animals that fertilized the grass with their manure (Beard et al., 2014). In the 19th century, human labor was engaged in lawn maintenance, and human intervention increased leading to manually cutting grass and applying nutrients (Beard et al., 2014). Due to the use of horses as a primary means of transportation, “manuring” became a popular method for fertilizing greenspaces (Beard et al., 2014). However as manure resources became scarce with the arrival of the combustion engine and vehicles, manure substitutes came on the scene such as blood meal, bone meal, fish meal, guano, etc (Beard et al., 2014).

The invention of the lawn mower in 1830 by Edwin B. Budding revolutionized turf management (Fort, 2001; Appl, 1982). The development in the United States that followed World War II saw increased use of lawns in the rapidly growing residential areas, consequentially expanding grass seed and sod production (Beard et al., 2014). Soon the maintenance of these dedicated green spaces became a vast industry that was removed from its more holistic beginnings as forage area. Turf managers came to consume large amounts of inputs such as fertilizers, pesticides, fuel, and water which were later discovered to pose environmental risks when misused (Robbins and

Birkenholtz, 2003). The area under turfgrasses (> 40 million km²) is estimated to be over thrice the area of any irrigated crop in the US today (Milesi et al., 2005), and modern lawns are part of a multi-billion dollar industry (Anonymous, 2003).

The areas of turfgrasses can be broadly categorized as lawns, athletic fields, and golf courses. This categorization serves to illustrate three levels of intensity of management. There are some people who may strive toward a “perfect” lawn, but for the most part homeowners and businesses want their green spaces simply to appear acceptable in the sense of aesthetic value. However, the homeowners are not usually trained in turf care and may not read or follow product labels, and therefore have a tendency to misuse commercial products. The US Fish and Wildlife Service reported that “homeowners use up to 10 times more chemical pesticides per acre on their lawns than farmers use on crops, and they spend more per acre, on average, to maintain their lawns than farmers spend per agricultural acre” (U.S. Fish and Wildlife, 2000). This is a common source of watershed contamination in residential areas, and could pose health risks to humans and animals if reentry directions are not heeded. Homeowners are difficult to regulate relative to lawn care professionals that are held to business ethics and government standards.

Athletic fields have to be maintained with an emphasis on wear caused by players, safety in the form of cushion to prevent injuries, and a relatively higher aesthetic quality than a residential or business’s green space. Legislature has been passed in the last decade in the U.S. and Canada restricting pesticide use or outright banning use on youth

sports fields as a result of health concerns, with punishment as severe as a year in jail and exorbitant fines (Hall, 2010).

Golf courses generally have high expectations for turf quality compared to most other areas. Fee-paying players have expectations concerned with any impediment to ball roll, evenness, and the best aesthetic quality possible. Achieving these attributes requires various intensive management practices such as low, frequent mowing on putting greens, core aeration, and control of weeds, diseases, and other pests. Higher intensity management decreases ecological diversity in the soil, as illustrated in a study on entomopathogenic nematode (EPN) abundance in three golf course areas (roughs, fairways, and greens) with varying levels of intensity (Alumai et al., 2006). It was found that significantly less EPNs were in greens and fairways than roughs, correlating the relationship between EPN abundance and management intensity (Alumai et al., 2006). This research indicates that cultural practices and pesticides could contribute to a cycle where more pesticides would be required to abate pests because the area has been made into an unfavorable environment for natural predators, therefore increasing pesticide use (Alumai et al., 2006).

Due to the unpopularity of organic management now and before the “green revolution” relative to conventional, the definitions and standards that apply to turfgrass are vague. The terms organic and nonsynthetic here refer to the use of materials of plant or animal origin, without use of chemically formulated substances, and/or materials approved for use in organic agriculture by the Organic Materials Review Institute (OMRI) (Organic Foods Production Act, 1990). Conventional herbicides are typically

chemically synthesized and are generally preferred by contemporary managers. Organic food production has been gaining momentum over the past few decades, but organic turfgrass management has more recently been a topic of interest among professionals and homeowners. The U.S. Department of Agriculture (USDA) regulates organically grown foodstuffs through the National Organic Program (NOP), however no U.S. government-enforced standards are in place for what constitutes organic lawns, fields, or other green spaces.

There is also a lack of scientific knowledge to understand the true potential in the compatible products available and practical cost-effective ways of using them. The misuse of chemical fertilizers and pesticides, particularly in turfgrasses close to residential and other areas, poses environmental and health risks and leads to an interest in for non-synthetic or organic management of turfgrass (Robbins and Birkenholtz, 2003). Increased public awareness in recent years regarding the dangers of pesticide use has resulted in a revival of organic approaches to manage turfgrasses (Miller and Henderson, 2012). The imposing of bans on use of certain turfgrass pesticides in public grounds in Canada are a testimony to this revival (Legislative Assembly of Nova Scotia, 2009; Legislative Assembly of Ontario, 2009). In the US, the states of Connecticut and New York banned pesticide use on school grounds (Connecticut General Assembly, 2009; New York State Department of Environmental Conservation, 2010). Legislative actions such as those mentioned above compel turf managers to resort to alternative management methods or in some cases no management at all. However, there are limitations to their use, the most important being a lack of sufficient research into efficacy, use, and safety.

Many problems are faced by researchers studying non-synthetic management strategies. The most prominent is the general absence of standardization of application methods and materials. For example, each batch of compost can have a different balance of nutrients and microorganisms due to its origins in various biological wastes, whereas the amount of N in 46-0-0 is exactly 460 g N/kg material which is one of many products regulated by all levels of government in the U.S. A professional knows exactly what to expect when granular urea or ammonium nitrate is applied, but with compost the desired effect is not as uniform, obvious, or reliable. By putting priority on cost and heightening the standard of quality, professionals have come to strongly prefer products that are consistent, show timely results, and are easy to apply. However, most of these products have negative ecological impacts that affect wildlife and human health, and misuse by professionals and homeowners who do not apply in accordance with the scientifically supported recommendations can have severe consequences such as pollution and pesticide resistance. Fertilizer runoff and the subsequent eutrophication of streams diminishing biological diversity is very well documented, but cases of pesticide poisoning are difficult to study as they are usually a product of human negligence. Along with industrial pollution, pesticide pollution in water supplies and soils in China has garnered much attention internationally for the observed environmental effects such as the ruination of soils by over-fertilization and ingestion of chemicals by livestock and humans (Liu and Diamond, 2005; Wu et al., 1999).

Pesticide resistance is an issue for integrated pest management. It arises when one or more pesticides have been applied to a crop frequently enough to select for the most resilient pests which then breed to produce more resistant pests that cannot be sufficiently

controlled by the same means. It can only be mitigated preventatively by a heavier reliance on cultural and integrated methods rather than pesticides. As a result, there is potential opportunity for organic methods in order to prevent this resistance. In Australia, annual ryegrass (*Lolium rigidum*) illustrates the intense need for research and implementation of recurring turf system weeds, as it is characterized by multiple selective herbicide resistance and has several resistance biotypes (Powles and Matthews, 1992).

Not all non-synthetic/organic products are 100% safe for humans and the ecosystem, but the majority of them are safer alternatives to the current industry standards. A compilation of organic and conventional products along with their toxicities are shown in Table 1.1 and 1.2, respectively. The Organic Materials Review Institute (OMRI) provides a comprehensive list of products certified by the USDA National Organic Program for use in organic management and processing. The list includes over 35,000 products ranging from composts and plant oils to sodium chloride and laboratory-synthesized chemicals that are identical to substances found in nature. Many of these products are biological controls, which are essential to integrated management practices. Examples of these that have or could be used in turf are compost materials and bacterial and fungi inoculum (Workman, 2012). Researchers have found that when compost was sterilized of biotic factors, a loss of disease suppression was observed (Noble, 2011; Noble and Coventry, 2005). This indicates there are biological and biochemical attributes that lend to composts suppressive benefits.

Many professionals and consumers believe that adopting this type of management is more sustainable than conventional methods, but more research needs to be done with a focus on the benefits and costs of implementation and use. This would include cost to

managers, environmental benefits and hazards, and future standardization of products and application. Additionally, there is little available research on warm-season turfgrasses relative to cool-season. For an example, non-synthetic management may work better in warm-season turfgrass systems because many products are made of complex organic molecules that will decompose better with increased temperature. On the other hand, increased metabolism due to increased temperature may increase the vigor of competitive organisms. In order to determine these relationships and comparisons, more research is required. A compilation of past and current research with regards to non-synthetic products and practices will now be discussed.

Management of any crop requires inputs such as fertilizers and pesticides from time to time. Integrated pest management (IPM) is a method of pest control based on monitoring populations of particular pests over time and using various strategies to maintain pest levels below a predefined threshold, putting emphasis on the use of biocontrol agents. In organic and IPM, the interventions are planned and executed in a way that minimizes resources and reduces the impact on the environment while effectively controlling pests. However, these management strategies require creative solutions as well as alternative products which are not as numerous, commercially-available, or researched as in depth as those produced by large-scale chemical companies. In organic food production, the types of non-synthetic products used are regulated in the United States and other countries. However, these regulations and guidelines do not apply to turfgrass systems. There are many different intensities of management depending on the use of the turf, but all programs have the same areas of concern. These

areas may be broadly categorized as general growth and development, control of insects and arthropods, pathogens, nematodes, and weeds.

Insects and Arthropods

The demand for research into IPM and the continuing growth of urban areas has increased the demand for turfgrass entomologists (Potter and Braman, 1991). Biological control agents as alternatives to chemical pesticides have been a popular subject of study due to their selectivity, however, they have not been promoted as openly as chemical pesticides have for consumer use. An effort to control a broad spectrum of mole cricket (Orthoptera: Gryllotalpidae) species has led to discovery and use of tachinid flies (*Ormia depleta*), steinernematid nematodes (*Steinernema scapterisci*), and sphecid wasps (*Larra bicolor*) as biopesticides (Frank and Parkman, 1999). Entomopathogenic nematodes have greater abundance in less intensively managed areas of turf such as fairways and rough areas relative to putting greens (Alumai et al., 2006). Parasitic wasps are abundant and diverse, and inhabit turf in residential areas. Certain wasp genuses show preference of particular turfgrass species (Joseph and Braman, 2011). Synergism against various carabid species (particularly third instar white grubs) has been observed in turfgrass between the use of imidocloprid and the entomopathic nematode *Heterorhabditis bacteriophora* (P.) (Koppenhöfer and Kaya, 1998). Additionally, prolonged exposure to imidocloprid had no negative effect on the entomopathic nematodes (Koppenhöfer and Kaya, 1998). Although research into biocontrols has revealed many preventative solutions, there is still a need for more immediate curative measures in the event of pest outbreaks.

Pathogens

Researchers have found that when compost was sterilized of biotic factors, a loss of disease suppression was observed, which points to biological and biochemical attributes as the source of composts suppressive benefits (Noble, 2011; Noble and Coventry, 2005). Although it has been used to build soil structure and add nutrients extensively, compost has not been as widely accepted for disease suppression. Other biological controls are popular among managers at present, however most of these products are for greenhouse and other horticultural uses.

Fungicides

The utility of composts has potential for suppressing disease, reducing fungicide inputs, and slowing the resistance of pathogens to fungicide (Boulter et al., 2000). The efficacy of compost to suppress disease is comparably similar to the effects of fungicide control (Nelson and Craft, 1992). Composts can also be stored for a year and reliably retain its disease suppressing properties (Boulter et al., 2002a). *Aspergillus spp.* were found to have high activity in compost and have potential as bacterial biological control agents against fungus (Suarez-Estrella et al., 2007). The proteolytic activity of bacteria is suspect as a suppressive mechanism. Bacteria isolates from composts are primarily Gram-negative and have antagonistic activity on common turfgrass pathogens (Boulter et al., 2002b).

In studies conducted by Noble and Coventry (2005), many turf diseases including Fusarium patch (*Fusarium oxysporum* and *Verticillium dahliae*), red thread (*Laetisaria fuciformis*), damping off (*Pythium graminicola*), brown patch (*Rhizoctonia solani*), dollar spot (*Sclerotinia homoeocarpa*), and snow mould (*Typhula ishikariensis*) were successfully suppressed by use of compost topdressing (Noble and Coventry, 2005).

Other diseases including wilts (*Fusarium oxysporum* and *Verticillium dahliae*) and root rots (*Pythium ultimum*, *Rhizoctonia solani*, *Phytophthora spp.*) were suppressed in containers under greenhouse conditions (Noble and Coventry, 2005). They also found that application rate has a direct relationship to the level of disease suppression (Noble and Coventry, 2005). Media used for pot studies included at least 20% compost to have a significant suppressive effect (Noble and Coventry, 2005).

Nematicides

Although plant-parasitic nematodes can pose a serious threat to root systems of turfgrass, little research has been conducted in this area, and there are fewer products available for control relative to insecticides and fungicides. In general, non-synthetic programs either promote habitat or inoculate the soil with beneficial nematodes so that plant-parasitic nematodes are kept in check. The *Actinomycetes*, *B. subtilis*, and *B. thuringiensis* has been shown to be an effective biological control against turf parasitizing nematodes and contribute to the health of the soil, and can be found in composts and municipal solid waste. Inoculation with *B. subtilis* decreased the number of soil nematodes from 423 individuals per 100 g soil in the control group to 148 individuals per 100 g soil (Zhao et al., 2013). Additionally, inoculation of *actinomycetes* and *B. thuringiensis* shifted the dominance of soil nematodes from the herbivores to the bacteriovores and fungivores.

Weeds

Some popular practices exist to manage and suppress weed populations in established turf stands such as using a taller mowing height or a high rate of fertilization. Certain methods of turfgrass management without the use of pesticides can impact the

prevalence of weeds (Larsen et al., 2004). The use of adapted cultivars can reduce or eliminate the input of herbicide (Busey, 2003). Ocean water has been shown to effectively control various species of weeds including broadleaf species in cultivated seashore paspalum (*Paspalum vaginatum*) and bermudagrass (*Cynodon dactylon*) (Zulkaliph et al., 2011; Wiecko, 2003). Mulch made from maple leaves can be used to control common dandelions (*Taraxacum officinale* W.) in established turfgrass stands via allelopathic action (Kowalewski et al., 2010). When applied to the detached leaves of dandelion, the essential oils of summer savory (*Satureja hortensis*), red thyme (*Thymus vulgaris*), cinnamon (*Cinnamomum zeylanicum*), and clove (*Syzygium aromaticum*) were found to have the most phytotoxicity of 25 different plant oils, and eugenol was identified as the active ingredient in cinnamon essential oil (Tworkoski, 2009).

Corn gluten meal (CGM) is a byproduct of wet milling corn grain, and has been a popular organic option for preemergence weed control. When applied one week before crabgrass (*Digitaria spp.*) germination, 594 g/ m² of CGM reduced infestation by 93% (Christians, 1993). Five dipeptides were found in CGM that inhibited root growth of newly germinated seedlings: alaninyl-alanine, alaninyl-asparagine, alaninyl-glutamine, glutaminyl-glutamine, and glyciny-alanine (Liu et al., 1994). Although these studies have shown an impact on weed populations, others have observed that this effect is not different from the use of other fertilizers and is most likely caused by increased competition spurred by fertilization (St. John and DeMuro, 2013).

General growth and development

Fertilizers

Nutrients and water are often the most limiting factors to turfgrass growth, and the aim of sustainable turfgrass management is to administer these resources as wisely and conscientiously as possible. Therefore, efficient nutrient acquisition and utilization are of utmost importance. Various organic products and best management practices have been tested to replace chemical fertilizers in turfgrasses. Organic fertilizers show a wide range of effectiveness in maintaining turf quality (Garling and Boehm, 2001; Gardner, 2004). Applications of composts are thought to provide various benefits to plants including fertility, disease suppression, and plant-parasitic nematode protection by increasing the soil biodiversity (Ingham, 2005). Higher application rates are often needed for organic fertilizers because their release rates may be slower than those of synthetic ones, and many need favorable soil conditions and microbial activity for their breakdown (Trenholm and Unruh, 2005; Tester et al., 1982; Landschoot and Waddington, 1987). Liquid fertilizer produced through composting and biofiltering of animal waste, known as “slurry composted and biofiltered” (SCB) liquid fertilizer applied four times during the growing season and dormant applications produced high turf quality and growth (Park et al., 2012). Dissolved organic matter (DOM) from organic fertilizers/amendments facilitates movement of organic chemicals through soils. Studies suggest that these materials might lead to enhanced transport of applied chemicals in turf soils (Li et al., 2005). The effectiveness of hydrolyzed squid waste as an organic fertilizer was evaluated on perennial ryegrass (Fetter et al., 2013). Application of squid hydrolysate provided

consistently higher quality, uniform turf and significantly higher microbial activity rates, compared to synthetic fertilizer (Fetter et al., 2013).

Compost teas are broadly defined as dilute compost extracts, which can include many ingredients such as molasses, fish meal, kelp extract, etc., and can be “brewed” under different conditions (aerated/nonaerated) to influence the desired microbial inoculum it may contain (Shaban et al., 2015). It can also be considered as a type of DOM. Compost tea had negligible effects on turf quality, turf color, and weed encroachment when applied to tall fescue (*Festuca arundinacea*), however slight improvement was reported when nitrogen was supplemented indicating that compost tea could be too dilute in nutrients to utilize on its own (Chen, 2015). Under athletic field conditions with simulated traffic, the use of compost tea did not show any improvement of turfgrass quality, cover, color, or soil physical properties over a two year study (Miller and Henderson, 2012). Although research is scarce on this subject, it has been growing in popularity with professionals and homeowners due to its efficacy in infiltrating the turfgrass canopy and soil surface as well as being present as a relatively accessible, organic means of nutrient and disease management.

Amendments

Amendments refer to anything added to the soil in order to enhance its ability to support plant life. This can be composts, fertilizers, lime, etc. One of the problems in turfgrass management is the accumulation of organic matter in the thatch, which restricts permeability. Use of the lignolytic enzyme laccase proved to be an effective and non-disruptive method to reduce organic matter accumulation (Sidhu et al., 2012). Beyond the layer of thatch, amendments are used to build soil structure and provide

micronutrients. With an appropriate liquid foliar fertilizer, tank-mixing an organic amendment derived from naturally mined humic substances reduced the need for mowing while maintaining the quality of creeping bentgrass (*Agrostis stolonifera*) (Gao and Li, 2012). Roadsides tend to be relatively harsh environments for grasses, and they often don't survive the first year after planting, which leaves bare ground to erode or a niche for weeds to take over. Soil amendments made from a 1:1 blend of processed biosolids and composted yard waste were found to have greater efficacy on perennial grass survival on roadsides than utilizing more salt tolerant and genetically improved cultivars (Brown and Gorres, 2011).

Growth Regulators & Biostimulants

A plant growth regulator (PGR) can be natural or synthetic, which acts by causing changes in growth and development of plants. Plant physiology can be manipulated to effect growth of the leaves or roots, providing benefits in terms of mowing, turfgrass quality, and water management through the use of PGRs. The fungicide and PGR propiconazole provided better turf quality of shaded creeping bentgrass later in the growing season, however they reported that the addition of seaweed extract and humic acid did not improve shade tolerance further (Ervin et al., 2004). In the same study, trinexapac-ethyl provided more efficient photochemical activity by inducing darker leaf color and increased root strength, but addition of organic amendments did not contribute further except for periodic increases in color (Ervin et al., 2004). The use of gibberellic acid, a naturally occurring plant hormone, to inhibit endogenous plant growth regulators increased the tolerance of cool-season turfgrasses to shade by inhibiting elongating leaf growth (Fletcher et al., 2000).

Biostimulants are any substance or microorganism which is used on a crop to enhance nutrient absorption, stress tolerance, and other desirable attributes.

Biostimulants containing cytokinins derived from marine plants used for at least two years combined with a mowing height of 4.0 mm or greater and an increased N fertilization regime of 24 or 48 kg N/ha/week has shown promotion of root growth in ‘TifEagle’ bermudagrass compared to changes in mowing height and N fertilization without the addition of a biostimulant (Tucker et al., 2006). Some biostimulants such as yucca and seaweed extracts have surfactant properties that reduce localized dry spot (Mueller and Kussow, 2005). Acibenzolar-S-methyl (ASM), a compound that activates plants’ natural defenses against pathogenic bacteria and fungi, applied with biostimulants has the potential to reduce inputs to control dollar spot (*Sclerotinia homoeocarpa* B.) but has no effect on brown patch (*Rhizoctonia solani* K.) (Lee et al., 2003). Increased activity of the important antioxidant superoxide dismutase due to the application of humic acid and seaweed extract biostimulants contributed to overall plant health, which offers an opportunity to reduce fertilizer inputs (Zhang, 2003).

Conclusion

The growing popularity of non-synthetic management strategies in order to lessen long-term environmental impacts has created demand for research into products that can serve that need. These products vary widely, from plant hormones to sea water, and many of these are not formally labeled for use in agricultural systems. No legal restrictions exist for what non-synthetic products are allowed in organic turfgrass systems, unlike food production. The different expectations and needs that turfgrasses serve will likely influence any regulation in the future. More non-synthetic products will

rise out of ongoing research, and find places within the IPM and organic management programs of the future.

