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Evaluation of Biological Thatch Control on Golf Greens

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EVALUATION OF BIOLOGICAL THATCH CONTROL ON GOLF GREENS

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ABSTRACT

Thatch is a layer of living and dead plant material (stems and roots) between turfgrass leaf tissue and the soil surface and if excessive, it can decrease playability of turf surfaces, increase mower scalping and disease pressure, reduce pesticide efficacy and water infiltration, plus harbor insects. In golf greens, mechanical, thus, disruptive practices such as vertical mowing, core cultivation, grooming, and topdressing are traditional agronomic methods for managing thatch/organic matter. Greenhouse and field experiments were conducted for two years to evaluate two commercial biostimulant products, Worm Power and Earth MAX, and their impact on thatch and rooting depth. Earth MAX had two rates, and was named Earth MAX (1) and Earth MAX (2). In addition to the biostimulants, two industry standards were included: blackstrap molasses and sand topdressing. Greenhouse studies yielded results showing Earth MAX (1), and sand topdressing provided an average of 16% greater root length than untreated control in year 1. However, in year 2, Worm Power provided 16% greater root length than untreated control. Earth MAX (1) provided 117% greater root mass than untreated control in year 2. No treatments provided greater root mass in Year 1. For both years, blackstrap molasses, Earth MAX (1), and Earth MAX (2) reduced thatch thickness by 30%, 24%, and 18% respectively, versus the untreated; however, no decrease in thatch weight by treatments was observed. Whereas, results from the two-year field trials, showed that all treatments, with the exception of blackstrap molasses, provided an average of

18% greater root length than untreated control. However, blackstrap molasses provided 146% greater root mass, and 9% less thatch weight over the two-year study when compared to the untreated control. For both years, blackstrap molasses, Earth MAX (1), and Earth MAX (2), and Worm Power reduced thatch thickness an average of 26% versus the untreated.

DEDICATION

In hopes that this work may in some way contribute to the turfgrass managers not only in South Carolina but around the world. I would like to dedicate this dissertation to my family and friends that helped me get to this point in my academic career. To my wife and kids who allowed me to study when I needed to study, pushed me when I needed to be pushed, and picked me up when I needed to be picked up. To my late grandfather, and uncle, who always told me to get my education and to let nothing stand in the way of doing so. To my mom who always made sure I always had what I needed and told me I could be and do anything in life. To my grandmother who always supported me and gave me constant words of encouragement. To Dr. Steve Cole, for mentoring and encouraging me through this journey. To all my professors during my college career, and to all my teachers, this is dedicated to you for all the help you provided me with and for all the words of encouragement.

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CHAPTER ONE

INTRODUCTION

Thatch has been defined by various researchers in previous years. McCarty (2018) defined thatch as a layer of living and dead plant material (stems and roots) between turfgrass leaf tissue and the soil surface. Ledeboer and Skogley (1967) referred to thatch as an "excessive accumulation of undecomposed surface organic matter." Beard (1973) defined thatch as "a tightly intermingled layer of dead and living stems and roots that develops between the zone of green vegetation and the soil surface." McCarty (2005) noted that a thatch layer between 0.25 and 0.5 inches (0.64 and 1.3cm) on golf greens is desirable and that this thin thatch layer would provide cushion for approaching golf shots and provide some protection of the grass crowns from traffic.

Warm-season turfgrass species such as bermudagrass (*Cynodon dactylon*), zoysiagrass (*Zoysia japonica*) and St. Augustine (*Stenotaphrum secundatum*) that exhibit vigorous, prostrate growth habits, in the form of stolons and/or rhizomes, are more susceptible to thatch accumulation (Harivandi 1984). Excessive thatch and other organic material can decrease playability of turf surfaces, mower scalping, increased disease pressure, reduced pesticide efficacy, and poor water infiltration (McCarty et al., 2016). Approximately 25% of thatch is made up of lignin, an alcohol containing polymer which, contributes to cell wall rigidity. Due to its complex makeup and high molecular weight, lignin is resistant to decay by microorganisms and a main reason why thatch accumulates faster than it decomposes. The remainder of thatch consists primarily of cellulose and hemicellulose compounds that decompose more readily (Ledeboer and Skogley, 1967).

Soil microorganisms are the primary means by which thatch is naturally decomposed. Turfgrass soils vary considerably in physical and chemical composition, however, regardless of their properties most contain living organisms ranging from earthworms and insects to microscopic invertebrates' bacteria, fungi, actinomycetes, yeasts, algae and protozoa. Mueller and Kussow (2005) applied biostimulants to a creeping bentgrass putting green and noted these had little influence on the soil microbial activity or composition of the microbial community; but did, improve the visual quality of the turfgrass. Chen et al. (2002) investigated two commercial biostimulants and found they could inhibit as well as stimulate soil microbial activities depending on the concentration of the application, the quality of organic materials in the soil, and time.

In a golf green setting, mechanical practices such as vertical mowing, core cultivation, grooming, and topdressing are used for managing thatch/OM. Of the aforementioned practices, vertical mowing and core cultivation are more disruptive to the playing surface than grooming or topdressing (McCarty et al., 2007). Carrow et al. (1987) reported an 8% decline in 'Tifway' bermudagrass [*Cynodon dactylon* (L.) Pers. × C. *transvaalensis* (Burtt-Davis)] thatch with vertical mowing twice a year and a 44% to 62% decrease with sand topdressing. Dunn et al. (1981) reported decreases of 12 to 18% in thatch depth for zoysiagrass over five years with vertical mowing. Greater reductions in thatch were reported by Weston and Dunn (1985) on bermudagrass when both vertical mowing and core cultivation were implemented. Some thatch in turfgrass is necessary and desirable. Thatch becomes a problem in turf when it develops more rapidly than it can naturally decompose. Previous studies have been conducted to investigate biological thatch control options to minimize it in turfgrass. By-in-large, these products have been dismissed by soil scientists and agronomists as largely ineffective, or at best, have shown limited valid scientific basis for their use (Miller, 1990). Most biological products contain an array of sucrose, glucose, or other sugar sources, low nutrient content, various acids, and inoculated microorganisms (McCarty et al., 2007). Biostimulants are defined by Schmidt et al. (2003) as organic materials that, when applied in small quantities, enhance plant growth and development. A commercial product, Thatch-X (biostimulant), did not control thatch-mat accumulation in creeping bentgrass (*Agrostis palustris subsp. stolonifera* L.) after a single year of use (McCarty et al. 2007). However, a 16% reduction in thatch thickness did occur in creeping bentgrass, but only after two years of continuous use (Willis et al. 2006). Tucker et al. (2006) noted the use of biostimulants did not influence thatch layer depth in ‘TifEagle’ bermudagrass (*Cynodon dactylon* (L.) Pers. × *Cynodon transvaalensis* (Burtt-Davy)), but did positively influence root length density. McCarty et al. (2016) reported a minimal reduction of thatch and organic matter on a ‘Tifway’ bermudagrass fairway with the use of biostimulants.

A commonly used practice of decreasing thatch is sand topdressing. Ledeboer and Skogley (1967) noted topdressing was an effective practice for controlling thatch by improving the microenvironment for its decomposition.

Eggens (1980) furthermore observed topdressing alone was an effective thatch control treatment on ‘Penncross’ creeping bentgrass. White and Dickens (1984) noted topdressing four times yearly reduced thatch accumulation more than a single topdressing application. McCarty et al. (2007) noted topdressing alone failed to control thatch/mat annual accumulation or improve water infiltration in the study, but turfgrass quality and water infiltration of plots receiving topdressing alone was vastly improved.

Another method employed for controlling thatch is applying a sucrose source such as molasses. One commercial molasses source, ‘The Plant Food Company’, claims “molasses reduces thatch by a carbohydrate energy source that feeds soil microorganisms and increases microbial activity. With continued applications, blackstrap molasses encourages a soil environment that helps reduce thatch” (Plant Food Company, 2017). Holl et al. (2005) found minimal effect on soil microorganisms with molasses while McCarty et al. (2016) noted no reduction of thatch/organic matter depth or organic matter weight reduction with molasses on a ‘Tifway’ bermudagrass fairway.

There are a few ways to measure thatch in a turfgrass setting, such as, (thatch-meter, organic matter loss-on-ignition, and a standard ruler. Callahan (1998) compared the effectiveness of commonly used mechanical practices and certain chemical/nutrient treatments in controlling thatch on a creeping bentgrass green constructed to USGA specifications. Callahan (1998) used a thatch-meter to measure the depth of the thatch layer versus the other methods because it proved to be the most sensitive, consistent, reliable, and the fastest of the methods.

Plant biostimulants are diverse substances and microorganisms used to enhance plant growth. The global market for biostimulants is projected to increase 12 % per year and reach over $2,200 million by 2018 (Calvo et al. 2014). Despite the growing use of biostimulants in agriculture, many in the scientific community consider biostimulants to be lacking peer-reviewed scientific evaluation (Calvo et al. 2014). Currently, in the United States (US), biostimulants are unregulated in that they don't require a regulatory label review prior to going to market, as fertilizers and pesticides do. However, The Agriculture Improvement Act of 2018, also known as the 2018 Farm Bill, was signed into law on December 20, 2018, and provides the first statutory language regarding plant biostimulants in any law in the US (Agriculture Improvement Act, 2018). The 2018 Farm Bill describes a plant biostimulant as "a substance or micro-organism that, when applied to seeds, plants, or the rhizosphere, stimulates natural processes to enhance or benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, or crop quality and yield." The 2018 Farm Bill included language that requires the Secretary of Agriculture, EPA Administrator, states and relevant stakeholders to provide a report to Congress that identifies any potential regulatory and legislative recommendations, including the appropriateness of any definition for plant biostimulants. The intent of this report is to facilitate the development a regulatory framework for plant biostimulant products and to ensure the efficient and appropriate review, approval, uniform national labeling, and availability of these products to agricultural producers. The inclusion of a description of a plant biostimulant is a huge development in the long-term goal of understanding and recognizing these beneficial products. This new law will support the development of new sustainable technologies for U.S. agriculture and its farmers. In contrast, The European Union (EU) Fertilizing Products Regulation has proposed a claim-based definition of plant biostimulants, stipulating that “plant biostimulant” means a product stimulating plant nutrition processes independently of the product’s nutrient content, with the aim of improving one or more of the following characteristics of the plant: nutrient use efficiency, tolerance to abiotic stress, crop quality traits or availability of confined nutrients in the soil and rhizosphere. The future regulation also specifies that a plant biostimulant “shall have the effects that are claimed on the label for the plants specified thereon” (Ricci et al. 2019). Regulations such as those being proposed in the EU would require manufacturers to demonstrate to regulators and customers that product claims are justified. It remains to be seen how the language added to the 2018 Farm Bill regarding biostimulants will be adopted by federal and state agencies, but perhaps it will bring uniformity to an unregulated space within our industry.

Two highly marketed biostimulant products currently on the market are Worm Power Turf and Earth MAX. Worm Power manufactured by Aqua Aid Solutions, is a vermicompost material derived from earthworm (*Eisenia fetida*) castings in a controlled environment setting (Aqua Aid Solutions, 2020). The company’s website claims the product provided a 50% thatch reduction on a

‘Poa’ fairway and a ‘TifEagle’ bermudagrass green after two applications at a rate of 473 ml 1,000 ft^{-2} 30 days apart. However, no known published research substantiates these claims. Earth MAX is marketed by Harrell’s and contains 3% organic matter (derived from Humus) and 4.3% Harrell’s.com, 2020).

The objectives of this research were:

1. Determine the effects biostimulants and cultural practices have on turfgrass rooting length.
2. Determine the effects biostimulants and cultural practices have on turfgrass rooting mass.
3. Determine the effects biostimulants and cultural practices have on turfgrass thatch thickness, and thatch weight.
4. Determine the effects biostimulants have on turfgrass quality.

By evaluating these objectives, it is hoped that a less or non-destructive means of reducing or naturally controlling thatch/OM buildup associated with golf greens is found. If successful, this could reduce the needs of traditional destructive means of obtaining this goal. Revenue reductions associated with aerification, verticutting, and topdressing would potentially be eliminated, providing a highly desirable playing surface with less imperfections.

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CHAPTER TWO

EVALUATING BIOLOGICAL THATCH CONTROL ON TURFGRASS IN GREENHOUSE TRIALS

Note: This work has been submitted to International Turfgrass Society Research Journal.

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Abstract

Thatch is a layer of living and dead plant material (stems and roots) between turfgrass leaf tissue and the soil surface. If excessive, it can decrease playability of turf surfaces, increase mower scalping and disease pressure, reduce pesticide efficacy and water infiltration, and harbor insects. In golf greens, disruptive mechanical practices such as vertical mowing, core cultivation, grooming, and topdressing are traditional agronomic methods for managing thatch/organic matter. Greenhouse experiments were conducted to evaluate two commercial biostimulant products, Worm Power and Earth MAX, and their impact on thatch and rooting depth. In addition to the biostimulants, two industry standards were included: blackstrap molasses and sand topdressing. In Year 1, Earth MAX (1) and sand topdressing provided an average of 16% greater root length than untreated control. In Year 2, Worm Power provided 16% greater root length than untreated control. Earth MAX (1) provided 117% greater root mass

than untreated control in year 2. No treatments provided greater root mass in Year 1. For both years, blackstrap molasses, Earth MAX (1), and Earth MAX (2) reduced thatch thickness by 30%, 24%, and 18% respectively, versus the untreated; however, no decrease in thatch weight by treatments was observed.

Abbreviations: NDVI, normalized difference vegetation index; TQ, turf quality.

Introduction

Thatch is a layer of living and dead plant material (stems and roots) between turfgrass leaf tissue and the soil surface (McCarty, 2018). Moderate levels of thatch provide desirable surface resiliency and nutrient retention, but excessive levels can decrease playability of turf surfaces, increase disease pressure and mower scalping, reduce pesticide efficacy and water infiltration (McCarty et al., 2016). In a high maintenance turf setting such as a golf green, plant tissue often is produced faster than decomposed, resulting in thatch accumulation. Various factors affect thatch buildup such as frequency of mowing, mowing height, type of grass, clipping removal, amount and type of fertilizer used, certain pesticides, insufficient topdressing and aeration, and excessive soil moisture.

In recent years, considerable attention has garnered toward controlling of thatch/organic material buildup in high quality golf greens without the use of traditional destruction/disturbance means such as aerification, verticutting, grooming, and topdressing. The desire to move away from these destructive methods is course revenue typically drops following these events for up to four weeks (McCarty, 2018).

Many recently introduced products claim they aid in thatch reduction but little scientific data exists to positively substantiate this. Previous studies have investigated biological thatch control options including biostimulants, a term commonly associated with such products. Biostimulants can be defined as organic materials that, when applied in small quantities, enhance plant growth and development (Schmidt et al. 2003). While these products may appear new in the industry, they have actually been around for many years. Ledeboer and Skogley (1967) noted thatch decomposition without physically disrupting the turfgrass soil surface would be of great value. Inconsistent results have been observed from these products, although, a valid scientific basis for their use may exist (Miller, 1990). Most biostimulants contain an array of sucrose, glucose, or other sugar sources, plant nutrients at low rates, various acids, and inoculated microorganisms (McCarty et al., 2007). A commercial product, Thatch-X (biostimulant), did not control thatch-mat accumulation in creeping bentgrass (*Agrostis palustris subsp. stolonifera* L.) after a single year of use (McCarty et al. 2007). However, a 16% reduction in thatch thickness did occur in creeping bentgrass, but only after two years of continuous use (Willis et al. 2006). Tucker et al. (2006) noted the use of biostimulants did not influence thatch layer depth in 'TifEagle' bermudagrass (*Cynodon dactylon (*L.*)* Pers. × *Cynodon transvaalensis* (Burtt-Davy)), but did positively influence root length density. McCarty et al. (2016) reported a minimal reduction of thatch and organic matter on a 'Tifway' bermudagrass fairway with the use of biostimulants.

The objective of this research was to evaluate two biostimulant products, Worm Power and Earth MAX, and their impact on thatch and rooting depth. In addition to the biostimulants, two industry standards, blackstrap molasses and sand topdressing were included.

Materials and Methods

Two 16-week greenhouse studies were conducted at Clemson University Greenhouse Complex in Clemson, SC, in the fall/winter of 2017/2018 and replicated in the fall/winter of 2018/2019. Greenhouse day/night temperatures averaged 24.4°C/20.5°C with 60-65% relative humidity. The experiment was arranged as a randomized complete block design with four replicates. ‘Diamond’ Zoysiagrass [*Zoysia matrella* (L.) Merr.] plugs, 10.8 cm diameter and 15 cm depth were harvested in October 2017 and October 2018 from the nursery green at Walker Golf Course, Clemson SC, USA, constructed with 85:15 sand: peat USGA soil mix and sodded in 2014 (personal communication with Don Garrett, 2018). Plugs were established in 15 cm diameter,15 cm deep pots with USGA greens mix of 85 sand:15 peat by volume (USGA, 2018). Treatments were applied using an enclosed spray chamber (DeVries Manufacturing, Hollandale, MN), calibrated to deliver 187 L/ha through flat fan nozzle’s (Tee Jet Technologies, Springfield, IL). Treatments and application frequencies are presented in **Table 2.1**. Treatments were watered in after application, and all pots were watered throughout the study as needed to prevent drought symptoms. Plugs were mowed weekly at a height of 3.8 mm. Foliar fertilization using Grigg Gary’s Green 18-3-4 (Brandt Consolidated Inc. Springfield, IL) at 9.8 kg/ha (0.2 lb N/1,000ft^2) was applied every 14d to all plugs throughout the study. Application rates for the two biostimulants were derived from product labels. Worm Power (Aqua-Aid Solutions, Rocky Mount, NC 27803), was applied at the “thatch reduction rate” of 0.453 kg/ha (16 oz/1,000 ft^2) in 7.57 l/ha (2 gallons) of water at 30-day intervals. Earth MAX (Hocking International Laboratories for Harrell’s LLC., Lakeland, FL 33802), was applied at 0.085-0.113 kg/ha (3 to 4 oz/1,000 ft^2) every 7 to 14 days. Two application timings were used for Earth MAX, 3.79 l/ha (1 gal/A), applied bi-weekly, and 7.58 l/ha (2 gal/A) applied monthly. Sand topdressing (greens grade sand) was applied at 0.6 mm depth, every 14-days. A commercial formulation of blackstrap molasses (Plant Food Company, Inc., Cranbury, NJ) was applied at 0.149 kg/ha (5.25 oz/1,000 ft^2), weekly.

Measurements

Treatment effects were assessed by measuring turf quality (TQ), normalized difference vegetation index (NDVI), turfgrass rooting length, rooting weight, thatch thickness and thatch weight.

Turfgrass Quality

Turfgrass quality (TQ) ratings included color, density, and vigor. Ratings were based on a visual 1 to 10 scale, where 1 equaled no live turfgrass and 10 equaled dark green, dense uniform grass (Johnson et al., 1987). A TQ value <7.0 was deemed unacceptable. Turfgrass quality ratings were recorded every 14d during the study, and ratings obtained were averaged for each plot before statistical analysis.

NDVI

Normalized difference vegetation index (NDVI) was quantified to evaluate treatment effects on turfgrass color. NDVI measures the relative amounts of red and near-infrared light reflected from the turfgrass canopy based on the following equation (Rouse et al., 1973).

$$NDVI = (\rho NIR - \rho Red) / (\rho NIR + \rho Red)$$

where

ρNIR = reflectance at the near infrared (NIR) region

ρRed = reflectance at the red region

NDVI was recorded every 14d throughout the study using a Field Scout TCM 500 NDVI Turf Color Meter (Spectrum Technologies, Bridgend, United Kingdom).

Turfgrass roots and thatch

At study initiation and completion, thatch thickness was measured with a ruler (mm). Thatch thickness was considered the distance between living green tissue and soil surface. In addition, at study completion, rooting mass measurements were taken. Soil was washed from turf and roots severed below the thatch layer. Root weight was determined using a procedure by Carrow et al. (1987) where roots were dried at 80˚C for 72 hours. After drying, roots were weighed, and then ashed in a muffle furnace for three hours as 550˚C. Remaining contents were reweighed. Total rooting weight was the difference between the weight of the oven dry roots and ashed roots. Thatch weight was determined via the same method as turf roots where thatch weight was the difference between the weight of the oven dry thatch and ashed thatch.

Statistical Analysis

Turf quality and NDVI means were compared using ANOVA followed by Fisher's protected Least Significant Difference test. The model for the analysis was:

$$Yij = \mu + \tau i + \beta j + \varepsilon ij$$

Where Y_{ij} is value of turf quality or NDVI in treatment i and block j, μ is the overall mean, τ_i is the effect of treatment i, β_j is the effect of block j, and ε_{ij} is the residual.

All statistical analysis was done using JMP software, (Version 14. SAS Institute Inc., Cary, NC, 1989-2019) and statistical significance was set at α = 0.05.

Mean rooting lengths, root weight, and thatch weights were also compared using ANOVA followed by Fisher's protected Least Significant Difference test. The model for the analysis was:

$$Yij = \mu + \tau i + \beta j + \varepsilon ij$$

Where Y_{ij} is value of rooting length, root mass, or thatch weights in treatment i and block j, μ is the overall mean, τ_i is the effect of treatment i, β_j is the effect of block j, and ε_{ij} is the residual.

All statistical were done using JMP software, (Version 14. SAS Institute Inc., Cary, NC, 1989-2019) and statistical significance was set at $\alpha = 0.10$.