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Table 1.1. Examples of organic products and corresponding oral LD₅₀ values.

Material	Use	Oral LD ₅₀	Source
Compost	Fertilizer	--- ²	---
Milorganite®	Fertilizer	---	---
Rock Phosphate	Fertilizer	---	---
Corn Gluten Meal	Fertilizer	---	---
Fish Hydrolysate	Fertilizer	---	---
Molasses	Fertilizer	---	---
20% Acetic Acid	Fungicide/Herbicide/Insecticide	---	---
Neem Oil	Fungicide/Insecticide	>5000 mg/kg	Neem Concentrate MSDS ³
Diatomaceous Earth	Insecticide	---	---
Hydrogen Peroxide	Fungicide	1193 mg/kg	Oxiphos® MSDS ⁴
d-Limonene Oil	Herbicide	>5000 mg/kg	Avenger® Weed Killer Concentrate MSDS ⁵
Cinnamon/Clove Oil	Herbicide	---	---
<i>Bacillus subtilis</i>	Fungicide	>5000 mg/kg	Rhapsody® MSDS ⁶
<i>Bt</i> ¹ toxin	Insecticide	7.2E+10 CFU/kg	Monterey B.t. MSDS ⁷

¹ *Bacillus thuringiensis*

² (---) denotes no information found

³ Green Light®

⁴ BioSafe Systems, LLC.

⁵ Cutting Edge Formulations, Inc.

⁶ Bayer Environmental Science

⁷ Lawn and Garden Products, Inc.

Table 1.2. Examples of conventional products and corresponding oral LD₅₀ values.

Material	Use	Oral LD ₅₀	Source
Urea 46-0-0	Fertilizer	14,300 mg/kg	Urea, Granular 46-0-0 MSDS ²
Triple Superphosphate	Fertilizer	1530 mg/kg	Triple Superphosphate MSDS ³
Muriate of Potash	Fertilizer	3000 mg/kg	Muriate of Potash MSDS ⁴
Micronutrient	Fertilizer	---	---
Boscalid	Fungicide	>2000 mg/kg	Emerald® MSDS ⁵
Chlorothalonil	Fungicide	>5000 mg/kg	DaconilUltrax® MSDS ⁶
Pyraclostrobin	Fungicide	>2000 mg/kg	Insignia®MSDS ⁵
Glyphosate	Herbicide	>5000 mg/kg	Roundup PRO® Concentrate Herbicide MSDS ⁷
Glufosinate	Herbicide	3570 mg/kg	Finale®Herbicide MSDS ⁸
MSMA	Herbicide	1738 mg/kg	MSMA 6 PLUS® MSDS ⁹
Atrazine	Herbicide	>5000 mg/kg	AATREX® 4L MSDS ⁶
Carbaryl	Insecticide	699 mg/kg	SEVIN® SL Carbaryl Insecticide MSDS ⁸
Chlorpyrifos	Insecticide	519 mg/kg	DURSBAN™ WG Insecticide MSDS ¹⁰
Bifenthrin	Insecticide	632 mg/kg	Talstar® Professional Insecticide MSDS ¹¹

¹ (---) denotes no information found

² Agrium US Inc.

³ Koch Fertilizers Ltd.

⁴ Mosaic USA

⁵ BASF Corp.

⁶ Syngenta Crop Protection, Inc.

⁷ Monsanto Co.

⁸ Bayer Environmental Science

⁹ Loveland Products, Inc.

¹⁰ Dow AgroSciences Ltd.

¹¹ FMC Corp.

CHAPTER 2
SURVEY OF VARIOUS ORGANIC HERBICIDES FOR THE POSTEMERGENT
CONTROL OF LARGE CRABGRASS¹

¹Babb-Hartman, M.E., G.M. Henry, M.Y. Habteselassie, and F.C. Waltz, Jr. To be submitted to *Weed Technology*.

Abstract

The objective of this research were to evaluate the efficacy of organic products for postemergence weed control in turfgrass. Greenhouse experiments were conducted in Athens, GA during the spring/summer of 2015. Large crabgrass [*Digitaria sanguinalis* (L.) Scop.] was seeded in containers. The main factor was large crabgrass growth stage (1-2 leaf, 1-2 tiller, and 3+ tiller) and the sub-factor was treatment. Treatments included Avenger, Espoma corn gluten meal, WeedZap, WeedPharm, and Scythe. Roundup PRO Max and Finale, were included as industry standard comparisons. Visual ratings of % large crabgrass control were recorded on a scale of 0 (no control) to 100% (complete control). Above-ground biomass was harvested 1 and 2 months after treatment, dried, and weighed. Data were subjected to ANOVA and means were separated using Tukey's HSD test at the 0.05 significance level. Field trials were established in fall 2015 and seeded with large crabgrass in Griffin, GA. The main factor was application timing (single or sequential) and the sub-factor was treatment. Applications were made at the 1-2 tiller stage, and half the plot received a single treatment, while the other half received sequential treatments applied two weeks apart. The same treatments were examined as described in the greenhouse trial except for corn gluten meal. Visual ratings of % large crabgrass cover were recorded. Statistics were analyzed by 2-way ANOVA, and means were separated using Tukey's HSD test at the 0.05 significance level. In the greenhouse trials, Finale, Roundup PRO Max, and Scythe maintained significantly higher injury than other treatments from 7 DAT to 56 DAT. In the field trial, Finale, Roundup PRO Max, Avenger, and Scythe led in significant injury levels from 7 DAIT to 56 DAIT with 99.4, 97.5, 87.5, and 78.8 % injury, respectively, at 7 DAIT. There was no significant

difference between applying one treatment and two sequential treatments. Avenger and Scythe are the best options from those tested for organic/nonsynthetic control of large crabgrass in warm-season turfgrass systems.

Introduction

The most challenging problem for managers of any crop, turfgrasses included, is weed control. Professionals seeking alternative management practices such as organics find it especially problematic. The terms organic and nonsynthetic here refer to the use of materials of plant or animal origin, without use of chemically formulated substances, and/or materials approved for use in organic agriculture by the Organic Materials Review Institute (OMRI) (Organic Foods Production Act, 1990). Conventional herbicides are typically chemically synthesized and are generally preferred by contemporary managers. In 2007, over 5,800 million dollars were spent on 531 million pounds of conventional herbicides in the U.S., which made up 25% of the world herbicide market (Grube et al., 2011). Organic food production has been gaining momentum over the past few decades, but organic turfgrass management has more recently been a topic of interest among professionals and homeowners. The U.S. Department of Agriculture (USDA) regulates organically grown foodstuffs through the National Organic Program (NOP), however no U.S. government-enforced standards are in place for what constitutes organic lawns, fields, or other green spaces. It is important to note that some local entities have implemented pesticide bans on and around playgrounds and athletic fields out of concern of exposure to and toxicological effects on children (Legislative Assembly of Nova Scotia, 2010; Legislative Assembly of Ontario, 2009; Connecticut General Assembly, 2009; New York State Department of Environmental Conservation, 2010). As weed

control is more often many consumers' reason to make chemical applications, the adoption of more holistic approaches to weed management in turf can satisfy demand for more ecological sustainability and consumer perception of health and safety.

Without the use of conventional herbicides, organic managers are severely limited in control options. This is particularly true in turf management for a couple of reasons. First, little research has been done since it is not a food or fiber commodity. However, the amount of area under turfgrasses is estimated to be greater than 40 million km², which is over three times the area of any other irrigated crop in the U.S. (Milesi et al., 2005). The second reason is that turf is a no-till system. Consequentially, this excludes many methods of control that organic farmers rely on such as plowing and crop rotation. Less published research exists pertaining to this issue in warm-season turfgrasses relative to cool-season species. Considering the warmer climate of the southern U.S., this knowledge gap potentially affects a large portion of people seeking information on alternative weed control methods.

Some popular practices exist to manage and suppress weed populations in established turf stands such as using a higher mowing height or an increased rate of fertilization. Certain methods of turfgrass management without the use of pesticides can impact the prevalence of weeds (Larsen et al., 2004). The use of adapted cultivars can reduce or eliminate the input of herbicides by increasing tolerance to environmental stresses and predation (Busey, 2003). Many organic methods serve to prevent weeds from establishing by encouraging healthy, vigorous turf stands that will outcompete the weeds, however some curative options have been researched.

The OMRI list is a compilation of products approved for use in organic agriculture in compliance with the NOP regulations, some of which are labeled for use in turfgrass. Examples of popular products on the market are 10-25% acetic acid (vinegar) and, although it is not OMRI listed, pelargonic acid (C9, nonanoic acid) is naturally occurring but is usually synthesized for herbicidal use (Dayan and Duke, 2010).

Ocean water has been shown to effectively control various species of weeds including broadleaves in the warm-season species seashore paspalum (*Paspalum vaginatum* Sw.) and bermudagrass [*Cynodon dactylon* (L.) Pers x *C. tranvaalensis* Burt-Davey] (Zulkaliph et al., 2011; Wiecko, 2003). Some allelopathic materials also have been investigated. Mulch made from maple and oak leaves can be used to control common dandelions (*Taraxacum officinale* W.) in established cool-season turfgrass stands (Kowalewski et al., 2010, Kowalewski et al., 2009). Mulches bought from a manufacturer or made from local leaves or pine needles could be useful.

Plant oils have been a popular topic of research because they are more easily used by consumers via conventional spray methods. Many have been labeled for use in horticultural crops including cinnamon, clove, pine, citrus, lemongrass, peppermint, and citronella (Dayan and Duke, 2010). When applied to the detached leaves of dandelion, the essential oils of summer savory (*Satureja hortensis* L.), red thyme (*Thymus vulgaris* L.), cinnamon (*Cinnamomum zeylanicum*), and clove (*Syzgium aromaticum* L.) were found to have the most phytotoxicity of 25 different plant oils, and eugenol was identified as the active ingredient in cinnamon essential oil (Tworkoski, 2009). While many of these oils damage weeds by nonselectively destroying leaf cells, one plant oil has been investigated for its preemergent, systemic herbicidal properties. Manuka oil's primary

component is leptospermone, and is rich in β -triketones which have the same target site as mesotrione herbicide (Dayan et al., 2007). It also has some soil persistence, which could offer a characteristic severely lacking among other organic herbicides (Dayan et al., 2011).

Corn gluten meal (CGM) is a byproduct of wet milling corn grain, and has been a popular organic option for preemergence weed control. Previous research has found that when applied in the spring two to four weeks before the germination of summer annuals, a rate of 97.6 kg per m² CGM will provide control of crabgrass in cool-season turfgrasses (Christians, 2002). When applied one week before crabgrass (*Digitaria spp.*) germination, 594.0 g per m² of CGM reduced infestation by 93% (Christians, 1993). Five dipeptides were found in CGM that inhibit root growth of newly germinated seedlings: alaninyl-alanine, alaninyl-asparagine, alaninyl-glutamine, glutaminyl-glutamine, and glyciny-alanine (Liu et al., 1994). Although the inhibitory components of the CGM persist up to six weeks after application, a cumulative effect of weed control has been observed over a three month period likely due to a more vigorous stand from the nitrogen applications and reduced weed seed bank (Christians, 2002). Although these studies have revealed an impact on weed populations, other cool-season turf experiments have shown that this effect is not different from the use of other fertilizers including milorganite and urea, and is most likely caused by increased competition spurred by fertilization (St. John and DeMuro, 2013). These findings are explained by the fact that CGM contains around 10% nitrogen, and although it is mostly marketed as a preemergence herbicide, some companies have included postemergence recommendations with their CGM product (Christians, 2002).

The objectives of this research were to (i) evaluate commercially-available organic herbicides, (ii) compare organic products against industry standards, (iii) determine efficacy of products and potential weed control programs.

Materials and Methods

Greenhouse Study

Experiments were conducted at the Crop and Soil Sciences greenhouse complex (33°55'51"N, 83°21'45"W) in Athens, GA during the spring/summer of 2015. Large crabgrass [*Digitaria sanguinalis* (L.) Scop. (Azlin Seed Service, Leland, MS)] was seeded at 1.12 kg ha⁻¹ into pots (15.24 cm diameter) containing a steamed Appling sandy loam (Fine, kaolinitic, thermic, Typic Kanhapludult) soil on 6 May 2015 in two separate greenhouses to account for experiment repetition. Approximately 3.8 cm of water wk⁻¹ was delivered to pots by hand. Large crabgrass plants were allowed to mature in the greenhouse for 1 wk for 1-2 leaves, 2 for 1-2 tillers, and 3 wk for 3+ tillers maturity levels. Natural light was supplemented with artificial light (metal halide) at 500 μmol m⁻² s⁻¹ photosynthetic photon flux (measured at the canopy) in a 12-h day to approximate summer light intensity and photoperiod. Conditions in the climate-controlled greenhouse were maintained at day/night temperatures of 33/29 and 29/24 °C. Large crabgrass plants were thinned to ten plants per pot in order to replicate a natural weed infestation and increase trial uniformity. Pots were mowed once a week up to single application using hand-held grass shearers to a height of 2.5 cm to simulate conditions present on a home lawn, athletic field, or golf course rough. Large crabgrass clippings were not returned to the canopy. Weed cover reached 100% for each pot prior to trial initiation and plants were mowed to a 2.5-cm height just prior to herbicide treatment. No irrigation was

applied during the 24-h period after herbicide treatment. Irrigation was applied by hand to deliver 3.8 cm of water wk^{-1} thereafter. Pots were only mowed after application to collect clippings to a 2.5 cm height at 28 and 56 DAT.

Pots received a single treatment at 0 DAT. Treatments included d-limonene oil [Avenger®, Avenger Organics, LLC.], corn gluten meal [Espoma®, The Espoma Co.], cinnamon/clove oil [WeedZap®, SaferGro Laboratories, Inc.], 20% acetic acid [WeedPharm, Pharm Solutions, Inc.], and pelargonic acid [Scythe®, DOW Agrosciences]. Non-selective treatments, glyphosate [Roundup PROMAX®, Monsanto Co.] and glufosinate [Finale®, Bayer Environmental Science], were included as industry standard comparisons. Liquid treatments were applied with a CO_2 backpack sprayer equipped with XR8004VS nozzles calibrated to deliver 375 L ha^{-1} at 221 kPa. Tank mixes were as follows: d-limonene oil 167 mL/L, cinnamon/clove oil 50 mL/L, acetic acid 1000 mL (RTU, not diluted in tank mix), pelargonic acid 70 mL/L, glyphosate 10 mL/L, and glufosinate 32 mL/L. Corn gluten meal was applied by hand with a shaker jar to the crabgrass canopy at a rate of 97.6 g/m^2 . Applications were made at three growth stages: 1-2 leaf (date), 1-2 tillers (date), and 3+ tillers (date).

Visual ratings of percent large crabgrass injury were recorded by the same researcher 1, 7, 14, 28, and 56 DAT on a scale of 0 (no injury) to 100% (completely dead). Following treatment, crabgrass was allowed to grow without mowing until harvest. Above-ground biomass was harvested 28 and 56 days after treatment (DAT) where aboveground biomass was hand-clipped down to 2.5 cm height and placed in paper bags. Clippings were oven dried at 60°C for 4 days, and weighed (g) without paper bag.

Pots were arranged in a 3 x 7 factorial with four replications. The main factor was large crabgrass growth stage and the sub-factor was treatment. Percent large crabgrass control and above-ground biomass were subjected to 2-way ANOVA using error partitioning appropriate to a split block analysis in the general linear models procedure. Means were separated using Tukey's HSD test at the 0.05 significance level.

Field Study

Plots were established during September of 2015 on the University of Georgia Griffin campus (33°15'41"N, 84°16'55"W). Plot area was cleared of all vegetation using Roundup and scalped with a rotary mower 2 wk prior to seeding with large crabgrass seed. Field plots (1.5 x 1.5 m) were seeded into Cecil sandy loam (fine, kaolinitic, thermic, Typic Kanhapludult) with large crabgrass at a rate of 2.24 kg ha⁻¹ on 2 September 2015. The site was maintained at a 3.81 cm height with a rotary mower throughout the trial duration. This field trial was conducted over the course of two months rather than a typically longer period because the results from the greenhouse study warranted a field comparison of a similar time frame.

Initial application for the sequential and the single were made at the 1-2 tiller stage on 18 September 2015, and the sequential application for half of the plots was made at 6 October 2015. Half the plots received a single treatment, while the other half received sequential treatments applied two weeks apart. The same treatments were examined as described in the greenhouse trial except for Espoma CGM. The CGM product was excluded due to the lack of effective results in the greenhouse study.

Visual ratings of percent large crabgrass control and percent cover were recorded 0, 14, 28, and 56 days after initial treatment (DAIT) by the same researcher. Percent large crabgrass cover was determined using a 1 x 1 m grid with 25 intersecting points that was randomly placed into each plot (Hephner et al., 2012).

Plots were arranged in a 2 x 6 factorial within a randomized complete block design with four replications. This trial was not repeated. The main factor was application timing (single or sequential) and the sub-factor was treatment. Statistics were analyzed by 2-way ANOVA in JMP software, and means were separated using Tukey's HSD test at the 0.05 significance level.

Results

Greenhouse Study

The ANOVA for percent injury and biomass from incremental harvests are presented in Table 2.1. A significant treatment effect was observed at every rating date for percent injury, as well as biomass at both harvests. Growth stage had significant effects at all DAT. Growth stage also had significant effects on biomass at both harvests. Significant interactions between treatments and growth stage at all DAT warranted additional analyses for mean separation of treatments within growth stage.

At the 1-2 leaf stage in Table 2.2, Scythe provided comparable performance to Roundup, except additional phytotoxic injury on 1 DAT. Avenger, Scythe, and WeedPharm had higher injury which was comparable to Roundup and Finale, at all DAT than other treatments.

At the 1-2 tiller stage in Table 2.3, Scythe and WeedPharm had significantly higher injury than other treatments at 1 DAT. Through 7 to 28 DAT, Scythe, Avenger, and WeedPharm injury was not significantly different.

At the 3+ tiller stage in Table 2.4, the organic treatments (except for the CGM) were significantly different from the NTC on 7 and 28 DAT. Scythe, Avenger, and WeedPharm were also significantly different from the NTC on 21 DAT. CGM did not injure crabgrass at any growth stage or evaluation date in this study.

For all growth stages, biomass was significantly higher for CGM than all other treatments at 28 DAT, followed by the control. WeedZap was no different from the NTC for all growth stages. Scythe, Avenger, and WeedPharm provided significantly less biomass than the NTC at the 1-2 leaf stage (Table 2.2). Scythe had significantly less biomass than the NTC at 1-2 tiller stage (Table 2.3).

Field Study

Results from the ANOVA of percent injury and percent weed cover can be seen in Tables 2.5 and 2.6, respectively. Treatment had a significant effect on injury at every DAIT. Application had a significant effect on injury at 15, 21, and 28 DAIT. Treatment had a significant effect on weed cover at 14 and 28. Application had a significant effect on weed cover at 28 DAIT. There were not enough degrees of freedom to test for interactions.

The mean separation for percent injury by treatment seen in Table 2.7 shows that at 1 DAIT, Avenger and WeedPharm provided significantly higher injury than all other

treatments. At 7 DAIT, Scythe provided injury significantly different from the NTC, but not from any other treatment. Also, Finale, Avenger, Roundup Pro Max, and WeedPharm provided significantly higher injury than other treatments. At 14 DAIT, Scythe, Avenger, and WeedPharm were significantly different from the NTC. Following the sequential treatment (15- 28 DAIT), Avenger and Scythe provided injury which was not significantly different from Finale and Roundup. WeedZap and WeedPharm provided significant injury relative to the NTC. The mean separation for percent injury by application in Table 2.8 shows that following the second application made on 14 DAIT, single and sequential applications were significantly different through 28 DAIT.

The mean separation for percent weed cover by treatment in Table 2.9 shows that Roundup Pro Max and Finale resulted in significantly less crabgrass cover than all other treatments throughout the study. WeedZap and WeedPharm had weed cover that was not significantly different than the NTC on all DAIT. At 14 DAIT, weed cover following Avenger provided significantly reduced crabgrass cover from NTC, but was not significantly different from Scythe and WeedPharm. At 28 DAIT, Scythe and Avenger provided significantly reduced weed cover compared with the NTC, but were not significantly different from WeedPharm. The mean separation for percent weed cover by application in Table 2.10 shows that following the second application made on 14 DAIT, single and sequential applications were significantly different through 28 DAIT.

Discussion

The greenhouse study showed that the treatments and the growth stage at which the herbicides were applied had significant effects on the crabgrass in terms of both

herbicidal injury and biomass. Growth stage had more of an effect after 1 DAT because most of the herbicides require more than 24 hours to cause noticeable damage. Plants treated with Scythe showed evidence of “burn” within 24 hours of application. However by 7 DAT, Roundup Pro Max, Finale, and Scythe caused the most phytotoxicity and least biomass. This result was as expected as Roundup Pro Max and Finale are long-standing, reliable industry standards. Scythe has been widely used by professionals as well, but it is an intermediate between conventional and organic products and the active ingredient in Scythe, pelargonic acid, is naturally occurring in plants, but is produced in large quantities by typical manufacturing processes.