Results and Discussion

Turfgrass Quality

No statistical differences were observed between any treatment for TQ, and all treatments provided satisfactory turf (>7). Turf was maintained in an unstressed state and received fertilizer every two weeks; these factors likely contributed to these results (**Figure 2.1**).

NDVI

At of the end of year 1, Earth Max (2) (0.735), Sand topdressing (0.733), Blackstrap molasses (0.729), and Worm Power (0.718) provided statistically higher NDVI readings than untreated (0.711); however, Earth Max (1) provided no differences from the control (0.716) (**Figure 2.2**). In year 2, no statistical differences were observed.

Turfgrass Rooting Length

In year 1, Earth MAX (1) (14.3 cm) and Sand topdressing (14.1 cm), provided greater rooting length than the untreated control (12.1 cm), no other treatments showed differences (**Figure 2.3**). In year 2, only Worm Power (20.3 cm) provided greater rooting length than the untreated control (17.1 cm).

Turfgrass Root Weight

In year 1, no differences were observed for rooting mass in any of the treated turfgrass compared to the untreated control (**Figure 2.4**). However, in year 2, Earth MAX (1) (22.1 g), provided greater rooting mass than the untreated control (6.0 g).

Turfgrass Thatch Weight

In year 1, Worm Power (171.0 g), provided higher thatch weight than the untreated (113.0 g), all other treatments were similar to untreated (**Figure 2.5**). In year 2, Earth MAX (1) (232.40 g), had greater thatch weight, than all treatments apart from sand topdressing.

Turfgrass Thatch Thickness

In year 1, blackstrap molasses (23.8 mm), Earth MAX (1) (23.8 mm), Earth MAX (2) (25.0 mm), and Worm Power (27.5 mm), provided lower thatch thickness than the untreated control (34.5 mm) (**Figure 2.6**). At completion of year 2, blackstrap molasses (25.0 mm), Earth MAX (1) (28.5 mm), and Earth MAX (2) (30.0 mm), had lower thatch thickness than the untreated control (31.8 mm).

Conclusion

This study indicates three treatments provided an average of 18% greater rooting length than the untreated control, Earth MAX (1) (18%), Sand topdressing (16.5%) and Worm Power (18.7%). Root weight results indicate none of the treatments showed an increase in year 1, and only Earth MAX (1) did in year 2, with a 268% increase when compared to the untreated control. No significant reduction of thatch weight occurred across all treatment's in either year of the study. Four treatments provided lower thatch thickness over the two-year study than the untreated control. In year 1, blackstrap molasses (31%), Earth MAX (1) (31%), Earth MAX (2) (27.5%), and Worm Power (20.2%), provided an average of 27% less thatch thickness. In year 2, plugs treated with blackstrap molasses (21.4%), Earth MAX (1) (10.4%), and Earth MAX (2) (5.7%) had an average of 13% lower thatch thickness than the untreated control. Both Earth MAX treatments and blackstrap molasses consistently reduced thatch thickness by an average of 21% throughout the study when compared to the untreated. Turf Quality ratings were consistent throughout both year 1 and year 2 among all treatments. All treatments, with the exception of Earth MAX (1) had an NDVI rating greater than that of the untreated control in year 1. However, in year 2, no differences were seen.

Data from this two-year study warrants further investigation of both biostimulants, Earth MAX and Worm Power, and the effects they have on rooting length and rooting mass. In addition, further investigation into Earth MAX and blackstrap molasses is warranted in regards to thatch thickness. These products provided a reduction in thatch thickness when compared to the untreated control over the two-year study. Further research should include different turfgrass types, soil profiles, and rates.

Acknowledgements

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Table 2.1. Treatments in two 16-week thatch control greenhouse studies at Clemson University to determine their effects on turfgrass rooting and thatch control.

Treatments	Rate	Application Frequency
Untreated	---	---
Worm Power	0.453 kg/ha (16 oz/1,000 ft^2)	30 days
Earth Max (1)	3.79 l/ha (1 gal/acre)	14 days
Earth Max (2)	7.57 l/ha (2 gal/acre)	30 days
Blackstrap Molasses	0.149 kg/ha (525 oz/1,000 ft^2)	7 days
Sand topdressing*	0.6 mm	14 days

*Sand topdressing was applied by hand.

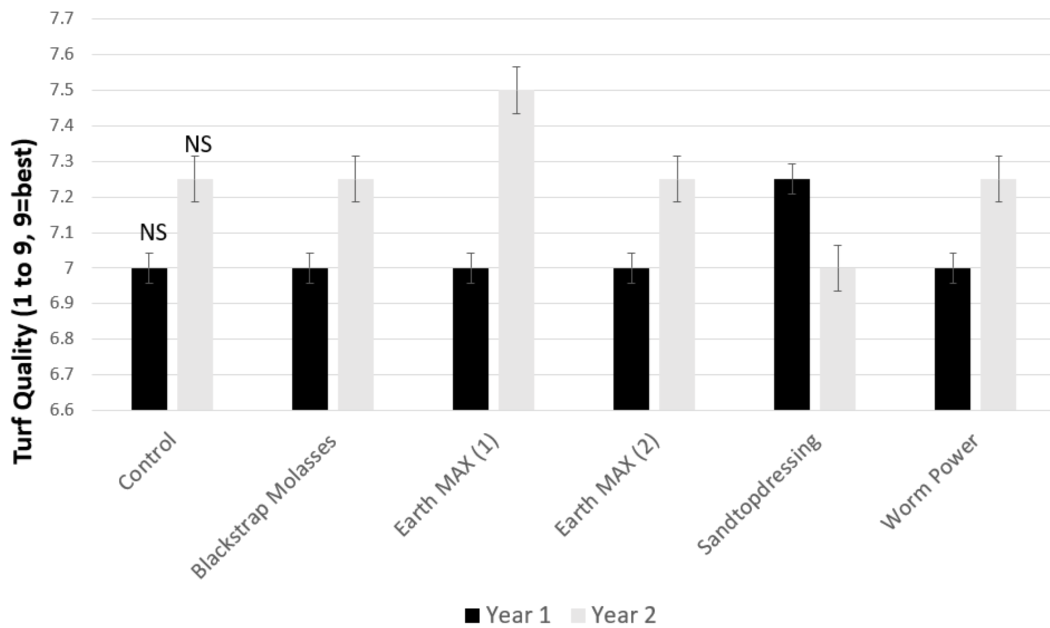

Figure 2.1. Turfgrass Quality measured every 14 days for two 16-week greenhouse thatch control studies at Clemson University. Turfgrass Quality ratings are from 1 to 9 with 9=dark green, dense uniform turfgrass. Means within each year were separated by Fisher's protected LSD (P ≤ 0.05). NS on control indicates no significant differences among the treatments.

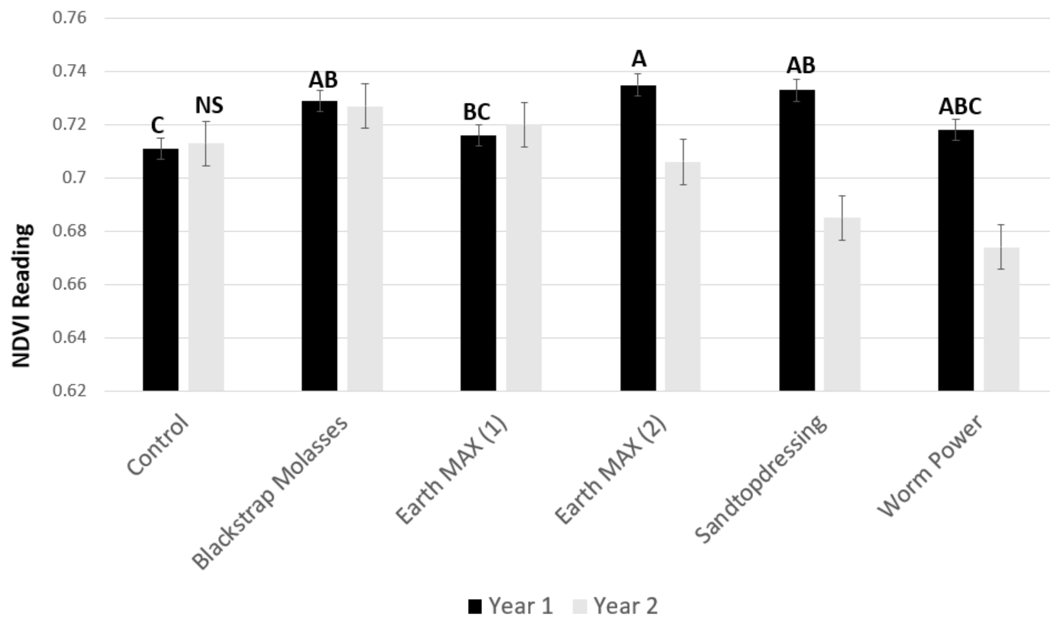

Figure 2.2 Normalized difference vegetation index (NDVI) taken every 14 days for two 16-week thatch control greenhouse studies at Clemson University. Different letters indicate significant differences between treatments. Means within each year were separated by Fisher's protected LSD ($P \leq 0.05$). NS on control indicates no significant differences among the treatments.

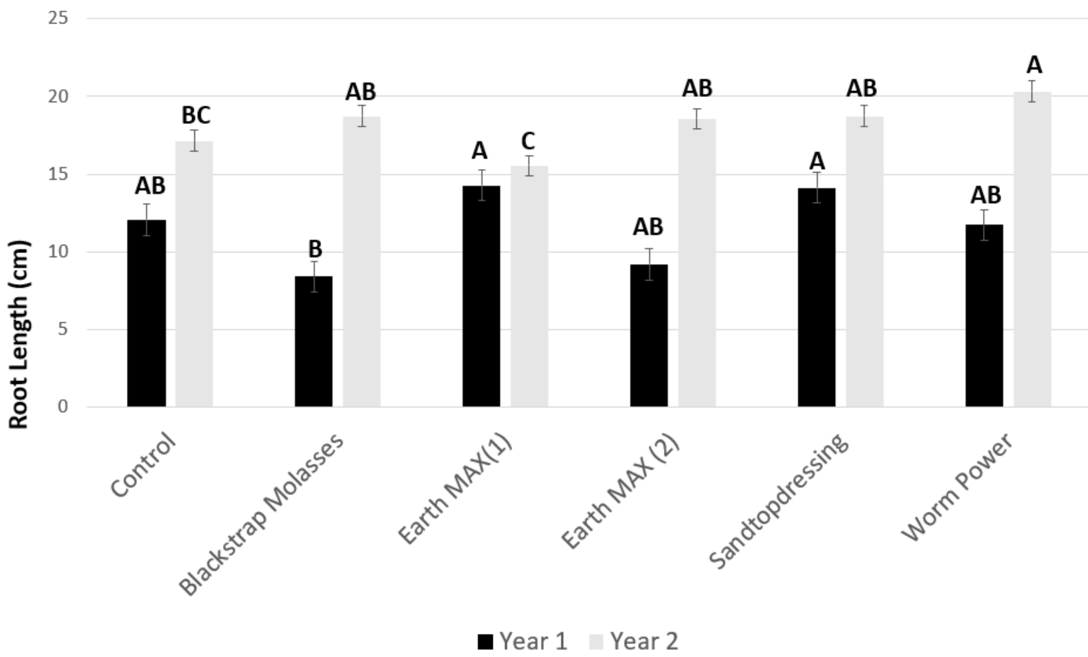

Figure 2.3. Turfgrass rooting length for two 16-week thatch control greenhouse studies at Clemson University. Means followed by the same letter are not significantly different according to Fisher's protected LSD (α = 0.10) test.

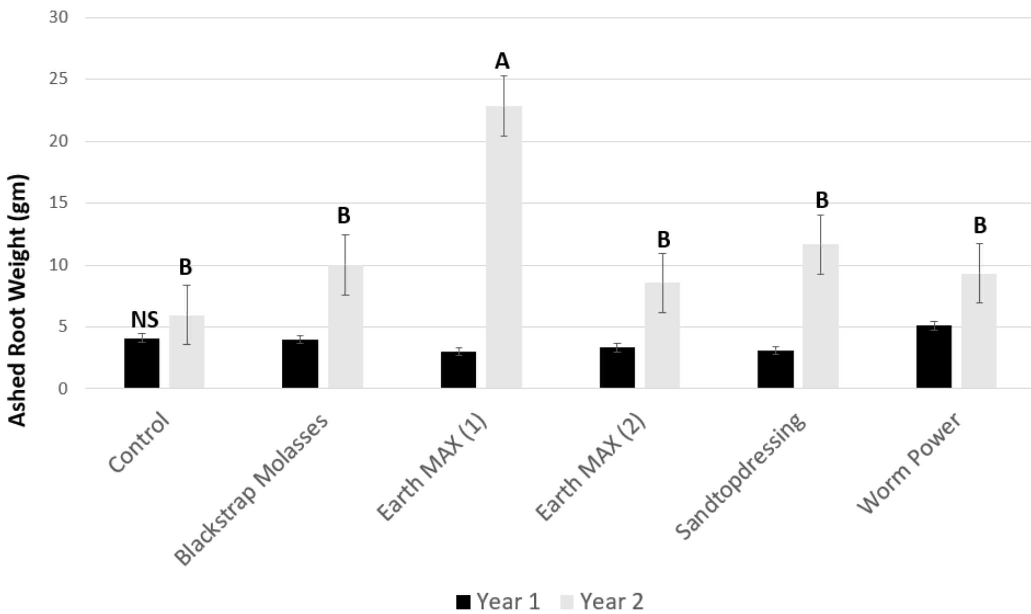

Figure 2.4. Turfgrass root weight for two 16-week thatch control greenhouse studies at Clemson University. Means followed by the same letter are not significantly different according to Fisher's protected LSD (α = 0.10) test. NS on control indicates no significant differences among the treatments.

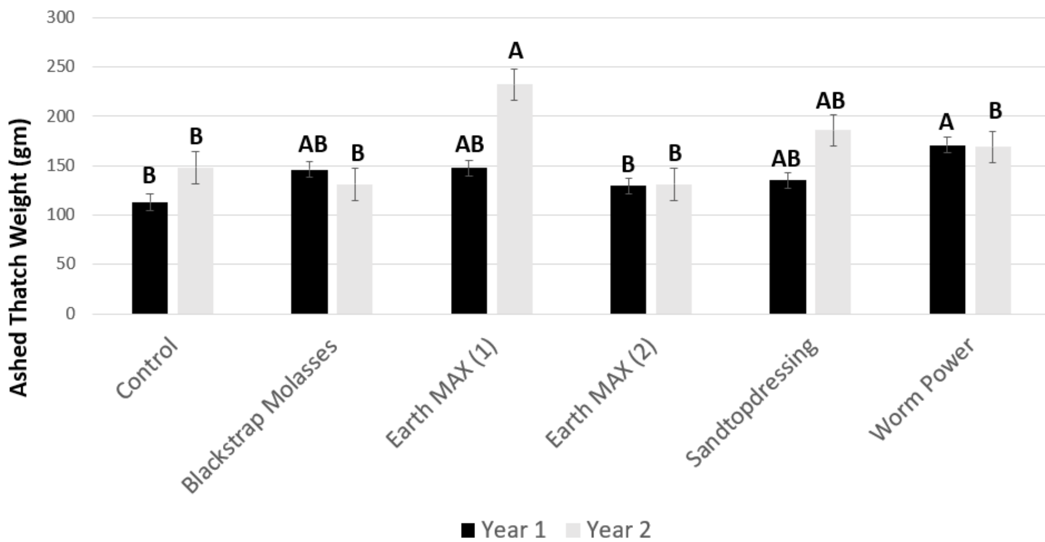

Figure 2.5. Turfgrass thatch weight for two 16-week thatch control greenhouse studies at Clemson University. Means followed by the same letter are not significantly different according to Fisher's protected LSD (α = 0.10) test.

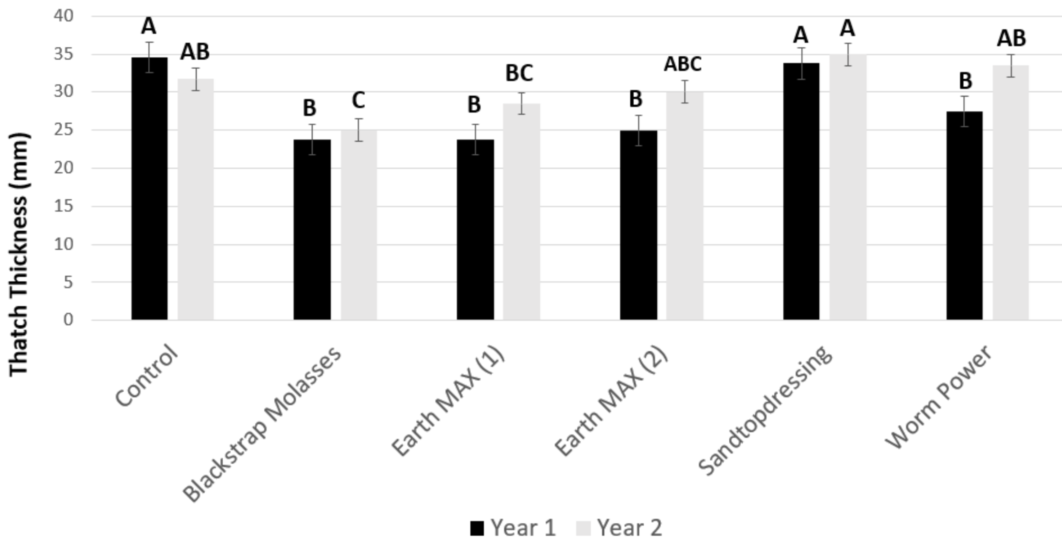

Figure 2.6. Turfgrass thatch thickness for two 16-week thatch control greenhouse studies at Clemson University. Means followed by the same letter are not significantly different according to Fisher’s protected LSD (α = 0.10) test.

Figure 2.7. ‘Diamond’ zoysiagrass plugs taken from the Walker Golf Course at Clemson University to be used in the greenhouse trail. Photo taken Fall 2018.

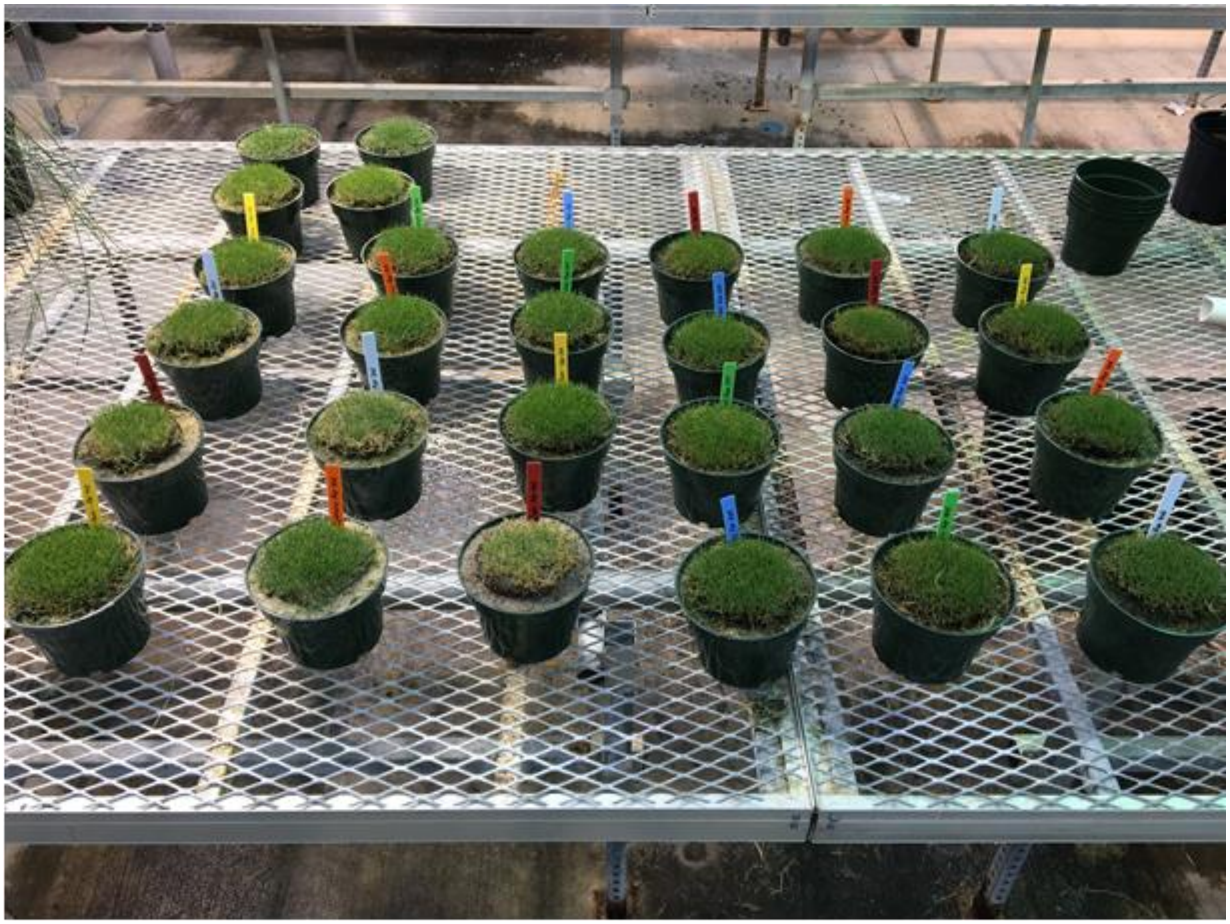

Figure 2.8. ‘Diamond’ Zoysiagrass plugs growing in year 1 of the 16-week greenhouse trial.