Avenger performed consistently better than the other OMRI listed products providing the most injury and least biomass among the organic treatments. WeedPharm performed better than the WeedZap, likely because it causes noticeable initial phytotoxicity. However, decreases in injury after application indicate recovery. Plants treated with WeedPharm tend to recover over a shorter period of time than Scythe and Finale. WeedZap did not perform as well as Avenger and WeedPharm, but still showed an effect in terms of both injury and reduction of biomass relative to the control and CGM. Differences that decrease over time between treatments at all growth stages can be attributed to plant recovery and regrowth. This trend is exacerbated by the maturity of the 3+ tiller growth stage, where the robust plants are not as affected by tissue damage and/or recover faster than the younger plants. This pattern indicates that repeated applications may be necessary to prevent weed recovery.

No injury was observed from treatment with CGM as well as higher biomass than the control. These findings support the conclusions of St. John and Demuro (2013), who attributed supposed postemergence weed control to a fertility effect which allowed the turfgrass to outcompete the weeds. For these reasons it was excluded from the field trial.

The results of the field study reflected similar findings as the greenhouse study. In addition to the treatment effect, application had a significant effect on injury which decreased through the time period much like the treatment effect. Application also had a significant effect on weed cover which increased through the course of the study, which was due to the sequential application. WeedPharm performed better than in the greenhouse trial, causing as much injury at 1 DAT as Avenger, which could be attributed to direct exposure to sunlight and heat aiding in the phytotoxic burn, in which case the product works better under warmer conditions than cool. However on all DAT, WeedZap and WeedPharm resulted in similar weed cover to the control, which supports previous observations of recovery. The decrease in differences as the study continued can also be attributed to a pattern of recovery. For both injury and weed cover, sequential applications and a single application were significantly different following the second application made 14 DAIT. This difference explains Scythe, Avenger, and WeedPharm reduced weed cover relative to the NTC at 28 DAT, supporting previous evidence in favor of making repeat applications.

Conclusion

Organic herbicides have potential to provide control for warm-season turfgrass weeds, particularly products with the active ingredients d-limonene such as Avenger, or acetic acid like WeedPharm. Scythe is an effective middle ground for consumers not strictly seeking nonsynthetic alternatives. Regardless of growth stage, repeat applications are necessary in an organic program, although the herbicides are more effective at younger growth stages. Previously reported postemergent weed control with CGM is likely due to a fertility effect that allowed the turfgrass to outcompete weeds.

These products are non-selective, meaning that they will cause tissue damage to any leaves it comes in contact with, ergo these products would best be utilized as a spot spray to preserve the aesthetic value of lawns, fields, and other warm-season turfgrasses especially since the heat can exacerbate phytotoxicity. In areas where warm-season turfgrasses go dormant in the winter, these products may be sprayed to control cool-season weeds in the spring and fall. The organic treatments and Finale were contact herbicides whereas Roundup is systemic, therefore repeat applications may be required in the event that foliar damage is not enough to kill the whole plant. Given that large crabgrass is an annual weed and plants will not persist from season to season, control of perennials may also require repeat applications to ensure that the regular disruption of cell membranes is fatal.

Future research should center around new products and effective programs for practical use by homeowners and professionals. New products should be investigated as they are developed, with an emphasis on new, more selective modes of action in organic

products that would be effective in warm-season turfgrasses. Due to the lack of commercially-available preemergence organic herbicides, searching for products that could fulfill this need is also a priority. Further study of effective programs in warm-season conditions will aid professionals in customizing programs in the future where organic programs may become more popular in the southeastern U.S. Lastly, studies should be conducted on warm-season weed species other than large crabgrass to test efficacy, such as various broadleaves. These topics would greatly add to the utilization of the commercially-available products investigated here, as well as aid in the placement of these products in organic and IPM programs.

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Table 2.1. Analysis of variance (ANOVA) for greenhouse study.

Source ¹	DF	Herbicide Injury (0-100%)					Aboveground Biomass (g)	
		1DAT ²	7DAT	14DAT	21DAT	28DAT	28DAT	
Treatment	7	*** ³	***	***	***	***	***	
Growth Stage	2	**	***	***	***	***	**	
Treatment*Growth Stage	14	***	***	***	***	***	***	

¹Source – 2 Way ANOVA

²DAT denotes days after treatment.

³P values – NS, *, **, and *** denote not significantly different, significantly different at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

Table 2.2. Mean separation¹ for greenhouse study for 1 to 2 leaves growth stage.

Treatment	Herbicide Injury (0- 100%)					Aboveground Biomass (g)
	1DAT ²	7DAT	14DAT	21DAT	28DAT	28DAT
Non-Treated	0.0 d ³	0.0 d	0.0 d	0.0 d	0.0 d	2.6 b
Finale	68.5 ab	83.5 a	85.0 a	85.0 a	80.0 a	0.7 d
Scythe	95.5 a	93.5 a	92.0 a	90.0 a	83.5 a	0.2 d
Avenger	76.0 ab	72.0 ab	76.0 ab	71.5 ab	65.0 ab	1.0 cd
WeedZap	41.0 bc	36.0 c	34.0 c	31.0 c	32.0 c	2.1 bc
Roundup Pro Max	22.0 cd	95.5 a	96.0 a	93.0 a	87.5 a	0.5 d
WeedPharm	48.5 bc	52.0 bc	53.0 bc	50.0 bc	51.5 bc	1.1 cd
Corn Gluten Meal	0.0 d	0.0 d	0.0 d	0.0 d	0.0 d	4.8 a

¹Source – Tukey’s HSD mean separation test

²DAT denotes days after treatment.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 2.3. Mean separation¹ for greenhouse study for 1 to 2 tillers growth stage.

Treatment	Herbicide Injury (0-100%)					Aboveground Biomass (g)
	1DAT ²	7DAT	14DAT	21DAT	28DAT	28DAT
Non-Treated	0.0 c ³	0.0 d	0.0 c	0.0 d	0.0 c	2.4 b
Finale	19.0 c	95.5 a	98.0 a	99.0 a	99.0 a	0.0 d
Scythe	90.0 a	51.5 b	51.0 b	46.5 b	46.0 b	1.0 cd
Avenger	53.0 b	41.5 bc	38.5 b	38.5 bc	46.5 b	1.5 bc
WeedZap	53.0 b	22.0 cd	14.0 c	18.5 cd	27.5 b	1.8 bc
Roundup Pro Max	12.5 c	82.0 a	94.5 a	95.5 a	96.5 a	0.0 d
WeedPharm	73.0 a	37.0 bc	39.0 b	38.5 bc	36.0 b	1.4 bc
Corn Gluten Meal	0.0 c	0.0 d	0.0 c	0.0 d	0.0 c	5.6 a

¹Source – Tukey’s HSD mean separation test

²DAT denotes days after treatment.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 2.4. Mean separation¹ for greenhouse study for 3+ tillers growth stage.

Treatment	Herbicide Injury (0-100%)					Aboveground Biomass (g)
	1DAT ²	7DAT	14DAT	21DAT	28DAT	28DAT
Non-Treated	0.0 a ³	0.0 d	0.0 a	0.0 d	0.0 d	1.1 b
Finale	38.5 a	92.0 a	97.0 a	100.0 a	100.0 a	0.1 c
Scythe	63.0 a	30.5 c	12.5 a	12.0 c	8.5 c	1.0 b
Avenger	62.0 a	31.0 c	22.5 a	15.5 c	12.0 c	0.9 b
WeedZap	34.0 a	20.5 c	13.0 a	7.5 cd	9.0 c	1.0 b
Roundup Pro Max	10.0 a	74.0 b	81.5 a	89.5 b	93.5 b	0.0 c
WeedPharm	59.0 a	29.0 c	13.5 a	12.0 c	9.0 c	1.1 b
Corn Gluten Meal	0.0 a	0.0 d	0.0 a	0.0 d	0.0 d	4.8 a

¹Source – Tukey’s HSD mean separation test

²DAT denotes days after treatment.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 2.5. Analysis of variance (ANOVA) for herbicide injury (0-100%) in field study.

Source ¹	DF	1DAIT ²	7DAIT	14DAIT	15DAIT	21DAIT	28DAIT
Treatment	6	*** ³	***	***	***	***	***
Application	1	NS	NS	NS	***	*	*

¹Source – ANOVA

²DAIT denotes days after initial treatment.

³P values – NS, *, **, and *** denote not significantly different, significantly different at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

Table 2.6. Analysis of variance (ANOVA) for weed cover (0-100%) in field study.

Source ¹	DF	0DAIT ²	14DAIT	28DAIT
Treatment	6	NS ³	***	***
Application	1	NS	NS	**

¹Source – ANOVA

²DAIT denotes days after initial treatment.

³P values – NS, *, **, and *** denote not significantly different, significantly different at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

Table 2.7. Mean separation¹ for herbicide injury (0-100%) by treatment in field study.

Treatments	1DAIT ²	7DAIT	14DAIT	15DAIT	21DAIT	28DAIT
Non-Treated	3.8 c ³	3.3 c	2.3 c	0.0 d	0.0 d	0.0 d
Finale	8.1 c	97.5 a	98.1 a	100.0 a	97.5 a	97.5 a
Scythe	45.0 b	78.8 ab	67.5 b	87.5 ab	85.0 ab	82.5 ab
Avenger	91.3 a	87.5 a	85.0 ab	88.8 ab	86.3 ab	85.6 ab
WeedZap	22.5 bc	53.8 b	21.9 c	62.5 c	46.3 c	40.6 c
Roundup Pro Max	5.6 c	99.4 a	97.5 a	100.0 a	98.1 a	98.1 a
WeedPharm	92.5 a	80.6 a	67.5 b	77.5 bc	78.1 b	76.9 b

¹Source – Tukey’s HSD mean separation test

²DAIT denotes days after initial treatment.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 2.8. Mean separation¹ for herbicide injury (0-100%) by application program in field study.

Application	1DAIT ²	7DAIT	14DAIT	15DAIT	21DAIT	28DAIT
Single	42.1 a ³	74.9 a	65.1 a	64.5 b	65.7 b	64.7 b
Sequential	34.6 a	68.2 a	60.5 a	80.7 a	73.6 a	71.8 a

¹Source – Tukey’s HSD mean separation test

²DAIT denotes days after initial treatment.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 2.9. Mean separation¹ for weed cover (0-100%) by treatment in field study.

Treatment	0DAIT ²	14DAIT	28DAIT
Non-Treated	99.6 a ³	100.0 a	100.0 a
Finale	100.0 a	1.0 c	1.0 c
Scythe	98.0 a	76.0 ab	57.5 b
Avenger	100.0 a	66.0 b	55.0 b
WeedZap	99.5 a	100.0 a	100.0 a
Roundup Pro Max	100.0 a	0.0 c	1.0 c
WeedPharm	100.0 a	85.5 ab	71.0 ab

¹Source – Tukey’s HSD mean separation test

²DAIT denotes days after initial treatment.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 2.10. Mean separation¹ for weed cover (0-100%) by application program in field study.

Treatment	0DAIT ²	14DAIT	28DAIT
Single	99.2 a ³	62.6 a	68.5 a
Sequential	100.0 a	60.1 a	45.0 b

¹Source – Tukey’s HSD mean separation test

²DAT denotes days after treatment.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

CHAPTER THREE
SURVEY OF ORGANIC FUNGICIDES AND FUNGAL SUPPRESSORS FOR THE
CONTROL OF DOLLAR SPOT IN BERMUDAGRASS¹

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submitted to *Applied Turfgrass Science*.

Abstract

The objectives of this research were to evaluate the efficacy of organic fungicides and suppressants for the control of dollar spot in turfgrass. Field experiments were conducted in Johns Creek, GA and Albany, GA during 2014 and 2015 on bermudagrass. Treatments included Foothills compost, Progress Earth compost tea, Biowash fertilizer enhancer, Rhapsody and Companion *Bacillus subtilis* inoculants, Natural Guard neem oil, Zerotel 2.0, TerraCyte Pro, and Oxiphos. Additionally at the Johns Creek site, a proprietary vermicompost and vermicompost tea (Rivermont) were utilized. Emerald (boscalid) and 46-0-0 urea were included for comparison. Applications were made approximately every four weeks during the growing season. Visual ratings were taken before, two weeks, and four weeks after treatment, and consisted of three assessments: percent dollar spot coverage on a scale of 0 (no presence) to 100% (completely covered), turfgrass quality on a scale of 1 (dead) to 9 (ideal), and turfgrass color on a scale of 1 (brown) to 9 (dark green). Data were subjected to one-way ANOVA and means were separated using Tukey's HSD at $\alpha=0.05$. TerraCyte Pro provided more dollar spot control at 56 DAIT (days after initial treatment) than other treatments at the Albany site in 2014, and 14 DAIT at the Johns Creek site in 2015. TerraCyte Pro, Zerotel 2.0, and Oxiphos provided similar quality to urea and Emerald at 42 and 56 DAIT in 2014 at the Albany site. At the Johns Creek site in 2014, Foothills provided greater quality than urea at 70 and 140 DAIT. At the Albany site, Foothills and TerraCyte Pro provided color similar to urea at 56 DAIT in 2014, and Foothills at 14 DAIT and TerraCyte Pro at 98 DAIT in 2015. At the Johns Creek site, Foothills provided similar color to urea at 14 and 84 DAIT in 2014.

TerraCyte Pro and Foothills are the best options from those tested for the suppression/control of dollar spot in bermudagrass.

Introduction

Dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) is the most common fungal disease of turfgrass in North America with exception of the Pacific Northwest region (Couch, 1995). The temperature range and typical humidity of the Southeastern United States makes for an ideal environment for this disease presenting a challenge for managers of warm-season turf. Dollar spot presents on leaves as yellow to light green spots that progress to tan lesions across the grass blade (Smith, 1955). From an overview of the canopy, the distinctive yellowed, circular spots can be as small as a few leaves to the approximate size of a silver dollar (about 7.5 cm diameter), a trait which lends this disease its common name (Smith, 1955; Couch, 1995). Additionally, sometimes a dew presence will make the white, cobweb-like mycelia visible on the leaves (Smith, 1955). Dollar spot has the ability to overwinter in leaf lesions and in subsurface thatch, lending added persistence to this already ubiquitous disease (Couch, 1995; Smiley et al., 1992). In a study where *S. homoeocarpa* was cultured in lab on potato dextrose agar, minimum and maximum temperatures for growth were found to be 4.5 and 32°C, respectively, with an optimal growing temperature of 26.8°C (Endo, 1963). Another study found that this disease reaches optimal growth and pathogenicity at a temperature range of 21 to 27°C and atmospheric humidity of 85% (Couch, 1995).

Dollar spot can cause damage to many types of green spaces, leading to decreased playability, reduction of aesthetics, and creating a niche for weeds (Goodman and Burpee, 1991; Smith et al., 1989). With regards to golf courses, more money is

spent on dollar spot management than any other turf disease (Goodman and Burpee, 1991). Infected material can easily be transported and therefore lead to the unintentional spread of disease, such as on bottoms of shoes, vehicle tires, and maintenance equipment, making an integrated management plan a necessity for prevention and control (Smith, 1955). Another problematic aspect of this disease is its increasing resistance to a wide range of chemical fungicides in the U. S. (Cole et al., 1968; Detweiler et al., 1983; Nicholson et al., 1971; Golembiewski et al., 1995). Field populations of dollar spot vary from area to area (such as putting green to a fairway) depending on management strategies, are genetically distinct, and react dynamically to fungicide applications (Jo et al., 2008). A secondary effect of synthetic fungicide use is that it has negative effects on nontarget soil organisms, which may create a niche for pathogens (Smiley and Craven, 1979; Melzer and Boland, 1998).

Currently, the cultural controls utilized are centered around keeping leaf surfaces free of moisture, such as mowing in the morning, and removing overhanging limbs and shrubbery to increase sunlight and air circulation (Williams et al., 1996). A drought study done in a greenhouse setting found that moisture stress predisposes turf to disease, which poses a challenge for managers to keep adequate soil moisture during typical cycles of periodic drought experienced in the southern U.S. (Couch and Bloom, 1960). Preventative fungicide applications at 7 to 28 day intervals during ideal seasonal conditions for disease prevalence are suggested, as well as choosing a more resistant turfgrass cultivar (Kennelly, 2010). Applying supplemental nitrogen is also a method of disease suppression. This effect is attributed to the increased nitrogen causing the grass to grow at a faster rate, and the consequential mowing will remove infected tissue

particularly when conditions for fungal growth are less favorable (Cook et al., 1964; Markland et al., 1969; Couch, 1995).

The utility of composts has potential for suppressing disease, reducing fungicide inputs, and slowing the resistance of pathogens to fungicide (Boulter et al., 2000; Workman, 2012). Composts can also be stored for a year and reliably retain its disease suppressing properties (Boulter et al., 2002a). The efficacy of compost to suppress disease is comparably similar to the effects of fungicide control (Nelson and Craft, 1992). Researchers have found that when compost was sterilized of biotic factors, a loss of disease suppression was observed, which points to biological and biochemical attributes as the source of composts suppressive benefits (Noble, 2011; Noble and Coventry, 2005). *Aspergillus spp.* (Micheli) were found to have high activity in compost and have potential as bacterial biological control agents against fungus (Suarez-Estrella et al., 2007). The proteolytic activity of bacteria is suspect as a suppressive mechanism. Bacteria isolates from composts are primarily Gram-negative and have antagonistic activity on common turfgrass pathogens (Boulter et al., 2002b).

In studies conducted by Noble and Coventry (2005), many turf diseases including Fusarium patch (*Fusarium oxysporum* Schlect and *Verticillium dahlia* Kleb.), red thread (*Laetisaria fuciformis*), damping off (*Pythium graminicola* Subramaniam), brown patch (*Rhizoctonia solani* Kuhn), dollar spot, and snow mold (*Typhula ishikariensis* Imai) were successfully suppressed by use of compost topdressing (Noble and Coventry, 2005). Other diseases including wilts (*F. oxysporum* Schlect and *V. dahlia* Kleb.) and root rots (*Pythium ultimum* Trow, *R. solani* Kuhn, *Phytophthora* spp. De Bary) were suppressed in containers under greenhouse conditions (Noble and Coventry, 2005). They also found

that application rate has a direct relationship to the level of disease suppression, and the media used for pot studies included at least 20% compost to have a significant suppressive effect (Noble and Coventry, 2005). In a study on creeping bentgrass and annual bluegrass, topdressings were applied at 1 month and 2 month intervals, and found that the effective amendments suppressed dollar spot consistently at 1 month after application, however suppressive effect was lost by the 2 month after application point (Nelson and Craft, 1992). The extent of disease suppression was not consistent in many studies, which is attributed to natural variation in nutrient content and microbial community (Nelson and Craft, 1992). Although it has been used extensively to build soil structure and add nutrients, compost has not been widely accepted for disease suppression in turfgrasses despite its popularity in horticultural disease management.

Compost tea, an extraction made from compost, water, and other materials, can contribute nutrients and microorganisms and improve soil and plant health when properly prepared and applied (Ingham, 2005). One of the aims of utilizing compost tea is to develop disease suppression and resistance therefore reducing need for fungicide inputs (Shaban et al., 2015). A couple of potential mechanisms by which compost tea may be effective are competition between the applied microbes and pathogens for nutrients, and parasitism of pathogens by the applied microbes (Shaban et al. 2015). A study on soil microbial enzyme activity was conducted in four evaluations over two summers where compost tea was applied at 1630 L ha⁻¹, and one of four evaluations had a significantly positive increase in microbial enzyme activity (Chen, 2015).

Other products approved for organic use are on the market, however not much information is available on their performance at this time. These products consist of

oxidizers like hydrogen dioxide and acetic acid, selected microorganism inoculants, and plant oils such as neem, cedar, citrus, etc (Keen, 2003; Kennelly, 2010). A plant defense activator, acibenzolar-s-methyl (Actigard, Syngenta Corp.) that induces fungal resistance was tested in conjunction with twelve biostimulants on creeping bentgrass (*Agrostis stolonifera* L.) (Lee & Fry, 2003). The Actigard reduced dollar spot by 38%, did not achieve additional suppression with biostimulant, and turf quality did not meet minimum standards through most of study (Lee & Fry, 2003). A culture of microorganisms was used as an amendment for the successful prevention of dollar spot on creeping bentgrass (Kremer et al., 2000). *Bacillus subtilis* (Ehrenburg) EW42- 1 and *Trichoderma harzanium* (Rifai) GBF-0208 were tested as biocontrols against fungicide-resistant dollar spot, and effectively suppressed the disease in nursery conditions (Shin et al., 2006). Another study tested three different biocontrols on their own, with fertilizers, and alternating applications with conventional fungicides and found that the level of control varied with program however all programs were effective in controlling dollar spot (Tomaso-Peterson & Perry, 2007).

This disease affects both warm- and cool-season turfgrass species, but there is relatively less literature on organic and non-synthetic products for use in warm-season turfgrass systems. Conventional fungicides are commonly used to control dollar spot, however more managers are showing interest in adopting organic practices. Field studies that monitor natural dollar spot occurrences offer opportunity to explore the potential of commercially available organic fungicides and fungal suppressors. The objectives of these studies were to (i) evaluate the response of dollar spot to sequential applications of organic fungicides and fungal suppressors, and (ii) to observe any other

treatment effects on the turfgrass such as quality, color, and phytotoxicity.

Materials & Methods

Field studies were conducted throughout the growing seasons of 2014 and 2015 on bermudagrass [*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burt-Davy] golf course fairways. One of these studies took place on Nonami Plantation (31°28'22"N, 84°11'07"W) on TifSport bermudagrass in Albany, GA an Albany sand (Aquic, Arenic Paleudults), and the other at Rivermont Golf Course and Country Club (34°00'18"N, 84°15'35"W) on TifWay bermudagrass in Johns Creek, GA a Bethlehem sandy loam (Fine, koalinitic, thermic, Typic Kanhapludults). The matured stands of turfgrass at both locations were maintained by the golf course maintenance staff and subjected to traffic. Treatments were irrigated with 0.64 cm an hour following the last plot being treated. Fertilizers and fungicides were withheld on the plot area except for treatments and an application of P and K at the Albany site 1 mo prior to first treatment application of 2015. At the Albany location, a blanket application of phosphorous (0-46-0) and potassium (0-0-62) at a rate of 0.56 kg ha⁻¹ and 1.12 kg ha⁻¹, respectively, was applied to mitigate extreme canopy thinning in April 2015. Field plots (1.5m x 1.5m) were established in October 2013 and April 2014 at the Albany and Johns Creek locations, respectively.

Organic treatments included thermal compost [Foothills™, Foothills Organics], compost tea [Progress Earth, Global Garden Supply], fertilizer enhancer [Biowash, 1st EnviroSafety, Inc.], *B. subtilis* OST 713 and GB03 inoculants [Rhapsody®, Bayer Environmental Science and Companion®, Growth Products Ltd., respectively], neem oil [Natural Guard, Voluntary Purchasing Groups, Inc.], hydrogen dioxide/ peroxyacetic

acid [ZeroTol 2.0, BioSafe Systems, LLC.], sodium carbonate peroxyhydrate [TerraCyte Pro, BioSafe Systems, LLC.], and phosphoric acid salts/ hydrogen peroxide [Oxiphos, BioSafe Systems, LLC.] at the Albany location. The Johns Creek location included the previously mentioned treatments as well as a proprietary vermicompost at 0.24 kg/m² and 0.48 kg/m² as well as vermicompost tea made and prepared by the golf course staff of Rivermont GCCC with the purpose of recycling kitchen waste. Rhapsody, Companion, Natural Guard, and all three oxidizer products, ZeroTol 2.0, TerraCyte Pro, and Oxiphos, are OMRI listed. Synthetic treatments included boscalid [Emerald, BASF Corp.] for comparison as a representative industry standard, and 46-0-0 urea to account for fertility effects on disease suppression. Application and mix rates were as follows: Emerald 1 g/L, Natural Guard 7.8 mL/L, Biowash 3.9 mL/L, Rhapsody 68 mL/L, Companion 40.8 mL/L, Foothills 0.76 kg/m², Progress Earth 1,261 mL/m², Rivermont vermicompost (1X) 0.24 kg/m² and (2X) 0.48 kg/m², and 46-0-0 urea 0.016 kg/m². The Foothills thermal compost, vermicompost, and 46-0-0 urea were applied by hand with a cylindrical shaker jar to the turfgrass canopy. The Progress Earth compost tea and vermicompost tea was applied by drench with a watering can. All other liquid treatments were applied with a CO₂ backpack sprayer equipped with XR8004VS nozzles calibrated to deliver 375 L ha⁻¹ at 221 kPa. Treatments were applied approximately every four weeks during the growing season starting from the end of the green-up period until just before dormancy. Application rates followed the standard rate suggested by manufacturers' labels. Sequential treatments were applied 0, 28, 56, 98, and 126 DAIT in 2014, and 0, 28, 56, 84, and 112 DAIT in 2015 at the Albany location. Sequential treatments were applied 0, 28, 70, 126, and 154 DAIT in 2014, and 0, 28, 56, 84, and

112 Johns Creek location.

Visual ratings were taken before, two weeks, and four weeks after each treatment. Visual ratings consisted of three assessments: percent dollar spot coverage on a scale of 0 (no presence) to 100% (completely covered), turfgrass quality on a scale of 1 (dead) to 9 (ideal), and turfgrass color on a scale of 1 (brown) to 9 (dark green) (Workman, 2012; Lee and Fry, 2003). In the case of turfgrass quality and color, minimum acceptable rating is 7.0 for golf courses (Lee and Fry, 2003).

Root biomass samples were taken each winter following dormancy using a 5.08 cm diameter corer, and two cores were taken per plot. Roots were washed of soil with water, and oven dried at 60°C for 4 days, and weighed. Soil samples in both locations were taken in November 2015. These soil samples were analyzed for nutrient content by the University of Georgia Soil Testing Laboratory (Athens, GA).

At the Albany location, plots were arranged in randomized complete block design (RCBD) with four replications. In a similar fashion, the Johns Creek location plots were arranged in RCBD with three replications. The data were organized using ARM software, and statistical analysis was conducted using JMP 13 software. Data were subjected to one-way ANOVA, where replications were assigned the role of “random effect” and subjected to Wald’s test. Means were separated using Tukey’s HSD at $\alpha=0.05$. Data presented in following tables are from relevant observation dates.

Results

Results from the ANOVA for dollar spot coverage at the Albany field site are presented in Table 3.1. The treatments had significant effects at 14 and 112 DAIT (days after initial treatment) in 2015. In the mean separation shown in Table 3.2,

TerraCyte Pro provided significantly more dollar spot control than the non-treated control (NTC) at 56 DAIT in 2014, but not from any other treatment.

The ANOVA for dollar spot coverage at the Johns Creek field site are presented in Table 3.3. In 2014, the treatments had significant effects at 14, 28, 42, 140, and 154 DAIT on dollar spot coverage. In 2015 the treatments had significant effects at 14 and 70 DAIT. In the mean separation shown in Table 3.4, Progress Earth tea provided more dollar spot control on 140 and 154 DAIT in 2014, as well as Vermicompost (1X) at 140 DAIT. In 2015, Foothills compost and TerraCyte Pro provided more control 14 DAIT. Emerald did not provide control significantly different from the NTC except at 28 DAIT, but was not significantly different from the control provided by other treatments.

The ANOVA for turfgrass quality at the Albany location presented in Table 3.5 shows that in 2014, the treatments had a significant effect on quality at 42, 56, 98, and 112 DAIT. In 2015, treatment had a significant effect on turfgrass quality at 56, 70, 84, and 98 DAIT. In the mean separation for turfgrass quality shown in Table 3.6 TerraCyte Pro, ZeroTol 2.0 and Oxiphos provided quality similar to the 46-0-0 urea and Emerald, and significantly higher quality than Progress Earth tea and NTC at 42 DAIT in 2014. ZeroTol 2.0, TerraCyte Pro, and Oxiphos provided significantly higher quality than Progress Earth Tea at 56 DAIT in 2014, but were not different from any other treatment. ZeroTol 2.0 also provided greater quality than Progress Earth Tea at 98 DAIT as well as higher quality than Natural Guard at 112 DAIT. ZeroTol 2.0, Oxiphos, and 46-0-0 urea met the minimum quality standard (MQS) at 98 DAIT, and at 112 DAIT all the oxidizer treatments and urea met MQS. In 2015, Oxiphos provided

greater turfgrass quality than Rhapsody, Progress Earth Tea, and Natural Guard at 56 DAIT. ZeroTol 2.0, provided more improved quality than other treatments at 70 DAIT, but was not different from TerraCyte Pro, Oxiphos, or 46-0-0 Urea. ZeroTol 2.0 also provided higher quality 84 DAIT than Rhapsody, but was not different from the other treatments. At 84 DAIT, ZeroTol 2.0, TerraCyte Pro, and Oxiphos provided higher quality than all other treatments, but were not different from the 46-0-0 urea. The three oxidizers and urea met MQS on 56 DAIT, and at 98 DAIT only the three oxidizers met MQS.

The ANOVA for turfgrass quality at the Johns Creek site shown in Table 3.7 shows treatment had a significant effect on quality at 42, 70, 154, and 168 DAIT in 2014, as well as 14, 42, and 84 DAIT in 2015. The mean separation presented in Table 3.8 shows Foothills compost, Rhapsody, Vermicompost (1X), and TerraCyte Pro provided significantly higher turfgrass quality than the 46-0-0 urea in 2014 at 70 DAIT, but was not significantly different from the NTC. At 140 DAIT in 2014, Foothills compost and Vermicompost (2X) provided improved quality than the 46-0-0 urea, but was also not different from the NTC. At 154 and 168 DAIT in 2014, all treatments and the NTC gave better turf quality than the urea. On all dates of dollar spot incidence in 2014, quality was below the MQS. At 14 DAIT in 2015, Natural Guard and Vermicompost tea provided less quality than the 46-0-0 urea, but was not different from any other treatment.

Results from the ANOVA for turfgrass color at the Albany location are presented in Table 3.9. The treatment had a significant effect on turfgrass color at 56, 98, and 126 DAIT in 2014 and 14 and 98 DAIT in 2015. In the mean separation shown

in Table 3.10, at 56 DAIT in 2014 Natural Guard, Foothills compost, ZeroTol 2.0, TerraCyte Pro, and Oxiphos provided color comparable to the urea, but not different from the NTC. At 126 DAIT in 2014, all treatments except for Rhapsody had comparable color to the 46-0-0 urea, but were not different from the NTC. At 98 DAIT, ZeroTol 2.0 and urea were the only treatments that met MQS for color, as well as Foothills, Emerald, and urea at 126 DAIT in 2014. At 14 DAIT in 2015, Foothills compost provided better color than Zerotol 2.0 and Oxiphos, but not different from any other treatment. At 98 DAIT, TerraCyte Pro and Oxiphos provided better color than Emerald, Biowash, Rhapsody, and Companion. On all dates of dollar spot incidence in 2015, color was substandard for all treatments.

The ANOVA for turfgrass color at the Johns Creek field site presented in Table 3.11 shows that treatment had a significant effect on turfgrass color on 42 and 84 DAIT of 2014, as well 14, 70, 84, 112, and 140 DAIT of 2015. The mean separation for turfgrass color presented in Table 3.12, all treatments except Companion and ZeroTol 2.0 provided similar color to urea at 14 DAIT in 2014. Foothills compost, Progress Earth tea, Vermicompost (1X), and Vermicompost (2X) also provided color similar to the urea at 84 DAIT, but were not significantly different from the NTC. At 14 DAIT in 2014, Foothills, Emerald, and urea were the only treatments that met MQS for color. The mean separation for 2015 showed no trends, however at 112 DAIT Foothills, Vermicompost (2X), and urea were the only treatments that met MQS for color.

The ANOVA shown in Table 3.13 for both locations and years showed no significant effect of treatment on root biomass. The mean separation for root biomass shown in Table 3.14 showed no significant trends for either location or year. However,

the root biomasses for both locations in 2015 for the urea treatment were the least mass for that year.

Discussion

Dollar spot disease incidence was generally observed earlier and later in the growing seasons. The disease was able to flourish during cooler, more ideal temperatures (Couch, 1995; Endo, 1963). The Johns Creek location provided more disease observations due to the clayey Piedmont soil retaining more moisture fostering more fungal activity than the sandy soil of Albany. In general, the treatments had an effect on disease, but the oxidizers in particular stood out, especially TerraCyte Pro. The mechanism is curative, as the material damages fungal cells living in the canopy as well as burning foliage they are living on that are removed when subsequently mowed, not unlike the effect of adding nitrogen to grow out the foliage and mow to remove them (Cook et al., 1964; Couch, 1995; Markland et al., 1969). Compost products also showed preventative activity, which is attributed to the microbial community it contains and its proteolytic activity on the fungal hyphae (Boulter et al., 2002b).

Although all the treatments impacted turfgrass quality, the oxidizers TerraCyte Pro, ZeroTol 2.0, and Oxiphos stood out among the others which can again be owed to its control of disease in the canopy. All of the treatments had an effect on turfgrass color, but only TerraCyte Pro, ZeroTol 2.0, Oxiphos, and Foothills compost maintained the minimum color standard on a regular basis relative to other treatments.

None of the treatments had an effect on plant growth as indicated by the yearly biomass results. The phytotoxicity observed at the Albany location in 2015 was negligible, and was likely exacerbated by heat and potential delayed watering. There

were reports of phytotoxicity at the Johns Creek location. However, they were not observed two weeks or four weeks after treatment. Foliar damage may have been present after treatment and recovered before the two week rating.

Conclusion

Disease is mostly a game of prevention, however it is wise to have curative measures at the ready for disease control no matter what program is used. Organic materials are often needed to be accompanied by cultural measures like mowing. Maintaining adequately fertilized turfgrass will also prevent and suppress disease (Cook et al., 1964; Markland et al., 1969). Compost and compost products have potential for disease suppression, as past research has indicated (Boulter et al., 2000; Nelson and Craft, 1992; Noble, 2011). TerraCyte Pro, an OMRI listed oxidizer product, stands out as an effective option. All of the organic treatments were as effective as the representative industry standard Emerald, however plots with these treatments were not significantly different from the non-treated plots. These organic options show potential for use in non-conventional turfgrass stands. Depending on the goals and standards of the turf manager, these products can be utilized alone or may be utilized in an integrated disease management plan in order to reduce inputs, particularly in preparation for cooler, more humid times of the year.

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Table 3.1. Analysis of variance (ANOVA) for dollar spot coverage (0-100%) at the Albany location during the 2014 and 2015 growing seasons.

Source ¹	DF	2014		2015			
		56DAIT ²	70DAIT	14DAIT	84DAIT	112DAIT	126DAIT
Treatment	11	NS ³	NS	*	NS	*	NS

¹Source – One-way ANOVA

²DAIT denotes days after initial treatment, sequential treatments were made on 0, 28, 56, 98, and 126 DAIT in 2014, and 0, 28, 56, 84, and 112 DAIT in 2015.

³P values – NS, *, **, and *** denote not significantly different, significantly different at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively. (---) denotes no dollar spot was present on that date.

Table 3.2. Mean separation¹ for dollar spot coverage (0-100%) at the Albany location during the 2014 and 2015 growing seasons.

Source ¹	2014		2015			
	56DAIT ²	70DAIT	14DAIT	84DAIT	112DAIT	126DAIT
Nontreated	37.5 a ³	1.3 a	---	10.0 a	7.5 a	3.8 a
Emerald	25.0 ab	---	---	7.5 a	7.5 a	2.5 a
Natural Guard	23.8 ab	---	---	6.3 a	10.0 a	2.5 a
Foothills Compost	20.0 ab	---	---	3.8 a	7.5 a	1.3 a
Progress Earth Tea	22.5 ab	1.3 a	---	6.3 a	7.5 a	1.3 a
Biowash	25.0 ab	1.3 a	---	6.3 a	8.8 a	1.3 a
Rhapsody	28.8 ab	1.3 a	---	7.5 a	7.5 a	2.5 a
Companion	28.8 ab	1.3 a	---	7.5 a	7.5 a	2.5 a
ZeroTol 2.0	23.8 ab	---	7.5 a	3.8 a	17.5 a	1.3 a
TerraCyte Pro	13.8 b	---	2.5 a	3.8 a	12.5 a	2.5 a
Oxiphos	23.8 ab	---	8.8 a	2.5 a	20.0 a	1.3 a
46-0-0 Urea	20.0 ab	---	---	2.5 a	17.5 a	---

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no dollar spot was present on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 3.3. Analysis of variance (ANOVA) for dollar spot coverage (0-100%) at the Johns Creek location during the 2014 and 2015 growing seasons.

Source ¹	DF	2014					2015					
		14DAIT ²	28DAIT	42DAIT	140DAIT	154DAIT	14DAIT	28DAIT	70DAIT	84DAIT	112DAIT	140 DAIT
Treatment	11	* ³	**	**	*	*	**	NS	*	NS	NS	NS

¹Source – One-way ANOVA

²DAIT denotes days after initial treatment, sequential treatments were made on 0, 28, 70, 126, and 154 DAIT in 2014, and 0, 28, 56, 84, and 112 DAIT in 2015.

³P values – NS, *, **, and *** denote not significantly different, significantly different at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively. (---) denotes no dollar spot was present on that date.

Table 3.4. Mean separation¹ for dollar spot coverage (0-100%) at the Johns Creek location during the 2014 and 2015 growing seasons.

Source ¹	2014					2015					
	14DAIT ²	28DAIT	42DAIT	140DAIT	154DAIT	14DAIT	28DAIT	70DAIT	84DAIT	112DAIT	140DAIT
Nontreated	15.0 ab ³	35.0 a	31.7 ab	10.0 ab	20.0 ab	18.3 ab	5.0 a	20.0 a	15.0 a	36.7 a	18.3 a
Emerald	6.7 ab	5.0 b	10.0 ab	6.7 ab	11.7 ab	15.0 ab	6.7 a	8.3 a	11.7 a	36.7 a	13.3 a
Natural Guard	11.7 ab	21.7 ab	35.0 ab	10.0 ab	11.7 ab	13.3 ab	5.0 a	13.3 a	15.0 a	30.0 a	13.3 a
Foothills Compost	5.0 ab	11.7 ab	11.7 ab	6.7 ab	11.7 ab	8.3 b	5.0 a	5.0 a	8.3 a	15.0 a	16.7 a
Progress Earth Tea	13.3 ab	11.7 ab	30.0 ab	5.0 b	10.0 b	13.3 ab	5.0 a	8.3 a	5.0 a	23.3 a	18.3 a
Biowash	13.3 ab	16.7 ab	15.0 ab	6.7 ab	13.3 ab	13.3 ab	5.0 a	13.3 a	11.7 a	36.7 a	10.0 a
Rhapsody	11.7 ab	10.0 ab	25.0 ab	8.3 ab	13.3 ab	11.7 ab	5.0 a	8.3 a	11.7 a	28.3 a	11.7 a
Companion	11.7 ab	28.3 ab	28.3 ab	15.0 ab	23.3 a	18.3 ab	5.0 a	18.3 a	16.7 a	36.7 a	5.0 a
Vermicompost(1X)	11.7 ab	13.3 ab	18.3 ab	5.0 b	13.3 ab	11.7 ab	5.0 a	5.0 a	10.0 a	23.3 a	10.0 a
Vermicompost(2X)	8.3 ab	21.7 ab	21.7 ab	6.7 ab	13.3 ab	10.0 ab	5.0 a	5.0 a	6.7 a	25.0 a	16.7 a
Vermicompost Tea	16.7 a	30.0 ab	31.7 ab	11.7 ab	15.0 ab	23.3 a	5.0 a	20.0 a	21.7 a	36.7 a	15.0 a
ZeroTol 2.0	13.3 ab	21.7 ab	23.3 ab	8.3 ab	13.3 ab	13.3 ab	5.0 a	5.0 a	5.0 a	26.7 a	26.7 a
TerraCyte Pro	13.3 ab	26.7 ab	11.7 ab	18.3 a	16.7 ab	8.3 b	5.0 a	5.0 a	8.3 a	33.3 a	26.7 a
Oxiphos	10.0 ab	25.0 ab	36.7 a	11.7 ab	15.0 ab	13.3 ab	6.7 a	8.3 a	8.3 a	30.3 a	21.7 a
46-0-0 Urea	3.3 b	6.7 ab	5.0 b	8.3 ab	10.0 b	5.0 b	3.3 a	6.7 a	5.0 a	26.7 a	16.7 a

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no dollar spot was present on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 3.5. Analysis of variance (ANOVA) for turfgrass quality (1-9) at the Albany location during the 2014 and 2015 growing seasons.

Source ¹	DF	2014				2015			
		42DAIT ²	56DAIT	98DAIT	112DAIT	56DAIT	70DAIT	84DAIT	98DAIT
Treatment	14	*** ³	***	**	**	***	***	***	***

¹Source – One-way ANOVA

²DAIT denotes days after initial treatment, sequential treatments were made on 0, 28, 56, 98, and 126 DAIT in 2014, and 0, 28, 56, 84, and 112 DAIT in 2015.

³P values – NS, *, **, and *** denote not significantly different, significantly different at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively. (---) denotes no dollar spot was present on that date.

Table 3.6. Mean separation¹ for turfgrass quality (1-9) at the Albany location during the 2014 and 2015 growing seasons.