Figure 2.9. Turfgrass plug treated with sand topdressing in the greenhouse study. This photo was taken at the conclusion of the study.

Figure 2.10. Turfgrass plug treated with Earth MAX (1) in the greenhouse study. This photo was taken at the conclusion of the study.

Figure 2.11. Turfgrass plug treated with Earth MAX (2) in the greenhouse study. This photo was taken at the conclusion of the study.

Figure 2.12. Turfgrass plug treated with Worm Power in the greenhouse study. This photo was taken at the conclusion of the study.

Figure 2.13. Turfgrass plug treated with blackstrap molasses in the greenhouse study. This photo was taken at the conclusion of the study.

Figure 2.14. Turfgrass plug from the untreated control in the greenhouse study. This photo was taken at the conclusion of the study.

CHAPTER THREE

EVALUATING BIOLOGICAL THATCH CONTROL ON GOLF GREENS

Note: This work is intended for Crop Science Journal

Joshua R. Weaver*, Lambert B. McCarty, Virgil Quisenberry, William C. Bridges, and L. Ray Hubbard, Jr.

Abstract

Thatch is a layer of living and dead plant material (stems and roots) between turfgrass leaf tissue and the soil surface and if excessive, it can decrease playability of turf surfaces, increase mower scalping and disease pressure, reduce pesticide efficacy and water infiltration, plus harbor insects. In golf greens, disruptive mechanical practices such as vertical mowing, core cultivation, grooming, and topdressing are traditional agronomic methods for managing thatch/organic matter. Field experiments were conducted to evaluate two commercial biostimulant products, Worm Power and Earth MAX, and their impact on thatch and rooting depth. In addition to the biostimulants, two industry standards were included: blackstrap molasses and sand topdressing. In both years, all treatments, with the exception of blackstrap molasses, provided an average of 18% greater root length than untreated control. However, blackstrap molasses provided 146% greater root weight, and 9% less thatch weight over the two-year study when compared to the untreated control. For both years, blackstrap molasses, Earth MAX (1), Earth MAX (2), and Worm Power reduced thatch thickness an average of 26% versus the untreated.

Abbreviations: NDVI, normalized difference vegetation index; SF, surface firmness; TQ, turf quality; WASI, weeks after study initiation

Introduction

Thatch is a layer of living and dead plant material (stems and roots) between turfgrass leaf tissue and the soil surface (McCarty, 2018). Moderate levels of thatch provide desirable surface resiliency and nutrient retention, but excessive levels can decrease playability of turf surfaces, increase disease pressure and mower scalping, reduce pesticide efficacy and water infiltration (McCarty et al., 2016). In a high maintenance turf setting such as a golf green, plant tissue often is produced faster than decomposed, resulting in thatch accumulation. Excessive thatch can cause several problems including shallow rooting, impaired soil hydraulic properties, localized dry spot, mower scalping, disease, and pests (Waddington, 1992).

In recent years, considerable attention has garnered toward controlling of thatch/organic material buildup in high quality golf greens without the use of traditional destruction/disturbance means such as aerification, verticutting, grooming, and topdressing. The desire to move away from these destructive methods is course revenue typically drops following these events for up to four weeks (McCarty, 2018). Many recently introduced products claim they aid in thatch reduction but little scientific data exists to substantiate this. Previous studies have investigated biological thatch control options including biostimulants, a term commonly associated with such products. Biostimulants can be defined as organic materials that, when applied in small quantities, enhance plant growth and development (Schmidt et al. 2003). While these products may appear new in the industry, they have actually been around for many years. Ledeboer and Skogley (1967) noted thatch decomposition without physically disrupting the turfgrass soil surface would be of great value. Inconsistent results have been observed from these products, although, a valid scientific basis for their use may exist (Miller, 1990). Most biostimulants contain an array of sucrose, glucose, or other sugar sources, plant nutrients at low rates, various acids, and inoculated microorganisms (McCarty et al., 2007). A commercial product, Thatch-X (biostimulant), did not control thatch-mat accumulation in creeping bentgrass (*Agrostis palustris subsp. stolonifera* L.) after a single year of use (McCarty et al. 2007). However, a 16% reduction in thatch thickness did occur, but only after two years of continuous use (Willis et al. 2006). Tucker et al. (2006) noted the use of biostimulants did not influence thatch layer depth in ‘TifEagle’ bermudagrass (*Cynodon dactylon* (L.) Pers. × *Cynodon transvaalensis* (Burtt-Davy)), but did positively influence root length density. McCarty et al. (2016) reported a minimal reduction of thatch and organic matter on a ‘Tifway’ bermudagrass fairway with the use of biostimulants.

The objective of this research was to evaluate two biostimulant products, Worm Power and Earth MAX, and their impact on thatch and rooting depth. In addition to the biostimulants, two industry standards, blackstrap molasses and sand topdressing were included.

Materials and Methods

Two 16-week field studies were conducted from May 2018 to September 2018 and replicated from May 2019 to September 2019 on a ‘Diamond’

Zoysiagrass [*Zoysia matrella* (L.) Merr.] nursery green at the Walker Golf Course at Clemson University. The same location on the nursery green was utilized in both years of the study. The first and second objectives of this study was to determine the effects biostimulants and cultural practices have on turfgrass rooting length and mass. Third and fourth objectives were to determine the effects biostimulants and cultural practices have on turfgrass thatch thickness and thatch weight. Fifth and sixth objectives were to determine if turf quality (TQ) and normalized difference of vegetative index (NDVI) were affected by biostimulants and cultural practices. Seventh objective was to measure surface firmness within the treated areas.

The 'Diamond' zoysiagrass green was established in June 2013 via sod in a former creeping bentgrass green constructed with USGA soil mix in 1995 (Donald Garrett, 2020, personal communication). The experiment was arranged with 2 m x 3 m plots as a randomized complete block design with four replicates. Treatments were applied using a pressurized CO_2 backpack boom sprayer with a carrier volume 190 L/ha through 8003 flat fan nozzles (Tee jet, Spraying Systems Co., Roswell, GA). Treatments and application frequencies are presented in **Table 3.1**. Maintenance overhead irrigation equivalent to 1.25 cm was applied as needed; however, all treatments were watered immediately after application with this rate. Plots were mowed daily by Walker Golf Course staff from 2.54 to 3.175 mm. Solid tine aerification, vertical mower grooming, and topdressing were all performed uniformly throughout this study. Core aeration was performed using 1.27 cm tines with 2.54 x 2.54 cm spacing on 25 June 2018 and 21 June 2019.

Fertilization was applied via foliar application equivalent to 9.8 g N m^{-2} $month^{-1}$ during rating dates. Fall fungicide applications were applied uniformly across plots, but no additional biostimulant products were applied by the golf course staff. Application rates for the two biostimulants were derived from product labels. Worm Power (Aqua-Aid Solutions, Rocky Mount, NC 27803), was applied at the "thatch reduction rate" of 0.453 kg/ha (16 oz/1,000 ft^2) in 7.57 l/ha (2 gallons) of water at 30-day intervals. Earth MAX (Hocking International Laboratories for Harrell's LLC., Lakeland, FL 33802), was applied at two separate rates and timings, 3.79 l/ha (1 gal/A), applied bi-weekly, and 7.58 l/ha (2 gal/A) applied monthly. For the topdressing treatment, sand (greens grade sand) was uniformly applied at 0.6 mm depth, every 14-days. For the molasses treatment, a commercial formulation of blackstrap molasses (Plant Food Company, Inc., Cranbury, NJ) was applied at 0.149 kg/ha (5.25 oz/1,000 ft^2), weekly.

Measurements

Treatment effects were assessed by measuring turf quality (TQ), normalized difference vegetation index (NDVI), surface firmness (SF), turfgrass rooting length, rooting weight, thatch thickness and thatch weight.

Turfgrass Quality

Turfgrass quality (TQ) ratings included color, density, and vigor. Ratings were based on a visual 1 to 10 scale, where 1 equaled no live turfgrass and 10 equaled dark green, dense uniform grass (Johnson et al., 1987). A TQ value <7.0 was deemed unacceptable. Turfgrass quality ratings were recorded every 14d during the study, and ratings were averaged for each plot before statistical analysis.

NDVI

Normalized difference vegetation index (NDVI) was quantified to evaluate treatment effects on turfgrass color. NDVI measures the relative amounts of red and near-infrared light reflected from the turfgrass canopy based on the following equation (Rouse et al., 1973).

$$NDVI = (\rho NIR - \rho Red) / (\rho NIR + \rho Red)$$

where

ρNIR = reflectance at the near infrared (NIR) region

ρRed = reflectance at the red region

NDVI was recorded every 14d throughout the study using a Field Scout TCM 500 NDVI Turf Color Meter (Spectrum Technologies, Bridgend, United Kingdom).

Surface firmness

Surface firmness (SF) was determined within each plot with a Clegg Impact Soil Tester (Lafayette Instrument Co., Lafayette, IN). The 2.25-kg weighted hammer was dropped from a distance of 0.45 m to the turfgrass surface. The energy transferred from the falling hammer to the turf surface was measured to provide a Clegg Impact Value (CIV) (Lush 1985, Clegg 1978). Measurements were made ~36 hr after irrigation or rainfall to help ensure uniform soil water content. Readings were recorded in CIV and converted to gmax (peak deceleration) according to the following equation (Bregar and Moyer, 1990):

$$gmax = 10(CIV)$$

The two measurements taken in each plot on each date were averaged before

statistical analysis.

Turfgrass roots and thatch

At study initiation and completion, thatch thickness was measured with a ruler (mm). Thatch thickness was considered the distance between living green tissue and soil surface. In addition, at study completion, rooting mass measurements were taken. Soil was washed from turf and roots severed below the thatch layer. Root weight was determined using a procedure by Carrow et al. (1987) where roots were dried at 80˚C for 72 h. After drying, roots were weighed, and then ashed in a muffle furnace for 3 h at 550˚C. Remaining contents were reweighed. Total rooting weight was the difference between the weight of the oven dry roots and ashed roots. Thatch weight was determined via the same method as turf roots where thatch weight was the difference between the weight of the oven dry thatch and ashed thatch.

Statistical Analysis

Turf quality, NDVI, and SF means were compared using ANOVA followed by Fisher's protected Least Significant Difference test. The model for the analysis was:

$$Yij = \mu + \tau i + \beta j + \varepsilon ij$$

Where Yij is value of turf quality or NDVI in treatment i and block j, μ is the overall mean, τi is the effect of treatment i, βj is the effect of block j, and εij is the residual.

All statistical analysis was done using JMP software, (Version 14. SAS Institute Inc., Cary, NC, 1989-2019) and statistical significance was set at α = 0.05.