Source ¹	2014				2015			
	42DAIT ²	56DAIT	98DAIT	112DAIT	56DAIT	70DAIT	84DAIT	98DAIT
Nontreated	6.8 c ³	5.9 ab	6.5 ab	6.4 ab	6.8 ab	6.5 b	6.5 ab	6.0 bc
Emerald	7.0 abc	6.0 ab	6.8 ab	6.8 ab	6.9 ab	6.5 b	6.6 ab	6.0 bc
Natural Guard	7.0 abc	5.9 ab	6.5 ab	6.3 b	6.5 b	6.5 b	6.5 ab	6.0 bc
Foothills Compost	6.9 bc	5.9 ab	6.8 ab	6.8 ab	6.9 ab	6.5 b	6.6 ab	6.3 bc
Progress Earth Tea	6.8 c	5.6 b	6.3 b	6.5 ab	6.5 b	6.5 b	6.5 ab	6.0 bc
Biowash	7.1 abc	5.9 ab	6.6 ab	6.6 ab	6.8 ab	6.5 b	6.5 ab	6.0 bc
Rhapsody	7.0 abc	5.9 ab	6.8 ab	6.6 ab	6.5 b	6.5 b	6.4 b	5.9 c
Companion	7.1 abc	6.0 ab	6.5 ab	6.6 ab	6.6 ab	6.5 b	6.5 ab	5.9 c
ZeroTol 2.0	7.6 ab	6.4 a	7.3 a	7.1 a	7.1 ab	7.0 b	6.9 a	7.0 a
TerraCyte Pro	7.8 a	6.3 a	6.9 ab	7.0 ab	7.1 ab	6.9 ab	6.8 ab	7.0 a
Oxiphos	7.6 ab	6.4 a	7.1 ab	7.0 ab	7.3 a	6.8 ab	6.8 ab	7.1 a
46-0-0 Urea	7.8 a	6.3 a	7.1 ab	7.0 ab	7.0 ab	6.8 ab	6.9 a	6.6 ab

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no dollar spot was present on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 3.7. Analysis of variance (ANOVA) for turfgrass quality (1-9) at the Johns Creek location during the 2014 and 2015 growing seasons.

Source ¹	DF	2014					2015		
		42DAIT ²	70DAIT	140DAIT	154DAIT	168DAIT	14DAIT	42DAIT	84DAIT
Treatment	14	*** ³	**	NS	**	***	*	**	*

¹Source – One-way ANOVA

²DAIT denotes days after initial treatment, sequential treatments were made on 0, 28, 70, 126, and 154 DAIT in 2014, and 0, 28, 56, 84, and 112 DAIT in 2015.

³P values – NS, *, **, and *** denote not significantly different, significantly different at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively. (---) denotes no dollar spot was present on that date.

Table 3.8. Mean separation¹ for turfgrass quality (1-9) at the Johns Creek location during the 2014 and 2015 growing seasons.

Treatments ¹	2014					2015		
	42DAIT ³	70DAIT	140DAIT	154DAIT	168DAIT	14DAIT	42DAIT	84DAIT
Non-Treated	5.8 b ²	6.0 ab	6.0 ab	6.0 a	6.0 a	6.8 ab	7.2 b	6.8 b
Emerald	6.2 ab	6.2 ab	6.0 ab	6.0 a	6.0 a	6.8 ab	7.3 ab	6.7 b
Natural Guard	5.8 b	6.0 ab	6.0 ab	6.0 a	6.0 a	6.7 b	7.2 b	6.8 b
Foothills Compost	6.2 ab	6.5 a	6.2 a	6.0 a	6.0 a	7.0 ab	7.7 ab	7.0 ab
Progress Earth Tea	5.8 b	6.0 ab	6.0 ab	6.0 a	6.0 a	7.0 ab	7.7 ab	7.0 ab
Biowash	6.3 ab	6.2 ab	6.0 ab	6.0 a	6.0 a	7.2 ab	7.5 ab	6.7 b
Rhapsody	6.2 ab	6.3 a	6.0 ab	6.0 a	6.0 a	7.2 ab	7.5 ab	7.0 ab
Companion	6.0 b	6.2 ab	6.0 ab	6.0 a	6.0 a	7.0 ab	7.3 ab	6.7 b
Vermicompost(1X)	6.2 ab	6.3 a	6.0 ab	6.0 a	6.0 a	7.0 ab	7.7 ab	7.0 ab
Vermicompost(2X)	6.3 ab	6.2 ab	6.2 a	6.0 a	6.0 a	7.3 ab	7.8 ab	7.2 ab
Vermicompost Tea	5.8 b	6.0 ab	5.8 ab	6.0 a	6.0 a	6.7 b	7.3 ab	6.7 b
ZeroTol 2.0	5.8 b	6.0 ab	6.0 ab	6.0 a	6.0 a	7.2 ab	7.5 ab	7.2 ab
TerraCyte Pro	6.3 ab	6.3 a	6.0 ab	6.0 a	6.0 a	7.0 ab	7.5 ab	7.0 ab
Oxiphos	5.7 b	6.0 ab	6.0 ab	6.0 a	6.0 a	6.8 ab	7.3 ab	6.8 b
46-0-0 Urea	7.0 a	5.5 b	5.5 b	5.5 b	5.3 b	7.7 a	8.0 a	8.0 a

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no dollar spot was present on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 3.9. Analysis of variance (ANOVA) for turfgrass color (1 - 9) at the Albany location during the 2014 and 2015 growing seasons.

Source ¹	DF	2014			2015	
		56DAIT ²	98DAIT	126DAIT	14DAIT	98DAIT
Treatment	11	*** ³	**	*	**	***

¹Source – One-way ANOVA

²DAIT denotes days after initial treatment, sequential treatments were made on 0, 28, 56, 98, and 126 DAIT in 2014, and 0, 28, 56, 84, and 112 DAIT in 2015.

³P values – NS, *, **, and *** denote not significantly different, significantly different at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively. (---) denotes no dollar spot was present on that date.

Table 3.10. Mean separation¹ for turfgrass color (1-9) at the Albany location during the 2014 and 2015 growing seasons.

Treatments ¹	2014			2015	
	56DAIT ²	98DAIT	126DAIT	14DAIT	98DAIT
Nontreated	5.8 bc ³	6.5 a	6.9 ab	6.0 ab	6.1 ab
Emerald	5.8 bc	6.8 a	7.0 ab	6.0 ab	5.9 b
Natural Guard	6.0 abc	6.5 a	6.6 ab	6.0 ab	6.0 ab
Foothills Compost	6.0 abc	6.8 a	7.1 ab	6.4 a	6.1 ab
Progress Earth Tea	5.8 bc	6.5 a	6.6 ab	5.9 ab	6.0 ab
Biowash	5.6 c	6.6 a	6.6 ab	6.0 ab	5.8 b
Rhapsody	5.8 bc	6.8 a	6.5 b	6.0 ab	5.9 b
Companion	5.9 bc	6.6 a	6.8 ab	5.9 ab	5.8 b
ZeroTol 2.0	6.4 ab	7.0 a	7.3 ab	5.6 b	6.5 ab
TerraCyte Pro	6.1 abc	6.9 a	7.3 ab	6.0 ab	6.8 a
Oxiphos	6.1 abc	7.0 a	7.0 ab	5.8 b	6.8 a
46-0-0 Urea	6.6 a	7.1 a	7.5 a	6.4 a	6.4 ab

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no dollar spot was present on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 3.11. Analysis of variance (ANOVA) for turfgrass color (1-9) at the Johns Creek location during the 2014 and 2015 growing seasons.

Source ¹	DF	2014				2015					
		14DAIT ²	28DAIT	42DAIT	84DAIT	14DAIT	28DAIT	70DAIT	84DAIT	112DAIT	140DAIT
Treatment	11	* ³	*	***	***	**	*	***	**	**	***

¹Source – One-way ANOVA

²DAIT denotes days after initial treatment, sequential treatments were made on 0, 28, 70, 126, and 154 DAIT in 2014, and 0, 28, 56, 84, and 112 DAIT in 2015.

³P values – NS, *, **, and *** denote not significantly different, significantly different at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively. (---) denotes no dollar spot was present on that date.

Table 3.12. Mean separation¹ for turfgrass color (1-9) at the Johns Creek location during the 2014 and 2015 growing seasons.

Treatments ¹	2014				2015					
	14DAIT ²	28DAIT	42DAIT	84DAIT	14DAIT	28DAIT	70DAIT	84DAIT	112DAIT	140DAIT
Nontreated	6.7 ab ³	6.3 a	6.0 b	5.5 b	6.7 b	7.0 ab	7.3 b	7.0 b	6.5 b	5.3 b
Emerald	7.0 ab	7.0 a	6.3 b	5.7 b	7.0 b	6.7 b	7.3 b	7.0 b	6.5 b	5.3 b
Natural Guard	6.7 ab	6.8 a	6.2 b	5.7 b	6.8 b	6.7 b	7.2 b	7.2 ab	6.5 b	5.7 b
Foothills Compost	7.0 ab	7.3 a	6.3 b	6.2 ab	7.0 b	7.3 ab	7.7 ab	7.2 ab	7.0 ab	6.2 b
Progress Earth Tea	6.7 ab	7.3 a	6.3 b	5.8 ab	7.2 ab	7.0 ab	7.5 ab	7.2 ab	6.3 b	5.8 b
Biowash	6.7 ab	7.5 a	6.3 b	5.7 b	7.0 b	6.7 b	7.3 b	7.0 b	6.5 b	5.5 b
Rhapsody	6.8 ab	7.7 a	6.0 b	5.7 b	7.0 b	7.2 ab	7.3 b	7.0 b	6.7 ab	5.5 b
Companion	6.5 b	7.0 a	6.0 b	5.3 b	6.8 b	6.5 b	7.2 b	6.5 b	6.3 b	5.5 b
Vermicompost (1X)	6.8 ab	7.0 a	6.5 b	6.0 ab	7.3 ab	7.0 ab	7.7 ab	7.0 b	6.8 ab	6.0 b
Vermicompost (2X)	6.7 ab	7.0 a	6.3 b	6.2 ab	7.2 ab	7.2 ab	7.5 ab	7.2 ab	7.2 ab	6.0 b
Vermicompost Tea	6.5 ab	6.7 a	6.2 b	5.5 b	6.8 b	6.8 ab	7.2 b	6.8 b	6.5 b	5.3 b
ZeroTol 2.0	6.5 b	6.2 a	6.0 b	5.5 b	6.8 b	7.0 ab	7.5 ab	7.2 ab	6.5 b	5.8 b
TerraCyte Pro	6.7 ab	6.8 a	6.3 b	5.3 b	7.2 ab	7.0 ab	7.8 ab	7.2 ab	6.5 b	5.3 b
Oxiphos	6.7 ab	6.2 a	6.0 b	5.5 b	6.7 b	7.0 ab	7.7 ab	6.8 b	6.2 b	5.8 b
46-0-0 Urea	7.3 a	7.3 a	7.7 a	6.7 a	8.0 a	7.8 a	8.2 a	8.0 a	7.7 a	7.3 a

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no dollar spot was present on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

Table 3.13. Analysis of variance (ANOVA) for root biomass (g) at Albany and Johns Creek for 2014 and 2015.

		Albany		Johns Creek		
Source ¹	DF	2014	2015	DF	2014	2015
Treatment	11	NS ²	NS	14	NS	NS

¹Source – 1-way ANOVA

²P values – NS, *, **, and *** denote not significantly different, significantly different at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

Table 3.14. Mean separation¹ for root biomass (g) at Albany and Johns Creek for 2014 and 2015.

Source ¹	Albany		Johns Creek	
	2014	2015	2014	2015
Nontreated	0.88 a ²	0.42 a	0.28 a	0.27 a
Emerald	0.89 a	0.40 a	0.33 a	0.17 a
Natural Guard	0.56 a	1.13 a	0.32 a	0.28 a
Foothills Compost	0.63 a	0.71 a	0.29 a	0.20 a
Progress Earth Tea	0.63 a	0.99 a	0.36 a	0.27 a
Biowash	0.69 a	0.55 a	0.33 a	0.23 a
Rhapsody	0.81 a	0.70 a	0.30 a	0.27 a
Companion	0.58 a	0.34 a	0.32 a	0.15 a
Vermicompost(1X)	---	---	0.25 a	0.20 a
Vermicompost(2X)	---	---	0.71 a	0.17 a
Vermicompost Tea	---	---	0.35 a	0.18 a
ZeroTol 2.0	0.13 a	0.25 a	0.32 a	0.37 a
TerraCyte Pro	0.54 a	0.27 a	0.20 a	0.08 a
Oxiphos	0.18 a	0.85 a	0.61 a	0.23 a
46-0-0 Urea	0.18 a	0.23 a	0.40 a	0.06 a

¹Source – Tukey’s HSD mean separation test at $\alpha = 0.05$

²Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level. (---) denotes no sample was measured for that date.

CHAPTER FOUR
SURVEY OF ORGANIC FERTILIZERS AND COMPOST TEAS IN
BERMUDAGRASS¹

¹Babb-Hartman, M.E., G.M. Henry, M.Y. Habteselassie, and F.C. Waltz, Jr. To be submitted to *Applied Turfgrass Science*.

Abstract

The objectives of this research were to evaluate the efficacy of organic fertilizers in bermudagrass (*Cynodon dactylon* (L.) Pers x *C. transvaalensis* Burt-Davy). Field experiments were conducted in Johns Creek, GA and Albany, GA during 2014 and 2015. Plots were established in Fall 2013 and Spring 2014. In the general fertilizer trials, treatments were applied at (1/2X), (X), and (2X) rates where (X) represents the standard label rate and included Foothills compost, Progress Earth compost tea, Organic Bountea compost tea, Casting4Growth compost tea, Casting4Growth vermicompost, Biowash fertilizer enhancer, Atlanta Gas Light processed municipal waste, and Milorganite. In the compost tea trials, treatments were also applied at (1/2X), (X), and (2X) rates and included Progress Earth compost tea, Organic Bountea compost tea, and Casting4Growth compost tea. Additionally, at the Johns Creek site, a proprietary vermicompost and vermicompost tea (Rivermont) were utilized. 46-0-0 urea was included for comparison. Applications were made approximately every four weeks during growing season. Visual ratings were taken before, two weeks, and four weeks after treatment, and consisted of two assessments: turfgrass quality on a scale of 1 (dead) to 9 (ideal), and turfgrass color on a scale of 1 (brown) to 9 (dark green). P-values were obtained via 2-way ANOVA, and least square means were obtained via 1-way ANOVA. Results from the general fertilizer trials showed that the processed municipal waste products performed as well or better than urea in terms of quality and color at varying times throughout both years at the Albany site, as well as the the processed municipal waste products and high rate composts both years at the Johns Creek site. Results from the compost tea trials showed that Organic Bountea treatments provided similar quality

and color to urea at varying times throughout both years at the Albany site, as well as Organic Bountea treatments followed by Rivermont treatments both years at the Johns Creek site. Thermal and vermicomposts as well as processed municipal waste products are the best options from those tested here for organic fertility applications, and of the compost teas, Organic Bountea for organic fertigation applications.

Introduction

Nutrients and water are often the most limiting factors to turfgrass growth, and the aim of sustainable turfgrass management is to administer these resources as wisely and conscientiously as possible. Therefore, efficient nutrient acquisition and utilization are of utmost importance. Fertilizers include a wide variety of materials from synthesized urea to livestock waste slurry. In 18th century Europe, lawns were maintained by grazing animals that fertilized the grass with their manure (Beard et al., 2014). In the 19th century, human labor was engaged in lawn maintenance, and human intervention increased leading to manually cutting grass and applying nutrients (Beard et al., 2014). Due to the use of horses as a primary means of transportation, “manuring” became a popular method for fertilizing greenspaces (Beard et al., 2014). However as manure resources became scarce with the arrival of the combustion engine and vehicles, manure substitutes came on the scene such as blood meal, bone meal, fish meal, guano, etc (Beard et al., 2014). In the early 20th century, Fritz Haber and Carl Bosch invented the Haber-Bosch process of artificially converting atmospheric nitrogen into ammonia, which was quickly adapted on an industrial level and marks the advent of synthetic fertilizers (Appl, 2005). In the past few decades, there has been a growing interest in decreasing the use of synthetic materials in favor of non-synthetic and organic materials in an effort to

be more ecologically sustainable, promote human and animal health, improve nutrient cycling, abate misuse of potent or damaging chemicals, and save money.

Various organic products and best management practices have been tested to replace chemical fertilizers in turfgrasses. Organic fertilizers show a wide range of effectiveness in maintaining turf quality (Garling and Boehm, 2001; Gardner, 2004). Higher application rates are often needed for organic fertilizers (Trenholm and Unruh, 2005) because their release rates may be slower than those of synthetic ones, and many need favorable soil conditions and microbial activity for their breakdown (Tester et al., 1982; Landschoot and Waddington, 1987). Liquid fertilizer produced through composting and biofiltering of animal waste, known as “slurry composted and biofiltered” liquid fertilizer applied four times during the growing season and dormant applications produced high turf quality and growth (Park et al., 2012). Dissolved organic matter (DOM) from organic fertilizers/amendments facilitates movement of organic chemicals through soils. Studies suggest that these materials might lead to enhanced transport of applied chemicals in turf soils (Li et al., 2005). The effectiveness of hydrolyzed squid waste (SQL) as an organic fertilizer was evaluated on perennial ryegrass (*Lolium perenne* L.) (Fetter et al., 2013). Application of SQL provided consistently higher quality, uniform turf and significantly higher microbial activity rates, compared to synthetic fertilizer (Fetter et al., 2013).

Municipal waste has been investigated as a potential fertilizer source and method of recycling nutrients. However due to the heavy metal content and potential for human pathogens, it is not allowed in organic food production. Microbes isolated from

composted municipal solid waste have been shown to have a positive effect on beneficial nematode communities and soil structure of turfgrass stands (Zhao et al., 2013). Nitrogen uptake by tall fescue (*Festuca arundinacea* Schreb.) was limited with regards to applications of composted sewage sludge due to the slow mineralization rate (Tester et al., 1982).

Composts are broadly defined as a mixture of aerobically decomposed organic materials, such as grass clippings, manure, food waste, etc., recycled for use in soils to fertilize, build soil structure, and promote the microbiological community (Nelson & Craft, 1992). Applications of composts contribute to providing various benefits to plants including fertility, disease suppression, and plant-parasitic nematode protection by increasing the soil biodiversity (Ingham, 2005; Nelson & Craft, 1992). In Kentucky bluegrass (*Poa pratensis* L.), tall fescue, and perennial ryegrass, enhanced color and growth was seen for up to 32 days after application of compost (Schumann et al., 1993). A direct relationship between increasing rate of compost and increasing foliar nitrogen and clipping yields was observed in both field and greenhouse trials in tall fescue (Sikora et al., 1980; Tester et al., 1982). Roadsides tend to be relatively harsh environments for grasses, and they often don't survive the first year after planting, which leaves bare ground to erode or a niche for weeds. Soil amendments made from a 1:1 blend of processed biosolids and composted yard waste were found to have greater efficacy on perennial grass survival on roadsides than utilizing more salt tolerant and genetically improved cultivars (Brown and Gorres, 2011).

Vermicompost is a type of compost utilizing certain species of earthworms to rapidly decompose a wide variety of organic matter via ingestion and creating a fine compost material with higher porosity and nutrient availability (Atiyeh et al., 2000). A study on Kentucky bluegrass found that two weeks following application of various vermicomposts (variety based on parent material), visual quality was increased but application rate and parent material of compost had little or no effect (Gardner, 2004).

Compost teas are broadly defined as dilute compost extracts, which can include many ingredients such as molasses, fish meal, kelp extract, etc., and can be “brewed” under different conditions (aerated/nonaerated) to influence the desired microbial inoculum it may contain (Shaban et al., 2015). It can also be considered a type of DOM. Advantages of fertigation applied foliarly include application uniformity, more efficient nutrient absorption by roots, and amendments can be combined saving time and labor for managers (Gao and Li, 2012). Compost tea had negligible effects on turf quality, turf color, and weed encroachment when applied to tall fescue, however slight improvement was reported when nitrogen was supplemented indicating that compost tea could be too dilute in nutrients to utilize on its own (Chen, 2015). Under athletic field conditions with simulated traffic, the use of compost tea did not show any improvement of turfgrass quality, cover, color, or soil physical properties over a 2 year study (Miller and Henderson, 2012). Although research is scarce on this subject, it has been growing in popularity with professionals and homeowners due to its efficacy in infiltrating the turfgrass canopy and soil surface as well as being present as a relatively accessible, organic means of nutrient and disease management. Specific ingredients commonly added or present in compost tea have been investigated individually. Seaweed extract is

known source of cytokinins and auxins, and humic acid is a source of auxins which have been shown to increase antioxidant levels of cool-season turfgrasses and allow turf to cope better with stresses such as drought and disease (Couch, 1995; Hamence, 1944; O'Donnell, 1973; Yan, 1993). While one study found that applying seaweed extracts and humic acids with fertilizer did not improve creeping bentgrass quality, it did reduce dollar spot (Zhang et al., 2003).

As noted above by named species, the existing research has mostly been done on cool-season turfgrass species. The growing interest in organic and sustainable agriculture combined with the void of organic research in warm-season turfgrasses has created an opportunity for scientific inquiry. The objectives of these studies are to (i) assess a variety of organic fertilizer materials on the basis of turf quality, color, and root growth, and (ii) to compare the efficacy of compost teas to other types of organic fertilizers.