Mean rooting lengths, root weight, and thatch weights were also compared using ANOVA followed by Fisher's protected Least Significant Difference test. The model for the analysis was:

$$Yij = \mu + \tau i + \beta j + \varepsilon ij$$

Where Yij is value of rooting length, root mass, or thatch weights in treatment i and block j, μ is the overall mean, τi is the effect of treatment i, βj is the effect of block j, and εij is the residual.

All statistical were done using JMP software, (Version 14. SAS Institute Inc., Cary, NC, 1989-2019) and statistical significance was set at α = 0.10.

Results and Discussion

Turfgrass Quality

Statistical differences were not observed between any treatment for TQ in either year of the study, and all treatments providing satisfactory turf (>7). All plots received similar fertilizer, irrigation, aerification, and mowing frequencies, thus probably why ratings were similar throughout the study. (**Figure 3.1**).

NDVI

Statistical differences also were not observed between any treatment for NDVI in either year of the study. As with TQ, all plots received similar fertilizer, irrigation, aerification, and mowing frequencies, thus why TQ ratings were consistent throughout the study. (**Figure 3.2**).

Surface firmness

For surface firmness, statistical differences were not observed between any treatment over the course of the study. (**Figure 3.3**).

Turfgrass Rooting Length

In year 1, Earth MAX (1), Earth MAX (2), Sand topdressing, and Worm Power, provided an average of 14% greater rooting length than blackstrap molasses, and an average of 18% greater than the untreated control. This also held true in year 2 as Earth MAX (1), Earth MAX (2), Worm Power, and Sand topdressing provided an average 15% greater rooting length than blackstrap molasses, and an average 23% than the untreated control. The treatments of Earth MAX (1), Earth MAX (2), Worm Power, and Blackstrap molasses did show an increase in rooting length of 7% in Year 2 when compared to Year 1. However, while Sand topdressing did have 11% greater rooting length in both year's when compared to the untreated control, it did not increase in Year 2 when compared to its rooting length in Year 1. (**Figure 3.4**).

Turfgrass Rooting Weight

In year 1, blackstrap molasses had an increase of 143%, and was the only treatment that provided statistical differences for rooting weight when compared to the untreated control. In year 2, blackstrap molasses, Earth MAX (2), Worm Power, and Earth MAX (1) provided an average of 93% greater rooting weight than the untreated control. (**Figure 3.5**).

Turfgrass Thatch Weight

In year 1, blackstrap molasses provided 8% lower thatch weight, and was the only treatment that provided statistical differences compared to the untreated control. With the exception of Worm Power and Earth MAX (1), which both had a greater thatch weights of 9% and 7% respectively, all other treatments were similar to untreated control. In year 2, Blackstrap molasses provided 9% lower thatch weight, and was the only treatment that provided statistical differences when compared to the untreated control. With the exception of Sand topdressing and Worm Power, which both had a greater thatch weights of 21% and 17% respectively, all other treatments were similar to the untreated control. (**Figure 3.6**).

Turfgrass Thatch Thickness

In year 1, blackstrap molasses, Earth MAX (1), Earth MAX (2), and Worm Power, collectively provided an average of 27% less thatch thickness than the untreated control. Whereas, sand topdressing had an increase in thatch thickness of 19% than the untreated control. At completion of year 2 Earth MAX (2), blackstrap molasses, Earth MAX (1), and Worm Power, collectively had 24% less thatch thickness than the untreated control. Conversely, sand topdressing had 27% greater thatch thickness than that of the untreated control. (**Figure 3.7**).

Conclusion

This study indicates four treatments, Earth MAX (1) (30%), Earth MAX (2) (19%), Worm Power (13%), and sand topdressing (10%), provided an average 18% greater rooting length than the untreated control. In year 1, blackstrap molasses provided an average of 143% greater rooting weight than the untreated control. In year 2, four treatments, blackstrap molasses (149%), Earth MAX (2)

(83%), Worm Power (82%), and Earth MAX (1) (65%), provided an average 95% greater rooting mass than the untreated control. In both years, blackstrap molasses had ~8.0% less thatch weight than the untreated control. Four treatments provided lower thatch thickness over the two-year study than the untreated control. In year 1, blackstrap molasses (30%), Earth MAX (1) (30%), Earth MAX (2) (25), and Worm Power (19%), provided an average of 27% less thatch thickness. In year 2, plugs treated with Earth MAX (2) (30%), blackstrap molasses (29%), Earth MAX (1) (30%), and Worm Power (14%), had an average 26% less thatch thickness than the untreated control. Over the two-year study, both Earth MAX treatments, blackstrap molasses, and Worm Power reduced thatch thickness by an average of 29%, 30%, and 17% respectively, when compared to the untreated control. TQ, NDVI, and SF ratings were consistent throughout both year 1 and year 2 among all treatments.

Data from this two-year study warrants further investigation of both biostimulants, Earth MAX and Worm Power, as well as sand topdressing and the effects they have on rooting length. In addition, further investigation into both biostimulants, Earth MAX and Worm Power, as well blackstrap molasses is warranted in regards to rooting weight, as these products provided more rooting weight than the untreated control. Blackstrap molasses did so in both years, where the biostimulants only did in year 2. Blackstrap molasses performed the best over the two-year study in terms of producing less thatch weight when compared to untreated control. Both biostimulants and blackstrap molasses consistently reduced thatch thickness by an average of 26% over the two-year study when compared to the untreated control. Data derived from this two-year study should be built upon through future research which should include; different turfgrass types, rates, soil profiles, and other cultural practices such as various aerification and verticutting schedules.

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Table 3.1. Treatments in two 16-week thatch control greenhouse studies at Clemson University to determine their effects on turfgrass rooting and thatch control.

Treatments	Rate	Application Frequency
Untreated	---	---
Worm Power	0.453 kg/ha (16 oz/1,000 ft^2)	30 days
Earth Max (1)	3.79 l/ha (1 gal/acre)	14 days
Earth Max (2)	7.57 l/ha (2 gal/acre)	30 days
Blackstrap Molasses	0.149 kg/ha (525 oz/1,000 ft^2)	7 days
Sand topdressing*	0.6 mm	14 days

*Sand topdressing was applied by hand.

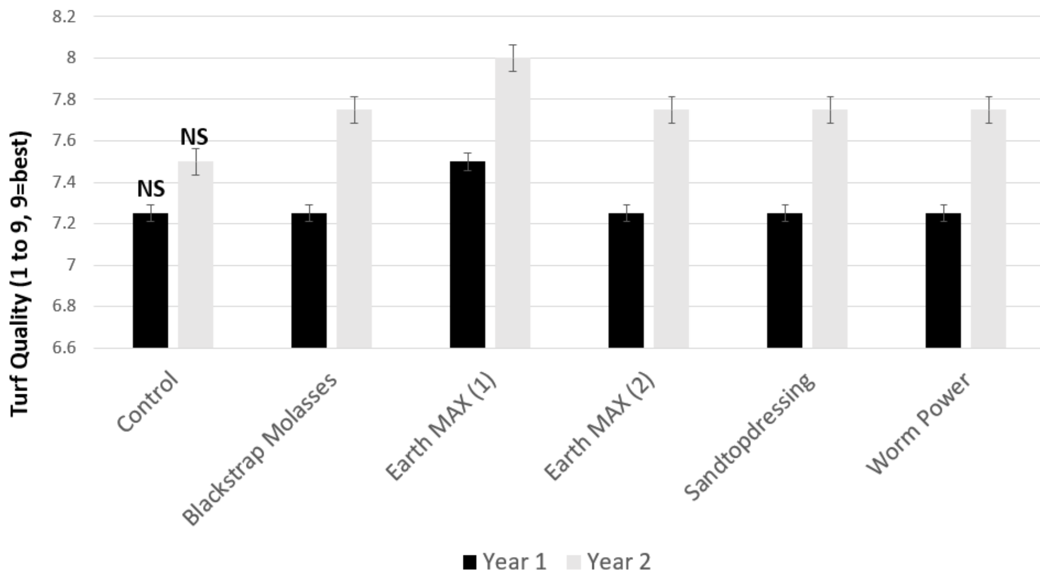

Figure 3.1. Turfgrass Quality measured every 14 d for two 16-week field thatch control studies at the Walker Golf Course at Clemson University. Turfgrass Quality ratings are from 1 to 9 with 9=dark green, dense uniform turfgrass. Means within each year were separated by Fisher's protected LSD ($P \leq 0.05$). NS on control indicates no significant differences among the treatments.

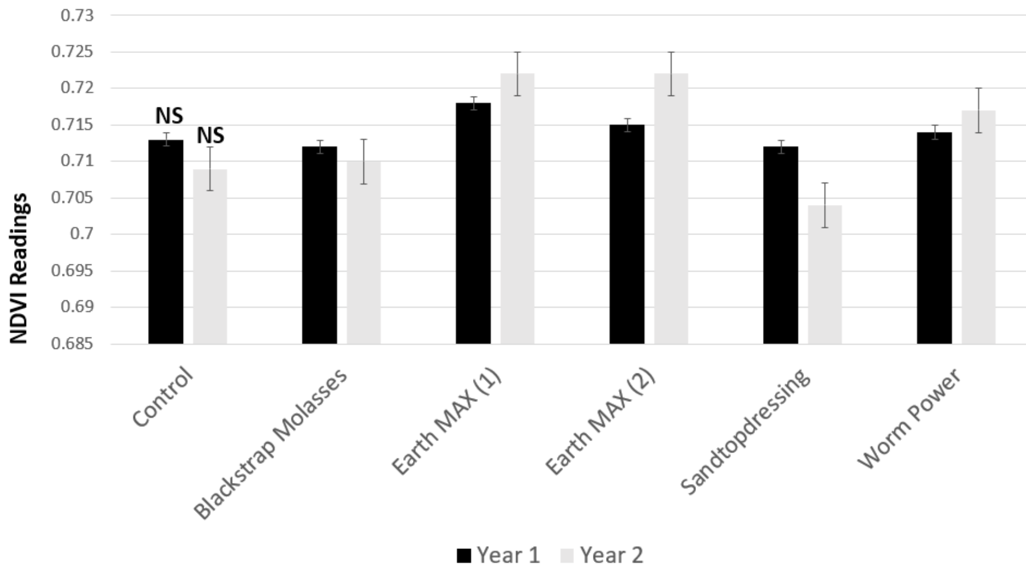

Figure 3.2. Normalized difference vegetation index (NDVI) taken every 14 d for two 16-week thatch control field studies at the Walker Golf Course at Clemson University. Different letters indicate significant differences between treatments. Means within each year were separated by Fisher's protected LSD ($P \leq 0.05$). NS on control indicates no significant differences among the treatments.

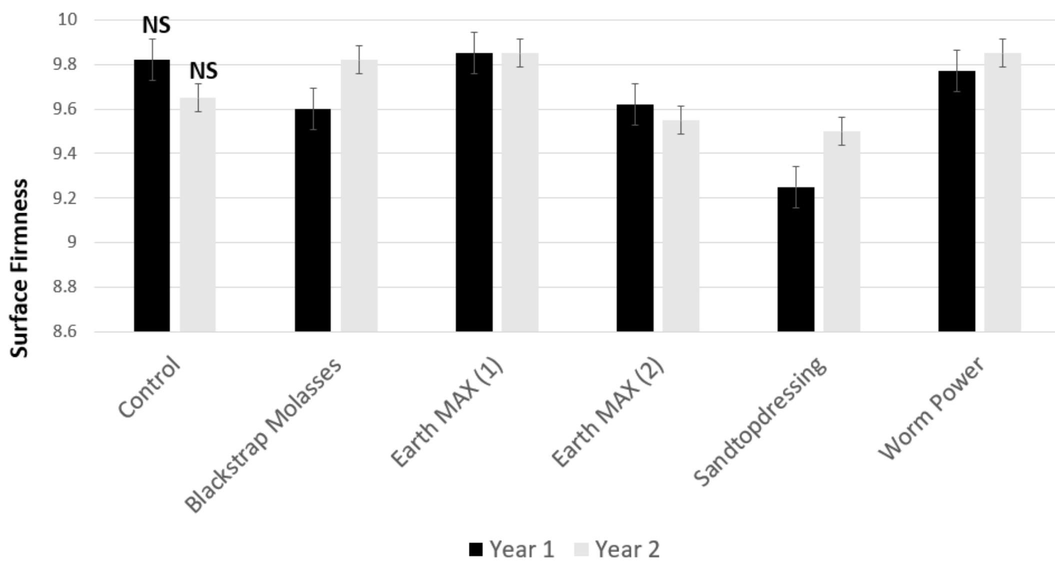

Figure 3.3. Surface firmness (SF) taken every 14 d for two 16-week thatch control field studies at the Walker Golf Course at Clemson University. Different letters indicate significant differences between treatments. Means within each year were seperated by Fisher's protected LSD ($P \leq 0.05$). NS on control indicates no significant differences among the treatments.

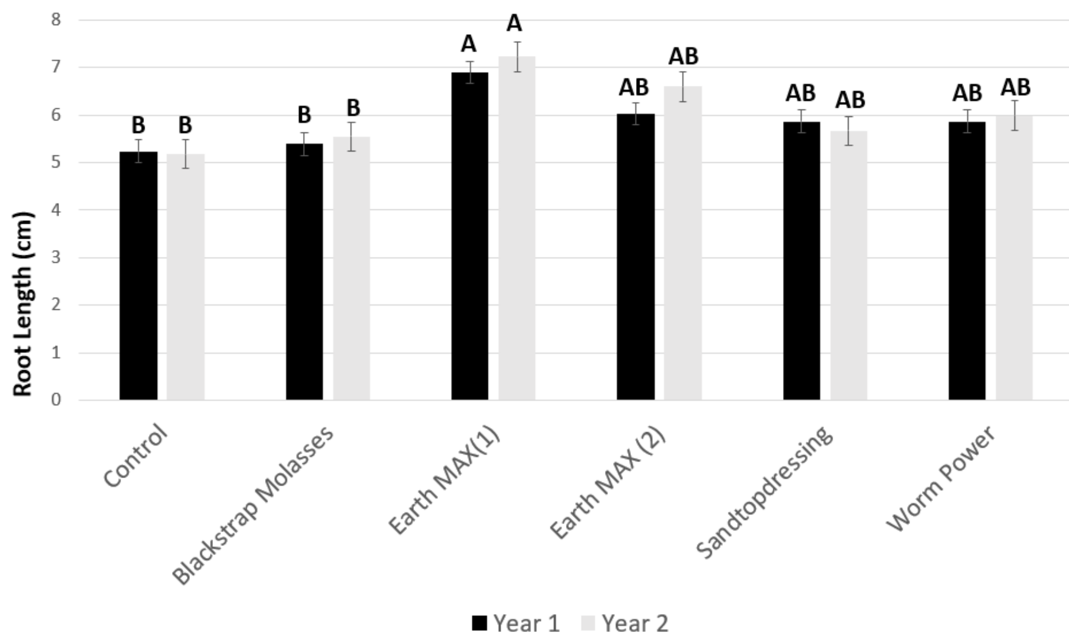

Figure 3.4. Turfgrass rooting length for two 16-week thatch control field studies at the Walker Golf Course at Clemson University. Means followed by the same letter are not significantly different according to Fisher's protected LSD (α = 0.10) test.

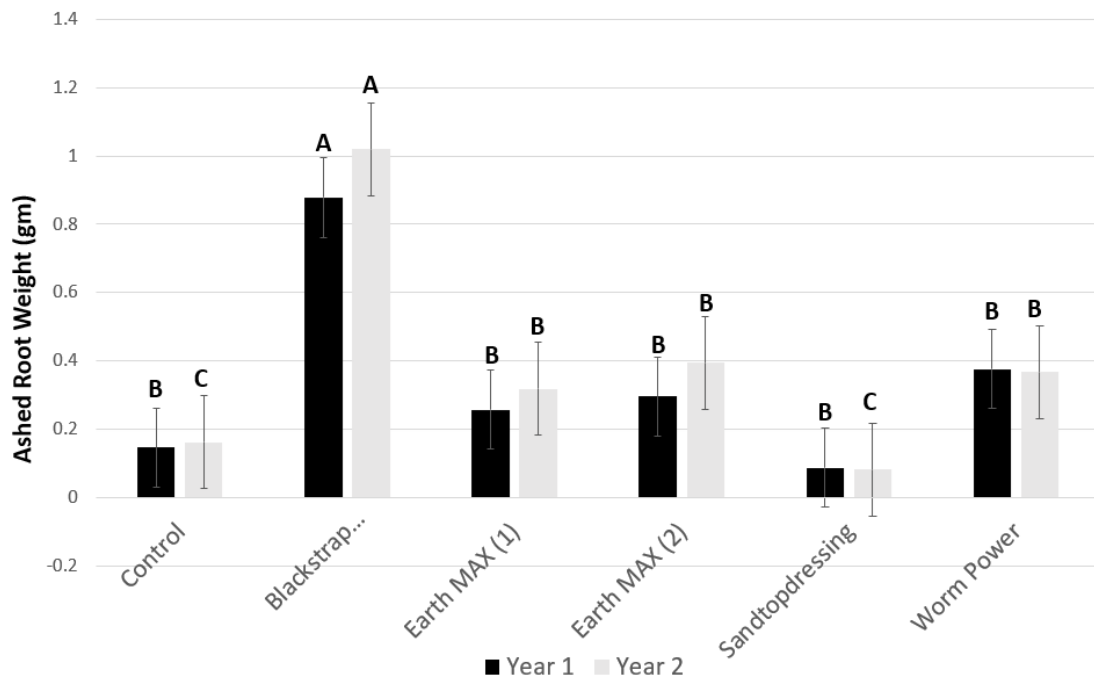

Figure 3.5. Turfgrass root weight for two 16-week thatch control field studies at the Walker Golf Course at Clemson University. Means followed by the same letter are not significantly different according to Fisher’s protected LSD (α = 0.10) test.

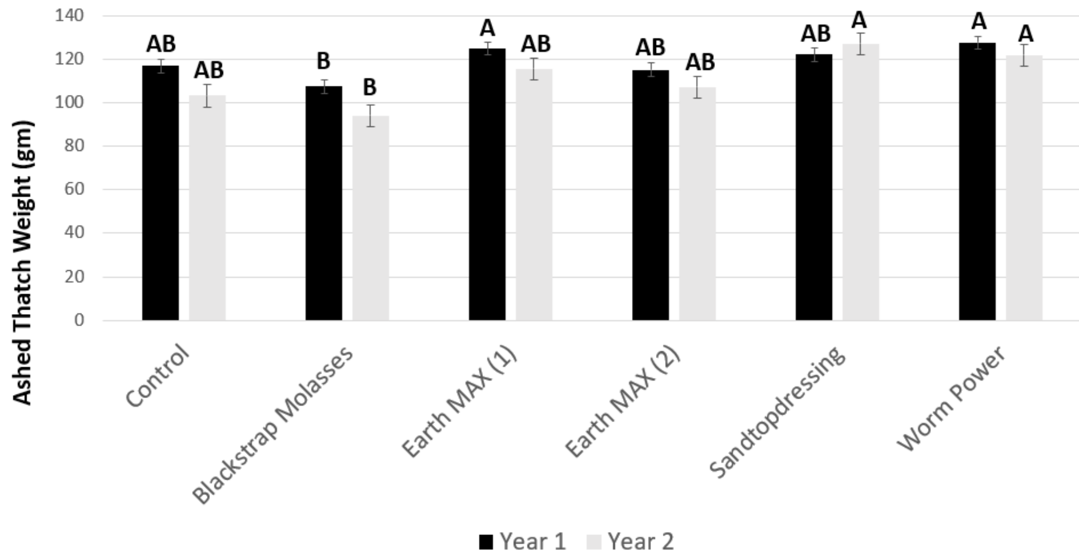

Figure 3.6. Turfgrass thatch weight for two 16-week thatch control field studies at the Walker Golf Course at Clemson University. Means followed by the same letter are not significantly different according to Fisher's protected LSD (α = 0.10) test.

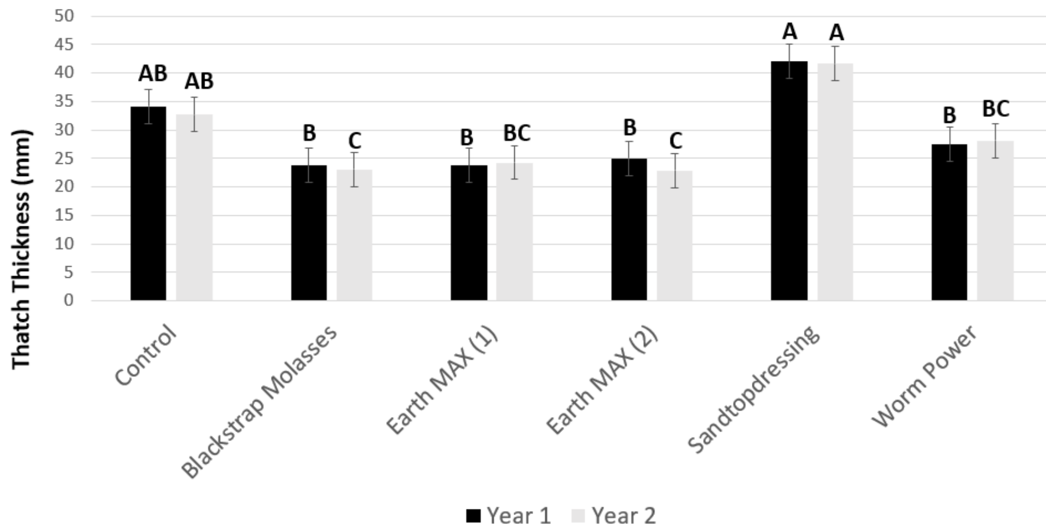

Figure 3.7. Turfgrass thatch thickness for two 16-week thatch control field studies at the Walker Golf Course at Clemson University. Means followed by the same letter are not significantly different according to Fisher's protected LSD (α = 0.10) test.