Materials & Methods

Field studies were conducted in 2014 and 2015 at Nonami Plantation (31°28'22"N, 84°11'07"W) in Albany, GA, an Albany sand (Aquic, Arenic Paleudults), and Rivermont Golf Course and Country Club (34°00'18"N, 84°15'35"W) in Johns Creek, GA, a Bethlehem sandy loam (Fine, kaolinitic, thermic, Typic Kanhapludults). Plots (1.5m x 1.5m) were established on matured TifSport and Tifway 419 bermudagrass (*Cynodon dactylon* (L.) Pers x *C. transvaalensis* Burt-Davy) golf course fairways, respectively, and were maintained by the golf course maintenance staff. Treatments were irrigated with 0.64 cm an hour following the last plot being treated. Typical traffic and golf course maintenance occurred and fertilizers and fungicides were withheld on the plot area except for treatments and an application of P and K at the Albany site 1 mo prior to

first treatment application of 2015. At the Albany location, trials were conducted during growing seasons between July 2013 and April 2016. Supplemental phosphorous (0-46-0) and potassium (0-0-62) at rates of 0.56 kg ha⁻¹ and 1.12 kg ha⁻¹, respectively, was applied over the plot area in a blanket application in April 2015 to mitigate extreme canopy thinning. At the Johns Creek location, trials were conducted during growing seasons between May 2014 and April 2016. At each location, fertilizer trials were conducted in two experiments simultaneously, where one experiment included all of the organic treatments (from here forward referred to as the general fertilizer trials) and the other only included the compost teas so that compost teas (referred to as the compost tea trials) could be compared against other organic materials and on their own.

The composts used were thermal compost [Foothills™, Foothills Organics] and vermicompost [Casting 4 Growth, Casting 4 Growth, LLC]. At the Rivermont site, a vermicompost cultivated by the golf course staff from country club kitchen waste referred to as Rivermont vermicompost was also applied. Two processed municipal solid wastes were used, Milorganite® [Milorganite] and a product made by Atlanta Gas Light (AGL) which has since been discontinued. A liquid fertilizer enhancer [Biowash, 1st EnviroSafety, Inc.] was also used to compare effects of added nutrients with an amendment utilizing the native nutrients. The compost teas used were Progress Earth compost tea [Progress Earth, Global Garden Supply], Organic Bountea compost tea [Organic Bountea], and Casting 4 Growth vermicompost tea [Casting 4 Growth, Casting 4 Growth, LLC]. The materials used in the compost teas are listed in Appendix A. The methods of brewing the compost teas were done in accordance with manufacturers' labels and instructions using deionized water, and were all brewed at ambient temperature for

24 hours prior to application in a non-air-conditioned building. Urea (46-0-0) was also included for comparison as a representative industry standard. The composts, municipal solid wastes, and urea were applied by hand with a cylindrical shaker jar to the turfgrass canopy. The compost teas were applied as a drench with a watering can, and the Biowash was applied with a CO₂ backpack sprayer equipped with XR8004VS nozzles calibrated to deliver 375 L ha⁻¹ at 221 kPa. Treatments were applied approximately every four weeks during the growing season starting from the end of the green up period until just prior to dormancy. The application rates followed as low (1/2X), medium (X), and high (2X), where X is the standard rate suggested by the manufacturers shown in Table 4.1. Sequential treatments were applied throughout the growing season as follows: Albany 2014 at 0, 28, 56, 84, and 126 DAIT; Albany 2015 at 0, 28, 56, 84, and 112 DAIT; Johns Creek 2014 at 0, 28, 56, 98, and 154 DAIT; and Johns Creek 2015 at 0, 28, 56, 84, and 112.

Data were taken at 14 and 28 days after initial treatment (DAIT) as well as after each sequential application. Turfgrass quality and color were taken visually on a 0-9 rating scale where 0 is dead and 9 is ideal (Lee & Fry, 2003). In the case of turfgrass quality and color, the minimum acceptable rating is 7.0 for golf courses (Lee & Fry, 2003). Soil samples taken in Nov 2015 at both locations were kept for nutrient analysis done by the University of Georgia Soil Testing Lab (Athens, GA). After dormancy, two root samples per plot were taken with a 5.08 cm diameter corer, and were washed with water. Samples were oven dried at 60°C for 4 days and weighed for measuring root biomass.

All plots were arranged in a randomized complete block design (RBCD) with three replications regardless of location. Data were subjected to 2-way ANOVA, where replications were assigned the role of “random effect” and subjected to Wald’s test using JMP 13 software. P-values were obtained via 2-way ANOVA to compare treatment, rate, and interaction between them. Least square means (LSMeans) were obtained via 1-way ANOVA to compare treatment means within assigned rates using Tukey’s HSD test at $\alpha = 0.05$. Data presented in following tables are from relevant observation dates.

Results

General Fertilizer Trials

In the ANOVA performed on data at the Albany site in 2014, treatment had a significant effect on quality at 14, 42, and 56 DAIT ($df = 27, p \leq 0.001$) and color on 14 and 42 DAIT ($df = 27, p \leq 0.001$) as well as 56 DAIT ($df = 27, p \leq 0.01$). Rate was not significant, therefore treatment is shown in LSMean without regard to rate in Table 4.2.

In the mean separation in Table 4.2 at 14 DAIT, the NTC was not significantly different from urea, and Foothills, Atlanta Gas Light, and Milorganite provided greater quality than other organic treatments. At 42 and 56, Foothills, Biowash, Casting4Growth VC, Atlanta Gas Light, and Milorganite provided greater quality than the compost teas and similar to the urea. At 14 and 56 DAIT, Milorganite met MQS.

At 14 DAIT, Foothills, Atlanta Gas Light, and Milorganite provided better color than NTC and other treatments, and similar to urea. At 42 DAIT, Foothills, Biowash, Casting4Growth VC, Atlanta Gas Light, and Milorganite provided better color than the compost teas, but were not different from the NTC or urea. At 56 DAIT, Milorganite provided color significantly better than Organic Bountea CT, but was not different from

the other treatments. Atlanta Gas Light and Milorganite met MQS for color at 14 DAIT, and Milorganite met MQS for color at 56 DAIT.

In the ANOVA performed for the Albany site in 2015, treatment had a significant effect on quality at 14 and 42 DAIT ($df = 27, p \leq 0.01$) as well as 28 and 56 DAIT ($df = 27, p \leq 0.001$), and on color at 14 and 56 DAIT ($df = 27, p \leq 0.01$) and 28 and 56 DAIT ($df = 27, p \leq 0.001$). Rate had a significant effect on color at 28 DAIT ($df = 2, p \leq 0.05$), and an interaction was present for color at 42 DAIT ($df = 54, p \leq 0.05$) indicating rate effect has a dependent relationship on the treatments' effect.

In the mean separation shown in Table 4.3, the NTC was not different from urea treatments. At 28 DAIT, Atlanta Gas Light (2X) and Milorganite (2X) provided higher quality than (X) and (1/2X) rates, but was not different from NTC or urea. Biowash (2X) provided lower quality than (1/2X) and (X) rates. At 56 DAIT, Atlanta Gas Light (X) and (2X) and Milorganite (2X) provided higher quality than lesser rates, but was not different from NTC, urea, and other treatments except Organic Bountea (X). Milorganite (2X) met MQS at 28 DAIT, Milorganite (X) met MQS at 42 DAIT.

For color, the NTC was not different from the urea treatments. At 28 DAIT, Milorganite (X) and (2X) provided better color than the (1/2X), but was not different from other treatments, NTC, or urea. At 42 DAIT, Casting4Growth VC (2X), Atlanta Gas Light (X) and (2X), and Milorganite provided better color than other treatments, but was not different from NTC or urea. Milorganite (X) and Milorganite (2X) met MQS at 28 DAIT, and Casting4Growth VC (2X) and Milorganite (2X) met MQS at 42 DAIT. Milorganite (2X) met MQS at 56 DAIT.

In the ANOVA performed for the Johns Creek site during 2014, treatment had a significant effect on quality at 14, 42, and 126 DAIT ($df = 30, p \leq 0.001$) as well as 28 and 56 DAIT ($df = 30, p \leq 0.01$). Rate had a significant effect on quality at 42 DAIT ($df = 2, p \leq 0.01$), and an interaction was present at 126 DAIT ($df = 60, p \leq 0.05$). Treatment had a significant effect on color at 56, 98, 126, and 133 DAIT ($df = 30, p \leq 0.001$) as well as 70 and 84 DAIT ($df = 30, p \leq 0.01$). Rate had a significant effect on color at 126 and 133 DAIT ($df = 2, p \leq 0.01$), and an interaction was present at 98 DAIT ($df = 60, p \leq 0.05$) indicating rate effect has a dependent relationship on the treatments' effect.

In the mean separation in Table 4.4, treatments were not significantly different from the NTC, although some treatments resulted in higher quality. At 14 DAIT, Foothills (X) and (2X) Progress Earth (2X), and AGL (2X) provided greater quality than NTC and other treatments, and was not different from urea treatments. At 42 DAIT, the Foothills treatments, Casting4Growth VC (X) and (2X), Rivermont VC (2X), and Atlanta Gas Light (2X) provided greater quality than the NTC and other treatments, and was not different from urea (X) and (2X). Progress Earth CT (2X) was the same as NTC, but provided greater quality than Progress Earth (1/2X) and (X) rates and was not different from urea (X) and (2X). At 126 DAIT, Foothills, Milorganite, Rivermont VC, Casting4Growth CT and VC, Organic Bountea (2X), and Atlanta Gas Light (X) and (2X) provided higher quality than the NTC as well as urea (2X). At 42 and 126 DAIT, Biowash (2X) provided less quality than its (1/2X) and (X) rates. At 14 and 28 DAIT, the majority of treatments met MQS, however at 56 DAIT Casting 4Growth VC (2X), Milorganite (2X), urea (X) and (2X) were the only treatments that met MQS.

In the mean separation in Table 4.4 at 56 DAIT, none of the treatments were significantly different from NTC or urea, but Rivermont VC (2X) provided better color than the (1/2X) and (X) rates. At 84 DAIT, none of the treatments were significantly different from NTC or urea, but Casting4Growth VC (X) and (2X) provided better color than (1/2X) rate. At 98 DAIT, Casting4Growth CT treatments were not different from NTC, but (2X) rate provided better color than (X) rate and (X) provided better color than (1/2X) rate. Milorganite (2X) was no different than urea and NTC, but provided better color than (1/2X) and (X) rates. Rivermont VC (X) and (2X) also was no different from NTC and urea, but provided better color than (1/2X). At 126 DAIT, no treatment was significantly different from the NTC, but Casting4Growth CT (X) and (2X) provided greater color than (1/2X). At 126 DAIT, Casting4Growth VC (2X), 46-0-0 urea (2X), and Rivermont VC (2X) met MQS for color. At 133 DAIT, Foothills (2X) and Casting4Growth VC (2X) provided better color than NTC and (1/2X) and (X). Milorganite and Atlanta Gas Light (X) and (2X) rates provided better color than NTC as well as (1/2X) rate.

In the ANOVA performed for the Johns Creek site during 2015, treatment had a significant effect on quality at 70, 140, 154, and 168 DAIT ($df = 30, p \leq 0.001$) as well as 112 DAIT ($df = 30, p \leq 0.01$). Rate had a significant effect at 154 DAIT ($df = 2, p \leq 0.01$), and interactions were present at 112DAIT ($df = 60, p \leq 0.05$), and 154 and 168 DAIT ($df = 60, p \leq 0.001$). Treatment had a significant effect on color at 42, 56, 70, 84, 140 DAIT ($df = 30, p \leq 0.001$) as well as 112 DAIT ($df = 30, p \leq 0.01$). Rate had a significant effect on color at 42 and 84 DAIT ($df = 2, p \leq 0.05$), and 56, 70, and 140 DAIT ($df = 2, p \leq 0.01$).

In the mean separation presented in Table 4.5, the NTC was not significantly different from the urea treatments except for 154 and 168 DAIT where urea (1/2X) went from being significantly higher than the NTC, urea (X) and (2X) to significantly lower than stated treatments. At 70 DAIT, Casting4Growth CT (2X) provided higher quality than the (1/2X) and (X) rates, but not different from the NTC and urea. Atlanta Gas Light and Milorganite (X) and (2X) treatments also provided higher quality than (1/2X), but were not different from NTC or urea. At 140 DAIT, Casting4Growth VC (2X), Milorganite (2X), and Rivermont VC (2X) provided higher quality than the (1/2X) and (X) rates, and Milorganite (2X) provided significantly higher quality than urea (2X). At 154 DAIT, Foothills (2X) and Casting4Growth (2X) provided higher quality than (1/2X) and (X) rates, and Milorganite (X) had significantly higher quality than all other treatments except urea (1/2X). At 168 DAIT, all treatments except for Milorganite (2X) were similar to urea (X) and (2X), and all treatments were similar to the NTC. At 70 DAIT, the majority of treatments met MQS. At 140 DAIT, the Milorganite (2X) met MQS.

In the mean separation shown in Table 4.5 at 42 DAIT, Casting4Growth CT (2X) and Milorganite (2X) provided better color than (1/2X) and (X) rates. NTC was significantly different from urea at 56, 70, 84, and 140 DAIT. At 56 DAIT, Foothills (X) and (2X), Casting4Growth VC (X) and (2X), and Casting4Growth CT (2X) provided better color than lesser rates, but were not different from NTC or urea. At 70 DAIT, Foothills (X) and (2X) provided better color than (1/2X). Also, Casting4Growth CT and Rivermont VC (2X) provided better color than the (X) rates, and (X) rates provided better color than the (1/2X) rates. At 84 DAIT, Atlanta Gas Light (X) and Milorganite (2X)

provided similar quality to urea treatments, but were not different from NTC. At 140 DAIT, Casting4Growth VC (X) and (2X), Atlanta Gas Light (X) and (2X), and Milorganite (2X) provided better color than lesser rates, and were not different from NTC or urea. Additionally, Milorganite (2X) was significantly different from the NTC. At 140 DAIT, only Milorganite (2X) and the 46-0-0 urea treatments met MQS.

In the ANOVA performed on root biomasses, there were no significant effects on root biomass for the Albany site either year, and treatment had a significant effect in 2015 at the Johns Creek site ($df = 30, p \leq 0.01$). In the mean separation performed, no one treatment stood out in terms of root biomass at the Johns Creek site for either year, however urea treatments results in less root mass than organic treatments except for Casting4Growth VC and NTC.

Compost Tea Trials

In the ANOVA performed for the Albany site in 2014, treatment had a significant effect on quality on 14 and 140 DAIT ($df = 12, p \leq 0.01$), 42 DAIT ($df = 12, p \leq 0.05$), and 119, 126, and 168 DAIT ($df = 12, p \leq 0.001$), but rate did not therefore treatments were analyzed without regard to rate in LSMeans. In the mean separation performed, the NTC was significantly different from urea at 14, 119, and 126 DAIT. At 14 DAIT, Organic Bountea CT provided higher quality than other compost teas but was not different from NTC or urea. At 119 DAIT, all treatments and NTC provided significantly higher quality than urea. At 14 DAIT, Organic Bountea CT provided better color than other compost teas, but was not different from NTC or urea.

In the ANOVA performed at the Albany site in 2015, treatment had a significant effect on quality at 56 DAIT ($df = 12, p \leq 0.05$), 84 and 126 DAIT ($df = 12, p \leq 0.01$),

and 98, 112, and 140 DAIT ($df = 12, p \leq 0.001$). Rate had a significant effect at 98 DAIT ($df = 2, p \leq 0.05$). Treatment had a significant effect on color at 28 and 112 DAIT ($df = 12, p \leq 0.001$), and 98 and 140 DAIT ($df = 12, p \leq 0.01$). In the mean separation shown in Table 4.6, the NTC had significantly higher quality than the urea (2X) at 84, 98, 112, 126, and 140 DAIT. At 84, 98, 112, and 140 DAIT, none of the treatments were different from the NTC or urea (1/2X). At 126 DAIT, Casting4Growth CT (X) and (2X) provided higher quality than the (1/2X), but was not different from the NTC. MQS was not met for any treatment throughout year.

In the mean separation shown in Table 4.6, urea (2X) provided significantly better color than the NTC at 28 DAIT, but was not different on other dates. At 112 DAIT, Organic Bountea CT provided better color than the (1/2X), but were not different from the NTC or urea.

In the ANOVA performed for the Johns Creek site in 2014, treatment had a significant effect on quality at 28, 42, and 70 DAIT ($df = 15, p \leq 0.001$), and 56 DAIT ($df = 15, p \leq 0.01$). Rate had a significant effect at 28 and 42 DAIT ($df = 2, p \leq 0.01$), as well as 70 DAIT ($df = 2, p \leq 0.001$). Interactions were present at 28 and 42 DAIT ($df = 30, p \leq 0.01$), and 70 DAIT ($df = 30, p \leq 0.001$). Treatment had a significant effect on color 42, 56, 70, and 98 DAIT ($df = 15, p \leq 0.001$), as well as 84 DAIT ($df = 15, p \leq 0.05$). Rate had a significant effect on color at 42 ($df = 2, p \leq 0.01$), and 84 DAIT ($df = 2, p \leq 0.05$). Interactions were present on 42 ($df = 30, p \leq 0.001$) and 98 DAIT ($df = 30, p \leq 0.01$).

In the mean separation shown in Table 4.7, compost teas were not different from the NTC at 28, 42, 56, 70, 84, and 98 DAIT for quality and color. At 42 DAIT, Organic

Bountea (2X) provided higher quality than the (1/2X) and (X), and was not different from the NTC or urea (1/2X) and (X). At 28 and 42 DAIT, urea (2X) provided significantly higher quality than the NTC, but at 70 DAIT the urea (2X) provided significantly lower quality than NTC. The majority of treatments met MQS at 28 DAIT, however by 42 DAIT only the 46-0-0 urea (X) and (2X) treatments met MQS.

In the mean separation shown in Table 4.7 at 42 DAIT, Organic Bountea CT (2X) provided better color than (X) rate, and (X) rate provided better color than (1/2X) rate. At 56 DAIT, Casting4Growth CT (2X) and Organic Bountea (2X) provided better color than (1/2X) and (X). At 70 DAIT, Organic Bountea (X) and (2X) provided better color than (1/2X). At 84 DAIT, Rivermont CT (X) and (2X) provided better color than (1/2X).

In the ANOVA performed on data at the Johns Creek site in 2015, treatment had a significant effect on quality at 14, 42, 56, 70, and 84 DAIT ($df = 15, p \leq 0.001$). Rate had a significant effect on quality at 14 ($df = 2, p \leq 0.001$) and 84 DAIT ($df = 2, p \leq 0.01$). Interactions were present at 14 ($df = 30, p \leq 0.001$), 70 ($df = 30, p \leq 0.05$), and 84 DAIT ($df = 30, p \leq 0.01$). Treatment had a significant effect on color at 14, 28, 70, 84, 112, 140, and 168 DAIT ($df = 15, p \leq 0.001$). Rate had a significant effect on color at 28, 84, and 112 DAIT ($df = 2, p \leq 0.01$), as well as 168 DAIT ($df = 2, p \leq 0.05$). Interactions were present at 14 and 70 DAIT ($df = 30, p \leq 0.05$), 28 and 140 DAIT ($df = 30, p \leq 0.01$), and 84, 112, and 168 DAIT ($df = 30, p \leq 0.001$).

In the mean separation shown in Table 4.8, the urea (2X) provided significantly higher quality and better color than the NTC except for 168 DAIT where urea (2X) provided significantly less color than NTC. At 14, 42, 56, 70, and 84 DAIT, compost teas were not different from from NTC in terms of quality. At 84 DAIT, Casting4Growth

CT (X) and (2X) provided higher quality than (1/2X). At 42 DAIT, Organic Bountea CT (1/2X) and Organic Bountea CT (X) met MQS, and at 70 DAIT Progress Earth CT (1/2X) and Rivermont CT (2X) met MQS.

In the mean separation shown in Table 4.8, at 14, 28, 70, 84, 112, 140, and 168 DAIT the compost teas were not different from NTC in terms of color. At 28 DAIT, Casting4Growth CT (2X) provided better color than (1/2X) and (X). At 168 DAIT, Organic Bountea CT (2X) provided better color than (1/2X) and (X). At 14 DAIT, Organic Bountea CT (1/2X) and Organic Bountea CT (X) met MQS for color, and at 70 DAIT the majority of treatments met MQS.

In the ANOVA performed on root biomass data, treatment had a significant effect on root biomass in 2015 at the Johns Creek site ($df = 15, p \leq 0.05$). In the mean separation, no one treatment provided more root mass at the Johns Creek site in either year, however urea treatments resulted in less root mass than compost teas and NTC.

Discussion

General Fertilizer Trials

Without regard to rate, the municipal wastes, composts, and Biowash fertilizer enhancer outperformed the compost tea treatments, as compost teas are diluted. In general the organic products were not different from the NTC and were less than or similar to the urea. The urea (2X) tended to outperform the organics all season until fall when turfgrass quality for urea (2X) plots would decline when organic treatments maintained quality longer.