Figure 3.8. Site of the two-year field study located at the Walker Golf Course at Clemson University. Photo was taken at study initiation in May 2018.

Figure 3.9. Site of the two-year field study located at the Walker Golf Course at Clemson University. Photo was taken post aerification in July 2018.

Figure 3.10. Site of the two-year field study located at the Walker Golf Course at Clemson University. Photo was taken at study conclusion of year 1 September 2018.

Figure 3.11. Turfgrass plug treated with Sand topdressing taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September 2018.

Figure 3.12. Turfgrass plug treated with Earth MAX (1) taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September 2018.

Figure 3.13. Turfgrass from the plot treated with Earth MAX (2) taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September2018.

Figure 3.14. Turfgrass from the plot treated with Worm Power taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September2018.

Figure 3.15. Turfgrass from the plot treated with blackstrap molasses taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September2018.

Figure 3.16. Turfgrass from the untreated control plot taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September 2018.

Figure 3.17. Site of the two-year field study located at the Walker Golf Course at Clemson University. Photo was taken post aerification in July 2019.

Figure 3.18. Turfgrass plug treated with sand topdressing taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September 2019.

Figure 3.19. Turfgrass plug treated with Earth MAX (1) taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September 2019.

Figure 3.20. Turfgrass plug treated with Earth MAX (2) taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September 2019.

Figure 3.21. Turfgrass plug treated with Worm Power taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September 2019.

Figure 3.22. Turfgrass plug treated with blackstrap molasses taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September 2019.

Figure 3.23. Turfgrass plug from the untreated control plot taken from the field study site located at the Walker Golf Course at Clemson University. This plug was taken at the end of year 1 in September 2019.

CHAPTER FOUR

SUMMARY

Conclusions and Future Research

. This research yielded results that indicate biostimulants, sand topdressing, and blackstrap molasses can provide benefits to turfgrass managers. Greenhouse studies yielded results showing Earth MAX (1), and sand topdressing provided an average of 16% greater root length than untreated control in year 1. However, in year 2, Worm Power provided 16% greater root length than untreated control. Earth MAX (1) provided 117% greater root weight than untreated control in year 2. No treatments provided greater root weight in Year 1. For both years, blackstrap molasses, Earth MAX (1), and Earth MAX (2) reduced thatch thickness by 30%, 24%, and 18% respectively, versus the untreated; however, no decrease in thatch weight by treatments was observed. Whereas, results from the two-year field trials, showed that all treatments, with the exception of blackstrap molasses, provided an average of 18% greater root length than untreated control. However, blackstrap molasses provided 146% greater root mass, and 9% less thatch weight over the two-year study when compared to the untreated control. For both years, blackstrap molasses, Earth MAX (1), and Earth MAX (2), and Worm Power reduced thatch thickness an average of 26% versus the untreated. Future research which should include; different turfgrass types, rates, soil profiles, and other cultural practices such as various aerification and verticutting schedules. If one of the products, or a combination of these products, used in this research could provide greater rooting lengths, rooting weights, and less thatch consistently then this would be a great benefit to turfgrass managers.

APPENDICES

Appendix A

ANOVA TABLES FOR BOTH YEARS OF STUDIES

Table A.1. ANOVA for root length in year 1 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	118.88417	23.7768	1.1950	0.3579
Rep	3	46.90851	15.6362	0.7859	0.5203
Error	15	298.45370	19.8969	---	---
C. Total	23	464.24638	---	---	---

Table A.2. ANOVA for ashed root weight in year 1 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	12.20523	2.44105	0.3043	0.9027
Rep	3	13.55870	4.51957	0.5633	0.6475
Error	15	120.34560	8.02304	---	---
C. Total	23	146.10953	---	---	---

Table A.3. ANOVA for ashed thatch weight in year 1 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	7672.345	1534.47	1.4193	0.2734
Rep	3	716.030	238.68	0.2208	0.8805
Error	15	16217.598	1081.17	---	---
C. Total	23	24605.973	---	---	---

Table A.4. ANOVA for thatch thickness in year 1 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	482.70833	96.5417	4.5760	0.0098
Rep	3	67.79167	22.5972	1.0711	0.3909
Error	15	316.45833	21.0972	---	---
C. Total	23	866.95833	---	---	---

Appendix continued

Table A.5. ANOVA for TQ in year 1 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	0.20833333	0.041667	1.0000	0.4509
Rep	3	0.12500000	0.041667	1.0000	0.4199
Error	15	0.62500000	0.041667	---	---
C. Total	23	0.95833333	---	---	---

Table A.6. ANOVA for NDVI in year 1 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	0.00197921	0.000396	3.0100	0.0446
Rep	3	0.00044113	0.000147	1.1181	0.3729
Error	15	0.00197263	0.000132	---	---
C. Total	23	0.00439296	---	---	---

Table A.7. ANOVA for root length in year 2 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	53.17927	10.6359	1.8128	0.1708
Rep	3	63.50305	21.1677	3.6078	0.0384
Error	15	88.00718	5.8671	---	---
C. Total	23	204.68950	---	---	---

Table A.8. ANOVA for ashed root weight in year 2 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	698.7676	139.754	2.4825	0.0790
Rep	3	213.8801	71.293	1.2664	0.3215
Error	15	844.4390	56.296	---	---
C. Total	23	1757.0867	---	---	---

Appendix continued

Table A.9. ANOVA for ashed thatch weight in year 2 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	30365.733	6073.15	2.6955	0.0624
Rep	3	643.511	214.50	0.0952	0.9615
Error	15	833795.765	2253.05	---	---
C. Total	23	64805.009	---	---	---

Table A.10. ANOVA for thatch thickness in year 2 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	260.87500	52.1750	3.0339	0.0435
Rep	3	56.79167	18.9306	1.1008	0.3795
Error	15	257.95833	17.1972	---	---
C. Total	23	575.62500	---	---	---

Table A.11. ANOVA for TQ in year 2 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	0.5000000	0.10000	0.4737	0.7902
Rep	3	4.8333333	1.61111	7.6316	0.0025
Error	15	3.1666667	0.21111	---	---
C. Total	23	8.5000000	---	---	---

Table A.12. ANOVA for NDVI in year 2 of the greenhouse trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	0.00843883	0.001688	1.2338	0.3417
Rep	3	0.03240950	0.010803	7.8972	0.0022
Error	15	0.02051950	0.001368	---	---
C. Total	23	0.06136783	---	---	---

Appendix continued

Table A.13. ANOVA for root length in year 1 of the field trial.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	6.884750	1.37695	1.1896	0.3602
Rep	3	6.768950	2.25632	1.9493	0.1651
Error	15	17.362550	1.15750	---	---
C. Total	23	31.016250	---	---	---

Table A.14. ANOVA for ashed root weight in year 1 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	1.6037969	0.320759	4.0862	0.0153
Rep	3	0.1330865	0.044362	0.5651	0.6463
Error	15	1.1774823	0.078499	---	---
C. Total	23	2.9143656	---	---	---

Table A.15. ANOVA for ashed thatch weight in year 1 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	1082.0530	216.41	1.1819	0.3636
Rep	3	4412.7987	1470.93	8.0333	0.0020
Error	15	2746.5656	183.10	---	---
C. Total	23	8241.4173	---	---	---

Table A.16. ANOVA for thatch thickness in year 1 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	10.787611	2.15752	2.9124	0.0494
Rep	3	1.648006	0.54934	0.7415	0.5437
Error	15	11.112053	0.74080	---	---
C. Total	23	23.547671	---	---	---

Appendix continued

Table A.17. ANOVA for TQ in year 1 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	0.208333	0.041667	0.1899	0.9618
Rep	3	1.4583333	0.486111	2.2152	0.1286
Error	15	3.2916667	0.219444	---	---
C. Total	23	4.9583333	---	---	---

Table A.18. ANOVA for NDVI in year 1 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	0.00011121	0.000022	0.1535	0.9757
Rep	3	0.00080879	0.000270	1.8602	0.1797
Error	15	0.00217396	0.000145	---	---
C. Total	23	0.00309396	---	---	---

Table A.19. ANOVA for SF in year 1 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	0.9970833	0.199417	0.5055	0.7678
Rep	3	2.8045833	0.934861	2.3696	0.1115
Error	15	5.9179167	0.394528	---	---
C. Total	23	9.7195833	---	---	---

Table A.20. ANOVA for root length in year 2 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	6.600971	1.32	1.1237	0.3896
Rep	3	5.429113	1.80970	1.5404	0.2451
Error	15	17.622612	1.17484	---	---
C. Total	23	29.652696	---	---	---

Appendix continued

Table A.21. ANOVA for ashed root weight in year 2 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	2.0452028	0.409041	5.4035	0.0049
Rep	3	0.1256310	0.041877	0.5532	0.6538
Error	15	1.1354975	0.075700	---	---
C. Total	23	3.3063313	---	---	---

Table A.22. ANOVA for ashed thatch weight in year 2 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	1239.9382	247.99	1.3291	0.3048
Rep	3	4394.9549	1464.98	7.8514	0.0022
Error	15	2798.8263	186.59	---	---
C. Total	23	8433.7194	---	---	---

Table A.23. ANOVA for thatch thickness in year 2 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	637.2708	127.454	5.1362	0.0061
Rep	3	58.5887	19.530	0.7870	0.5197
Error	15	372.2250	24.815	---	---
C. Total	23	1068.0846	---	---	---

Table A.24. ANOVA for TQ in year 2 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	0.3750000	0.075000	0.2523	0.9321
Rep	3	0.7916667	0.263889	0.8879	0.4699
Error	15	4.4583333	0.297222	---	---
C. Total	23	5.6250000	---	---	---

Appendix continued

Table A.25. ANOVA for NDVI in year 2 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	0.00024538	0.000049	0.3750	0.8580
Rep	3	0.00095646	0.000319	2.4365	0.1049
Error	15	0.00196279	0.000131	---	---
C. Total	23	0.00316463	---	---	---

Table A.26. ANOVA for SF in year 2 of the field trail.

Source	DF	Sum of Squares	Mean Square	F ratio	Prob > F
Treatment	5	1.3321875	0.266438	0.9617	0.4714
Rep	3	1.9540125	0.651338	2.3511	0.1134
Error	15	4.1555625	0.277037	---	---
C. Total	23	7.4417625	---	---	---