Biowash treatments have a negative relationship with rate, where the (2X) rate provided less quality and color than the (1/2X) and (X) rates. As Biowash is a fertilizer

enhancer with the aim of making nutrients available to plants quicker, this rate effect can be explained by applications of high rate Biowash allowing for more mineralization and uptake by plants or leaching of the existing soil nutrients and therefore depleting the soil.

The majority of treatments performed better early to mid-season which was not expected as the nutrients required more time to diffuse and metabolize in the soil. However, this effect may have been a holdover from residual nutrients in the soil from winter and spring green-up which has been documented in cool-season species (Landschoot and Waddington, 1987; Powell et al., 1967). Two months from initial application to late season, the compost and municipal waste products continued to provide better quality and color relative to the other treatments. In some cases, they outperformed the high rate urea treatments in the fall. This is likely due to: 1) higher rate of urea led to early senescing of turf foliage in the fall relative to lower rates, and 2) later time in the year gave organic materials more time to decompose and metabolize in soil. High nitrogen application has been shown to result in a higher susceptibility to environmental stress than lower application rates (Green and Beard, 1969; Funk et al., 1967).

Effects of rate were more pronounced the longer the trial continued at the Albany site, and rate had greater impact each year at the Johns Creek site. This is due to the nutrient capacity of the soil at each location, with the more clayey soil of Johns Creek allowing for greater nutrient retention from one application to the next while leaching could have occurred at the sandy Albany soil. It is evident that higher rates applied resulted in better quality of Foothills, Casting4Growth VC, Milorganite, Atlanta Gas Light, and Rivermont VC, as well as better color for Milorganite, Atlanta Gas Light,

Casting4Growth CT, and Rivermont VC. The biomass was only impacted at the Johns Creek site in 2015 and the only difference was that the urea treatments had less root mass than the organic treatments except Casting4Growth VC and the NTC, due to frequent nitrogen addition encouraging the shoot growth over roots.

Compost Tea Trials

The compost teas were not different from the NTC at either site in either year. Without regard to rate, Organic Bountea provided higher quality and color early season, and was not different from urea or NTC. Organic Bountea provided higher quality than urea late-season when high rate urea resulted in a decline of quality. As mentioned previously, the application rate effect was a greater factor later in the growing season at the Johns Creek site. Although performance was unreliable through the seasons, higher rates applied resulted in higher quality and color for Casting4Growth and Organic Bountea compost teas. Similarly, the biomass was only impacted at the Johns Creek site in 2015 and the only difference was that the urea treatments had less root mass than compost teas and the NTC, due to frequent nitrogen addition encouraging the shoot growth over roots.

Conclusion

Efficacy varied greatly during the course of these field trials, however using a high application rate of some materials and understanding the local soil type can produce more consistent results (Garling and Boehm, 2001; Gardner, 2004; Tester et al., 1982; Landschoot and Waddington, 1987). In the general fertilizer study, the municipal wastes, composts, and Biowash fertilizer enhancer outperformed the compost tea treatments, however high rate Biowash yielded lower quality than other organic treatments due to

how it breaks down nutrients in the soil. Among the compost teas, Organic Bountea was the most consistent. The application of compost tea to a turfgrass canopy was not as noticeable to the naked eye for the week following application (Shaban et al., 2015; Ingham, 2005). Depending on the goals of the turfgrass manager, municipal wastes, thermal compost, vermicompost, and some compost teas have potential for use in a fertility management plan in order to reduce synthetic and/or non-renewable chemical inputs.

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Table 4.1. Standard rates (X) used for fertility applications at Albany and Johns Creek sites.

Treatments	(X) Rate	Manufacturer	Location
Foothills TC ¹	244 g/m ²	Foothills Organics	Gainesville, GA
Biowash	0.32 mL/m ²	1 st EnviroSafety, Inc.	St. James City, FL
Casting4Growth VC ²	488 g/m ²	Casting4 Growth,LLC	Jacksonville, FL
Casting4Growth CT ³	407 mL/m ²	Casting4 Growth,LLC	Jacksonville, FL
Progress Earth CT	407 mL/m ²	Global Garden Supply	Burlingame, CA
Organic Bountea CT	407 mL/m ²	Organic Bountea	Forestville, CA
Atlanta Gas Light	1.6 g/m ²	Atlanta Gas Light	Atlanta, GA
Milorganite	1.9 g/m ²	Milorganite	Milwaukee, WI
Rivermont CT	407 mL/m ²	Rivermont GCCC	Johns Creek, GA
Rivermont VC	244 g/m ²	Rivermont GCCC	Johns Creek, GA
46-0-0 Urea	4.8 g/m ²		

¹TC denotes thermal compost.

²VC denotes vermicompost.

³CT denotes compost tea.

Table 4.2. Mean separation¹ for turfgrass quality and color (1-9) at the Albany location during the 2014 growing season.

Treatments	Quality			Color		
	14DAIT ²	42DAIT	56DAIT	14DAIT	42DAIT	56DAIT
Non-Treated	6.5 ab ³	5.5 abcd	5.7 abc	6.0 bc	5.4 abcd	6.2 ab
Foothills TC ⁴	6.8 ab	6.0 ab	6.4 abc	6.9 abc	5.9 abc	6.7 ab
Biowash	6.3 b	5.6 abcd	5.8 abc	6.1 c	5.4 abcd	6.7 ab
Casting4Growth VC ⁵	6.1 b	5.8 abcd	5.9 abc	6.2 c	6.2 a	6.4 ab
Casting4Growth CT ⁶	6.2 b	5.0 bcd	5.5 bc	6.3 bc	4.9 cd	6.1 ab
Progress Earth CT	6.2 b	4.8 cd	5.6 bc	6.3 bc	4.8 d	6.3 ab
Organic Bountea CT	6.1 b	4.7 d	5.3 c	6.2 c	5.0 bcd	5.9 b
Atlanta Gas Light	6.9 ab	6.1 a	6.8 ab	7.0 abc	5.8 abcd	6.9 ab
Milorganite	7.1 ab	6.2 a	7.1 ab	7.3 ab	6.3 a	7.1 a
46-0-0 Urea	7.5 a	5.9 abc	6.4 ab	7.9 a	5.9 ab	6.8 ab

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no data available on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

⁴TC denotes thermal compost.

⁵VC denotes vermicompost.

⁶CT denotes compost tea.

Table 4.3. Mean separation¹ for turf quality and color (1-9) at the Albany location during the 2015 growing season.

Treatments	Quality				Color			
	14DAIT ²	28DAIT	42DAIT	56DAIT	14DAIT	28DAIT	42DAIT	56DAIT
Non-Treated	5.7 a ³	5.8 abc	6.3 a	6.3 ab	5.7 a	6.0 ab	6.2 ab	6.3 a
Foothills TC ⁴ (1/2X)	5.5 a	6.3 abc	6.8 a	6.7 ab	5.7 a	6.5 ab	6.3 ab	6.0 a
Foothills TC (X)	5.7 a	6.3 abc	6.5 a	6.3 ab	5.7 a	6.3 ab	6.5 ab	6.3 a
Foothills TC (2X)	6.2 a	6.5 abc	6.8 a	6.7 ab	6.2 a	6.8 ab	6.5 ab	6.3 a
Biowash (1/2X)	4.5 a	5.3 abc	6.0 a	6.0 ab	4.5 a	5.5 b	6.2 ab	6.0 a
Biowash (X)	5.3 a	6.2 abc	6.7 a	6.3 ab	5.3 a	6.0 ab	6.3 ab	6.5 a
Biowash (2X)	4.8 a	5.2 bc	6.5 a	6.0 ab	5.0 a	5.8 ab	6.2 ab	6.3 a
Casting4Growth VC ⁵ (1/2X)	5.3 a	5.7 abc	6.0 a	6.0 ab	5.3 a	5.8 ab	6.2 ab	6.2 a
Casting4Growth VC (X)	5.2 a	5.8 abc	6.5 a	6.3 ab	5.2 a	6.0 ab	6.3 ab	6.3 a
Casting4Growth VC (2X)	5.3 a	6.0 abc	6.8 a	6.7 ab	6.0 a	6.3 ab	7.0 a	6.2 a
Casting4Growth CT ⁶ (1/2X)	5.5 a	5.7 abc	6.2 a	6.5 ab	5.2 a	5.7 ab	6.2 ab	6.0 a
Casting4Growth CT (X)	5.5 a	5.8 abc	6.5 a	6.5 ab	5.2 a	5.5 b	6.5 ab	6.3 a
Casting4Growth CT (2X)	5.3 a	5.7 abc	6.2 a	6.3 ab	5.3 a	5.8 ab	6.0 ab	6.0 a
Progress Earth CT (1/2X)	5.7 a	5.5 abc	6.3 a	6.3 ab	5.3 a	5.8 ab	6.0 ab	6.2 a
Progress Earth CT (X)	5.5 a	5.7 abc	6.2 a	6.3 ab	6.2 a	5.7 ab	6.0 ab	6.0 a
Progress Earth CT (2X)	5.5 a	5.8 abc	6.2 a	6.0 ab	6.0 a	6.0 ab	6.3 ab	6.0 a
Organic Bountea CT (1/2X)	5.5 a	5.5 abc	6.5 a	6.2 ab	5.5 a	6.2 ab	6.3 ab	6.3 a
Organic Bountea CT (X)	5.3 a	5.5 abc	5.7 a	5.7 b	5.3 a	5.5 b	5.5 b	6.0 a
Organic Bountea CT (2X)	5.5 a	5.7 abc	6.2 a	6.3 ab	5.7 a	5.8 ab	6.5 ab	6.2 a
Atlanta Gas Light (1/2X)	6.0 a	6.2 abc	7.0 a	6.7 ab	5.6 a	6.3 ab	6.5 ab	6.3 a
Atlanta Gas Light (X)	6.0 a	6.7 abc	6.8 a	6.8 a	5.7 a	6.5 ab	6.7 a	6.8 a
Atlanta Gas Light (2X)	6.5 a	6.8 ab	7.0 a	7.0 a	6.0 a	6.8 ab	6.7 a	6.7 a
Milorganite (1/2X)	5.8 a	6.3 abc	6.7 a	6.8 a	6.0 a	6.4 ab	6.7 a	6.5 a
Milorganite (X)	6.2 a	6.8 ab	7.0 a	6.7 ab	6.0 a	7.0 a	6.7 a	6.8 a
Milorganite (2X)	6.7 a	7.2 a	7.0 a	7.0 a	6.7 a	7.0 a	7.0 a	7.2 a
46-0-0 Urea (1/2X)	6.0 a	5.8 abc	6.5 a	6.5 ab	6.2 a	6.0 ab	6.7 a	6.5 a
46-0-0 Urea (X)	6.3 a	6.7 abc	6.8 a	6.5 ab	6.3 a	6.7 ab	6.8 a	6.8 a
46-0-0 Urea (2X)	6.0 a	6.2 abc	6.0 a	6.2 ab	6.0 a	6.5 ab	6.3 ab	6.5 a

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no data available on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

⁴TC denotes thermal compost.

⁵VC denotes vermicompost.

⁶CT denotes compost tea.

Table 4.4. Mean separation¹ for turfgrass quality and color (1-9) at the Johns Creek location during the 2014 growing season in general fertilizer study.

Treatments	Quality					Color					
	14DAIT ²	28DAIT	42DAIT	56DAIT	126DAIT	56DAIT	70DAIT	84DAIT	98DAIT	126DAIT	133DAIT
Non-treated	7.2 ab ³	6.8 a	6.5 bc	6.5 a	6.3 ab	6.5 ab	6.2 ab	6.0 ab	5.7 bc	6.3 ab	6.0 b
Foothills TC ⁴ (1/2X)	7.5 ab	7.0 a	6.7 abc	6.5 a	6.5 a	6.5 ab	6.5 ab	6.5 ab	6.0 abc	6.3 ab	6.0 b
Foothills TC (X)	7.8 a	7.0 a	6.7 abc	6.3 a	6.5 a	6.5 ab	6.0 b	6.3 ab	6.2 abc	6.5 ab	6.2 b
Foothills TC (2X)	7.7 a	6.8 a	6.8 abc	6.8 a	6.7 a	7.0 ab	6.2 ab	6.0 ab	5.8 abc	6.7 ab	6.3 ab
Biowash (1/2X)	7.3 ab	7.0 a	6.5 bc	6.3 a	6.5 a	6.5 ab	6.5 ab	6.3 ab	5.7 bc	6.2 b	6.0 b
Biowash (X)	7.3 ab	6.8 a	6.3 bc	6.3 a	6.5 a	6.7 ab	6.2 ab	6.2 ab	5.8 abc	6.5 ab	6.0 b
Biowash (2X)	7.0 ab	7.0 a	6.0 c	6.2 a	6.3 ab	6.5 ab	6.5 ab	6.0 ab	5.5 c	6.0 b	6.0 b
Casting4Growth VC ⁵ (1/2X)	7.3 ab	7.0 a	6.5 bc	6.5 a	6.5 a	6.7 ab	6.2 ab	5.8 b	5.8 abc	6.3 ab	6.0 b
Casting4Growth VC (X)	7.5 ab	6.8 a	6.8 abc	6.2 a	6.8 a	6.5 ab	6.2 ab	6.2 ab	5.3 c	6.7 ab	6.2 b
Casting4Growth VC (2X)	7.5 ab	7.0 a	7.0 abc	7.0 a	6.8 a	7.0 ab	6.3 ab	6.2 ab	5.7 bc	7.0 ab	6.3 ab
Casting4Growth CT ⁶ (1/2X)	7.2 ab	7.0 a	6.2 c	6.2 a	6.5 a	6.5 ab	6.2 ab	6.3 ab	5.3 c	6.0 b	6.2 b
Casting4Growth CT (X)	7.0 ab	7.0 a	6.0 c	6.2 a	6.5 a	6.3 b	6.2 ab	6.6 ab	5.7 bc	6.5 ab	6.2 b
Casting4Growth CT (2X)	7.2 ab	7.0 a	6.2 c	6.2 a	6.5 a	6.5 ab	6.2 ab	6.7 ab	6.0 abc	6.3 ab	6.0 b
Progress Earth CT (1/2X)	7.0 ab	7.0 a	6.2 c	6.3 a	6.5 a	6.5 ab	6.3 ab	6.2 ab	5.7 bc	6.3 ab	6.2 b
Progress Earth CT (X)	7.5 ab	7.0 a	6.2 c	6.7 a	6.3 ab	7.0 ab	6.2 ab	6.7 ab	5.7 bc	6.2 b	6.2 b
Progress Earth CT (2X)	7.7 a	7.0 a	6.3 bc	6.3 a	6.3 ab	6.5 ab	6.2 ab	6.2 ab	5.5 c	6.2 b	6.0 b
Organic Bountea CT (1/2X)	7.0 ab	6.8 a	6.5 bc	6.3 a	6.3 ab	6.7 ab	6.5 ab	6.3 ab	5.5 c	6.3 ab	6.0 b
Organic Bountea CT (X)	7.3 ab	7.0 a	6.5 bc	6.7 a	6.3 ab	6.7 ab	6.3 ab	6.0 ab	5.5 c	6.0 b	6.0 b
Organic Bountea CT (2X)	7.2 ab	6.8 a	6.3 bc	6.3 a	6.5 a	6.3 b	6.2 ab	6.3 ab	5.5 c	6.5 ab	6.0 b
Atlanta Gas Light (1/2X)	7.0 ab	7.0 a	6.2 c	6.2 a	6.3 ab	6.5 ab	6.5 ab	6.5 ab	6.2 abc	6.5 ab	6.0 b
Atlanta Gas Light (X)	7.0 ab	7.2 a	6.5 bc	6.7 a	6.7 a	6.8 ab	6.3 ab	6.8 ab	6.0 abc	6.7 ab	6.3 ab
Atlanta Gas Light (2X)	7.7 a	7.0 a	6.7 abc	6.7 a	6.8 a	6.8 ab	6.2 ab	6.3 ab	6.2 abc	6.7 ab	6.3 ab
Milorganite (1/2X)	7.5 ab	7.0 a	6.5 bc	6.7 a	6.5 a	6.7 ab	6.7 ab	6.5 ab	6.2 abc	6.5 ab	6.0 b
Milorganite (X)	7.7 a	7.3 a	7.0 abc	6.7 a	6.7 a	6.7 ab	6.3 ab	6.3 ab	6.0 abc	6.8 ab	6.3 ab
Milorganite (2X)	7.5 ab	7.0 a	7.0 abc	7.2 a	6.5 a	7.0 ab	6.2 ab	6.3 ab	6.5 ab	6.8 ab	6.5 ab
46-0-0 Urea (1/2X)	7.8 a	7.0 a	6.5 bc	6.7 a	6.5 a	6.8 ab	6.7 ab	6.3 ab	6.0 abc	6.7 ab	6.3 ab
46-0-0 Urea (X)	7.7 a	7.3 a	7.3 ab	7.2 a	6.2 ab	7.3 ab	7.0 a	6.8 ab	6.2 abc	6.8 ab	6.7 ab
46-0-0 Urea (2X)	8.2 a	7.3 a	7.7 a	7.0 a	5.5 b	7.7 a	6.7 ab	7.0 a	6.7 a	7.3 a	7.0 a
Rivermont VC (1/2X)	7.0 ab	7.0 a	6.3 bc	6.3 a	6.5 a	6.3 b	6.3 ab	6.2 ab	5.5 c	6.3 ab	6.0 b
Rivermont VC (X)	6.3 b	6.8 a	6.2 c	6.2 a	6.5 a	6.2 b	6.5 ab	6.2 ab	5.8 abc	6.7 ab	6.2 b
Rivermont VC (2X)	7.0 ab	6.8 a	6.7 abc	6.3 a	6.8 a	6.7 ab	6.5 ab	6.5 ab	5.8 abc	7.0 ab	6.0 b

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no data available on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

⁵VC denotes vermicompost.

⁶CT denotes compost tea.

Table 4.5. Mean separation¹ for turfgrass quality and color (1-9) at the Johns Creek location during the 2015 growing season.

Treatments	Quality					Color					
	70DAIT ²	112DAIT	140DAIT	154DAIT	168DAIT	42DAIT	56DAIT	70DAIT	84DAIT	112DAIT	140DAIT
Non-Treated	7.2 abc ³	6.2 ab	6.2 b	6.0 c	5.8 ab	7.0 abc	6.7 b	7.0 cd	6.7 cd	6.3 a	5.5 ef
Foothills TC ⁴ (1/2X)	7.3 abc	6.2 ab	6.2 b	6.0 c	6.0 a	7.0 abc	6.5 b	7.2 bcd	6.7 cd	6.3 a	5.8 cdef
Foothills TC (X)	7.5 abc	6.3 ab	6.0 b	6.0 c	6.0 a	7.3 abc	6.8 ab	7.3 abcd	7.0 bcd	6.5 a	6.2 bcdef
Foothills TC (2X)	7.5 abc	6.7 ab	6.0 b	6.2 bc	6.0 a	7.2 abc	6.8 ab	7.5 abcd	7.0 bcd	6.3 a	6.0 cdef
Biowash (1/2X)	7.0 bc	6.0 b	6.0 b	6.0 c	6.0 a	6.7 bc	6.7 b	6.8 cd	6.7 cd	6.0 a	5.5 ef
Biowash (X)	7.2 abc	6.5 ab	6.0 b	6.0 c	6.0 a	7.2 abc	7.0 ab	7.2 bcd	7.0 bcd	6.7 a	6.0 cdef
Biowash (2X)	6.8 c	6.0 b	6.0 b	6.0 c	6.0 a	6.7 bc	6.5 b	7.0 cd	6.5 cd	6.0 a	5.2 f
Casting4Growth VC ⁵ (1/2X)	7.3 abc	6.3 ab	6.0 b	6.0 c	6.0 a	7.0 abc	6.5 b	7.3 abcd	6.8 bcd	6.2 a	5.7 def
Casting4Growth VC (X)	7.3 abc	6.3 ab	6.2 b	6.0 c	6.0 a	7.2 abc	6.8 ab	7.3 abcd	7.0 bcd	6.3 a	6.3 abcdef
Casting4Growth VC (2X)	7.7 abc	6.3 ab	6.3 ab	6.2 bc	6.2 a	7.2 abc	7.0 ab	7.5 abcd	6.7 cd	6.3 a	6.3 abcdef
Casting4Growth CT ⁶ (1/2X)	7.0 bc	6.0 b	6.0 b	6.0 c	6.0 a	6.3 c	6.5 b	6.5 d	6.2 d	6.0 a	5.5 ef
Casting4Growth CT (X)	7.0 bc	6.2 ab	5.8 b	6.0 c	6.0 a	6.8 bc	6.7 b	7.2 bcd	6.7 cd	6.3 a	5.3 ef
Casting4Growth CT (2X)	7.2 abc	6.0 b	5.8 b	6.0 c	6.0 a	7.0 abc	6.8 ab	7.3 abcd	6.8 bcd	6.2 a	5.7 def
Progress Earth CT (1/2X)	7.0 bc	6.0 b	5.8 b	6.0 c	6.0 a	6.8 bc	6.7 b	7.0 cd	6.3 cd	6.0 a	5.2 f
Progress Earth CT (X)	7.3 abc	6.2 ab	5.8 b	6.0 c	6.0 a	7.2 abc	7.0 ab	7.3 abcd	6.8 bcd	6.2 a	5.3 ef
Progress Earth CT (2X)	6.8 c	6.2 ab	5.8 b	6.0 c	6.0 a	6.8 bc	6.7 b	7.2 bcd	6.5 cd	6.0 a	5.5 ef
Organic Bountea CT (1/2X)	7.5 abc	6.5 ab	5.8 b	6.0 c	6.0 a	7.3 abc	6.7 b	7.2 bcd	6.8 bcd	6.5 a	5.8 cdef
Organic Bountea CT (X)	7.0 bc	6.0 b	6.0 b	6.0 c	6.0 a	6.5 c	6.5 b	7.2 bcd	6.7 cd	6.0 a	5.5 ef
Organic Bountea CT (2X)	7.3 abc	6.5 ab	6.0 b	6.0 c	6.0 a	7.3 abc	7.0 ab	7.7 abcd	7.0 bcd	6.5 a	6.0 cdef
Atlanta Gas Light (1/2X)	7.0 bc	6.2 ab	6.0 b	6.0 c	6.0 a	7.2 abc	6.8 ab	7.3 abcd	6.7 cd	6.2 a	5.8 cdef
Atlanta Gas Light (X)	7.5 abc	6.8 ab	6.3 ab	6.0 c	6.0 a	7.5 abc	7.2 ab	7.7 abcd	7.2 abcd	6.8 a	6.7 abcde
Atlanta Gas Light (2X)	7.3 abc	6.2 ab	6.5 ab	6.0 c	6.0 a	7.2 abc	7.0 ab	7.3 abcd	6.8 bcd	6.2 a	6.5 abcdef
Milorganite (1/2X)	7.3 abc	6.3 ab	6.3 ab	6.0 c	6.2 a	7.2 abc	6.8 ab	7.3 abcd	6.8 bcd	6.3 a	6.3 abcdef
Milorganite (X)	7.8 ab	6.5 ab	6.7 ab	6.5 a	6.0 a	7.3 abc	7.0 ab	7.7 abcd	7.0 bcd	6.3 a	6.5 abcdef
Milorganite (2X)	7.8 ab	6.7 ab	7.2 a	6.0 c	5.5 b	7.8 ab	7.3 ab	8.0 abc	7.5 abc	6.7 a	7.2 abc
46-0-0 Urea (1/2X)	7.8 ab	6.5 ab	6.7 ab	6.3 ab	4.8 c	7.3 abc	7.0 ab	7.8 abcd	7.3 abcd	6.3 a	7.0 abcd
46-0-0 Urea (X)	8.0 a	6.5 ab	6.7 ab	6.0 c	6.0 a	7.8 ab	7.5 ab	8.5 ab	8.0 ab	6.8 a	7.5 ab
46-0-0 Urea (2X)	7.7 abc	7.2 a	6.2 b	6.0 c	6.0 a	8.2 a	8.0 a	8.7 a	8.3 a	7.0 a	7.7 a
Rivermont VC (1/2X)	7.3 abc	6.5 ab	6.2 b	6.0 c	6.0 a	7.0 abc	6.8 ab	7.0 cd	7.0 bcd	6.7 a	5.8 cdef
Rivermont VC (X)	7.2 abc	6.2 ab	6.2 b	6.0 c	6.2 a	7.3 abc	6.8 ab	7.2 bcd	6.7 cd	6.3 a	5.8 cdef
Rivermont VC (2X)	7.2 abc	6.5 ab	6.3 ab	6.0 c	6.0 a	7.0 abc	7.2 ab	7.3 abcd	7.0 bcd	6.5 a	6.3 abcdef

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no data available on that date

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

⁵VC denotes vermicompost.

⁶CT denotes compost tea

⁴TC denotes thermal compost.

Table 4.6. Mean separation¹ for turfgrass quality and color (1-9) comparing compost teas at the Albany location during the 2015 growing season.

Treatments	Quality					Color			
	84DAIT ²	98DAIT	112DAIT	126DAIT	140DAIT	28DAIT	98DAIT	112DAIT	140DAIT
Non-Treated	6.5 a ³	6.2 a	6.0 a	6.7 a	6.0 a	5.0 b	5.9 a	6.2 ab	5.7 ab
Casting4Growth CT ⁴ (1/2X)	6.3 a	6.0 a	6.2 a	6.5 ab	6.0 a	5.5 ab	6.2 a	6.2 ab	6.0 ab
Casting4Growth CT (X)	6.3 a	6.0 a	6.3 a	6.7 a	6.0 a	5.3 ab	6.0 a	6.0 ab	5.3 b
Casting4Growth CT (2X)	6.2 ab	6.0 a	6.2 a	6.7 a	5.8 a	5.0 b	5.7 a	5.8 b	5.5 ab
Progress Earth CT (1/2X)	6.5 a	6.0 a	6.2 a	6.5 ab	6.0 a	5.7 ab	5.7 a	6.0 ab	6.0 ab
Progress Earth CT (X)	6.0 ab	5.7 ab	6.0 a	6.0 ab	5.7 a	5.5 ab	5.8 a	5.7 b	5.2 b
Progress Earth CT (2X)	6.2 ab	5.7 ab	6.2 a	6.5 ab	6.0 a	5.5 ab	5.7 a	5.8 b	6.0 ab
Organic Bountea CT (1/2X)	6.5 a	6.0 a	5.8 a	6.3 ab	5.8 a	6.0 ab	6.0 a	5.8 b	5.7 ab
Organic Bountea CT (X)	6.3 a	6.2 a	6.3 a	6.3 ab	6.0 a	6.0 ab	6.2 a	6.0 ab	5.7 ab
Organic Bountea CT (2X)	6.5 a	6.0 a	6.2 a	6.3 ab	6.0 a	6.0 ab	6.0 a	6.0 ab	6.0 ab
46-0-0 Urea (1/2X)	6.0 ab	5.5 ab	5.5 ab	6.0 ab	5.5 a	6.2 ab	5.5 a	6.5 ab	6.3 ab
46-0-0 Urea (X)	5.8 ab	4.8 bc	5.0 ab	6.0 ab	5.3 ab	6.0 ab	5.3 a	6.7 ab	6.3 ab
46-0-0 Urea (2X)	4.8 b	4.3c	4.3 b	5.3 b	4.5 b	6.3a	4.7 a	7.0 a	7.0 a

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no data available on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

⁴CT denotes compost tea

Table 4.7. Mean separation¹ for turfgrass quality and color (1-9) comparing compost teas at the Johns Creek location during the 2014 growing season.

Treatments	Quality				Color			
	28DAIT ²	42DAIT	56DAIT	70DAIT	42DAIT	56DAIT	70DAIT	84DAIT
Non-Treated	7.0 b ³	6.2 c	6.0 ab	6.5 a	6.2 cd	6.2 c	6.5 ab	6.0 b
Casting4Growth CT ⁴ (1/2X)	7.0 b	6.2 c	6.2 ab	6.5 a	6.5 cd	6.3 bc	6.5 ab	6.3 ab
Casting4Growth CT (X)	7.0 b	6.2 c	6.2 ab	6.5 a	6.5 cd	6.3 bc	6.5 ab	6.3 ab
Casting4Growth CT (2X)	7.0 b	6.0 c	6.5 ab	6.5 a	6.5 cd	6.7 abc	6.3 b	6.5 ab
Progress Earth CT (1/2X)	7.0 b	6.0 c	6.2 ab	6.5 a	6.5 cd	6.2 c	6.3 b	6.2 ab
Progress Earth CT (X)	7.0 b	6.3 bc	6.2 ab	6.5 a	6.5 cd	6.2 c	6.3 b	6.2 ab
Progress Earth CT (2X)	7.0 b	6.0 c	5.8 b	6.5 a	6.0 d	6.0 c	6.2 b	6.3 ab
Organic Bountea CT (1/2X)	6.8 b	6.2 c	6.0 ab	6.5 a	6.0 d	6.2 c	6.3 b	6.2 ab
Organic Bountea CT (X)	7.0 b	6.2 c	6.2 ab	6.5 a	6.3 cd	6.2 c	6.5 ab	6.3 ab
Organic Bountea CT (2X)	7.0 b	6.7 bc	6.3 ab	6.5 a	6.8 bc	6.5 bc	6.5 ab	6.5 ab
46-0-0 Urea (1/2X)	7.0 b	6.3 bc	6.7 ab	6.5 a	6.7 bcd	6.7 abc	6.8 ab	6.5 ab
46-0-0 Urea (X)	7.3 a	7.0 ab	6.8 ab	6.3 a	7.3 ab	7.3 ab	7.2 a	6.8 ab
46-0-0 Urea (2X)	7.5 a	7.5 a	7.2 a	5.3 b	7.8 a	7.7 a	7.2 a	7.0 a
Rivermont Tea (1/2X)	7.0 b	6.0 c	6.2 ab	6.5 a	6.5 cd	6.3 bc	6.5 ab	6.0 b
Rivermont Tea (X)	7.0 b	6.2 c	6.2 ab	6.3 a	6.7 bcd	6.2 c	6.3 b	6.5 ab
Rivermont Tea (2X)	7.0 b	6.2 c	6.3 ab	6.3 a	6.5 cd	6.2 c	6.5 ab	6.5 ab

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no data available on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

⁴CT denotes compost tea.

Table 4.8. Mean separation¹ for turfgrass quality and color (1-9) comparing compost teas at the Johns Creek location during the 2015 growing season.

Treatments	Quality					Color						
	14DAIT ²	42DAIT	56DAIT	70DAIT	84DAIT	14DAIT	28DAIT	70DAIT	84DAIT	112 DAIT	140DAIT	168DAIT
Non-Treated	6.5 c ³	6.8 c	6.5 bc	6.7 c	6.5 bc	6.7 c	7.0 bc	7.0 c	6.5 b	6.2 b	5.0 d	4.0 ab
Casting4Growth CT ⁴ (1/2X)	6.7 c	6.8 c	6.5 bc	6.7 c	6.3 c	6.8 bc	6.7 c	7.0 c	6.5 b	6.2 b	5.3 cd	4.0 ab
Casting4Growth CT (X)	6.5 c	6.7 c	6.7 bc	6.7 c	6.5 bc	6.8 bc	6.7 c	7.2 c	6.5 b	6.2 b	5.3 cd	4.3 a
Casting4Growth CT (2X)	6.7 c	6.8 c	6.5 bc	6.8 c	6.5 bc	6.7 c	6.8 bc	7.2 c	6.5 b	6.0 b	5.2 d	4.0 ab
Progress Earth CT (1/2X)	6.3 c	6.8 c	6.7 bc	7.0 c	6.5 bc	6.3 c	6.5 c	6.8 c	6.5 b	6.0 b	5.5 cd	4.2 a
Progress Earth CT (X)	6.5 c	6.8 c	6.5 bc	6.8 c	6.7 bc	6.7 c	6.7 c	7.0 c	6.7 b	6.0 b	5.2 d	3.8 ab
Progress Earth CT (2X)	6.5 c	6.7 c	6.3 c	6.7 c	6.5 bc	6.5 c	6.5 c	6.8 c	6.3 b	6.0 b	5.0 d	4.0 ab
Organic Bountea CT (1/2X)	6.5 c	7.0 bc	6.5 bc	6.8 c	6.7 bc	7.0 bc	6.5 c	7.0 c	6.5 b	6.0 b	5.3 cd	3.8 ab
Organic Bountea CT (X)	6.5 c	7.0 bc	6.3 c	6.8 c	6.5 bc	7.0 bc	6.7 c	7.2 c	6.3 b	6.0 b	5.0 d	3.8 ab
Organic Bountea CT (2X)	6.7 c	6.7 c	6.5 bc	6.8 c	6.7 bc	6.8 bc	6.5 c	7.0 c	6.5 b	6.0 b	5.5 cd	4.2 a
46-0-0 Urea (1/2X)	7.2 b	7.3 abc	7.2 ab	7.3 bc	7.0 b	7.2 bc	7.0 bc	7.5 bc	7.0 b	6.2 b	6.3 bc	3.3 ab
46-0-0 Urea (X)	7.7 a	7.7 ab	7.2 ab	8.0 ab	7.7 a	7.8 ab	7.7 ab	8.2 ab	8.0 a	7.2 a	7.3 ab	2.8 b
46-0-0 Urea (2X)	8.0 a	7.8 a	7.7 a	8.2 a	7.8 a	8.5 a	8.2 a	8.7 a	8.5 a	7.0 a	7.7 a	1.3 c
Rivermont CT (1/2X)	6.5 c	6.8 c	6.5 bc	6.8 c	6.5 bc	6.7 c	6.5 c	7.3 bc	6.5 a	6.0 b	5.7 cd	4.2 a
Rivermont CT (X)	6.5 c	6.8 c	6.5 bc	6.8 c	6.5 bc	6.8 bc	7.0 bc	7.0 c	6.8 b	6.0 b	5.7 cd	4.2 a
Rivermont CT (2X)	6.5 c	6.8 c	6.5 bc	7.0 c	6.5 bc	6.5 c	6.7 c	7.2 c	6.5 b	6.0 b	5.5 cd	4.2 a

¹Source – Tukey’s HSD mean separation test at $\alpha=0.05$

²DAIT denotes days after initial treatment. (---) denotes no data available on that date.

³Means within a column followed by the same lowercase letter are not statistically different according to Tukey’s HSD at the $p \leq 0.05$ significance level.

⁴CT denotes compost tea.

CHAPTER 5
SUMMARY & CONCLUSIONS

Introduction

The growing popularity of non-synthetic management strategies in order to lessen long-term environmental impacts has created demand for research into products that can serve that need. These products vary widely, from plant hormones to sea water, and many of these are not formally labeled for use in agricultural systems. No legal restrictions exist for what non-synthetic products are allowed in organic turfgrass systems, unlike food production.

Herbicide Trials

Organic herbicides have potential to provide control for warm-season turfgrass weeds, particularly products with the active ingredients d-limonene such as Avenger, or acetic acid like WeedPharm. Scythe is an effective middle ground for consumers not strictly seeking nonsynthetic alternatives. Regardless of growth stage, repeat applications are necessary in an organic program, although the herbicides are more effective at younger growth stages. Previously reported postemergent weed control with CGM is likely due to a fertility effect that allowed the turfgrass to outcompete weeds. These products are non-selective, meaning that they will cause tissue damage to any leaves it comes in contact with, ergo these products would best be utilized as a spot spray to preserve the aesthetic value of lawns, fields, and other warm-season turfgrasses especially since the heat can exacerbate phytotoxicity.

Future research should center around new products and effective programs for practical use by homeowners and professionals. New products should be investigated as they are developed, with an emphasis on new, more selective modes of action in organic products that would be effective in warm-season turfgrasses. Due to the lack of

commercially-available preemergent organic products, searching for products that could fulfill this need is also a priority.

Fungicide Trials

Disease is mostly a game of prevention, however it is wise to have curative measures at the ready for disease control no matter what program is used. Organic materials are often needed to be accompanied by cultural measures like mowing. Compost and compost products have potential for disease suppression. TerraCyte Pro, an OMRI listed oxidizer product, stands out as an effective option. All of the organic treatments were as effective as the representative industry standard Emerald, however plots with these treatments were not significantly different from the non-treated plots. These organic options show potential for use in non-conventional turfgrass stands. Depending on the goals and standards of the turf manager, these products can be utilized alone or may be utilized in an integrated disease management plan in order to reduce inputs, particularly in preparation for cooler, more humid times of the year.

Fertilizer Trials

Efficacy varied greatly during the course of these field trials, however using a high application rate of some materials and understanding the local soil type can produce more consistent results. In the general fertilizer study, the municipal wastes, composts, and Biowash fertilizer enhancer outperformed the compost tea treatments, however high rate Biowash yielded lower quality than other organic treatments due to how it breaks down nutrients in the soil. Among the compost teas only, Organic Bountea had the most effect. The application of compost tea to a turfgrass canopy was not as noticeable to the naked eye for the week following application. Depending on the goals of the turfgrass

manager, municipal wastes, thermal compost, vermicompost, and some compost teas have potential for use in a fertility management plan in order to reduce synthetic and/or non-renewable chemical inputs.

Overall Conclusion

The different expectations and needs that turfgrasses serve will likely influence any regulation in the future. More non-synthetic products will rise out of ongoing research, and find places within the IPM and organic management programs of the future. Further study of effective programs in warm-season conditions will aid professionals in customizing programs in the future where organic programs may become more popular in the southeastern U.S. Lastly, studies should be conducted on warm-season species other than bermudagrass to test efficacy. These topics would greatly add to the utilization of the commercially-available products investigated here, as well as aid in the placement of these products in organic and IPM programs.

APPENDIX

A. Compost tea mixtures for 20 L batch.

Casting4Growth	Progress Earth	Organic Bountea
296 mL molasses	62.37 g Earth syrup	154 g Bioactivator
1497 g earthworm castings	15.6 g Earth compound	1.9 L Humisoil
	16.3 mL Earth	154 g M3 (Marine Mineral Magic)
	32.5 mL Earth Kelp	

B. Soil samples from trials at the Albany site in Nov 2015.

Sample Zone	P (ppm)	K(ppm)
General Fertilizer Trial		
Zone 1	57.6	33
Zone 2	71.7	30
Zone 3	53.3	24
Zone 4	70.4	32
Zone 5	64.0	27
Zone 6	69.8	34
Compost Tea Trial		
Zone 1	62.8	25
Zone 2	61.8	24
Zone 3	74.3	25
Fungicide Trial		
Zone 1	70.5	57
Zone 2	54.0	44
Zone 3	54.6	51
Zone 4	50.3	47

C. Soil samples from trials at the Johns Creek site in Nov 2015.

Sample Zone	P (ppm)	K(ppm)
General Fertilizer Trial		
Zone 1	24.8	118
Zone 2	23.3	97
Zone 3	31.9	114
Zone 4	33.8	118
Zone 5	26.6	140
Zone 6	32.6	120
Compost Tea Trial		
Zone 1	29.2	104
Zone 2	21.7	102
Zone 3	20.6	100
Fungicide Trial		
Zone 1	27.3	108
Zone 2	24.8	109
Zone 3	27.3	100

D. Weather data during applications for trials at the Albany site in 2014 and 2015.

Date	Temp High (°C)	Temp Low (°C)	Rainfall (cm)
General Fertilizer & Compost Tea Trials			
25-May-2014	34.4	20.2	0
19-Jun-2014	33.7	22.9	0.25
17-Jul-2014	30.4	18.4	0
14-Aug-2014	33.8	21.4	0
24-Sep-2014	21.7	14.3	0
02-Jun-2015	29.3	18.7	2.87
30-Jun-2015	30.4	20.9	0.99
28-Jul-2015	36.3	22.6	0
25-Aug-2015	32.7	21.5	0
30-Sep-2015	31.4	22.7	0.91
Fungicide Trial			
05-Jun-2014	33.2	21.7	0
03-Jul-2014	35.3	24.9	0
31-Jul-2014	32.7	18.2	0
18-Sept-2014	30.4	19.3	0
09-Oct-2014	31.9	18.1	0
17-Jun-2015	36.9	22.7	2.06
15-Jul-2015	35.7	23.9	0.64
12-Aug-2015	34.8	23.3	0
10-Sep-2015	35.6	21.7	0.36
13-Oct-2015	28.1	15.7	0.25

E. Weather data during applications for trials at the Johns Creek site in 2014 and 2015.

Date	Temp High (°C)	Temp Low (°C)	Rainfall (cm)
General Fertilizer & Compost Tea Trials			
20-May-2014	28.2	10.8	0
17-Jun-2014	33.2	19.9	0
15-Jul-2014	30.1	20.6	0
12-Aug-2014	31.6	21.7	0
07-Oct-2014	27.3	13.0	0
16-Jun-2015	35.0	20.9	0
14-Jul-2015	34.2	20.3	3.51
11-Aug-2015	32.4	21.7	0.58
08-Sep-2015	28.9	19.9	0.13
06-Oct-2015	24.6	14.4	0
Fungicide Trial			
03-Jun-2014	30.2	17.1	0
30-Jun-2014	27.4	20.3	0.15
12-Aug-2014	31.6	21.7	0
30-Sept-2014	29.1	16.7	0
23-Oct-2014	20.4	3.1	0
16-Jun-2015	35.0	20.9	0
14-Jul-2015	34.2	20.3	3.51
11-Aug-2015	32.4	21.7	0.58
08-Sep-2015	28.9	19.9	0.13
06-Oct-2015	24.6	14.4	0

F. Weather data during applications for herbicide trials at the Griffin site in 2015.

Date	Temp High (°C)	Temp Low (°C)	Rainfall (cm)
18-Sep-2015	27.9	14.3	0
06-Oct-2015	24.4	14.4	0.03
