ABSTRACT

Title of Thesis: EVALUATION OF ORGANIC INPUTS FOR REDUCING DOLLAR SPOT DISEASE ON COOL-SEASON TURFGRASSES

Cody James Beckley, Master of Science, 2018

Thesis Directed By: Assistant Professor, Dr. Joseph A. Roberts Plant Science and Landscape Architecture

Lolium perenne, Poa annua, and *Agrostis stolonifera* are turfgrass species commonly grown on golf course fairways; however, they are susceptible to dollar spot (*Clarireedia* spp.). Field studies were conduction to assess: 1) the effects of organic fertilizer treatments and fungicide programs on dollar spot severity; and 2) the impact of organic amendments on dollar spot severity and residual fungicide efficacy. Alternating applications of organic and conventional fungicides reduced seasonal dollar spot severity to the same degree as conventional fungicides. Dollar spot was more severe in *Lolium perenne* and *Poa annua* treated with organic fungicides. On *A. stolonifera,* organic biosolids compost, biochar, and vermicompost amendments suppressed dollar spot to the same degree as conventional fertilizer in year one of the trial, while dollar spot was more severe on *A. stolonifera* fertilized with organic biosolids compost in year two. Fertilizer treatments had no effect on residual fungicide efficacy on *A. stolonifera.*

EVALUATION OF ORGANIC INPUT EFFECTS FOR REDUCING DOLLAR SPOT DISEASE ON COOL-SEASON TURFGRASSES

By

Cody James Beckley

Thesis submitted to the Faculty of the Graduate School of the
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Advisory Committee:
Assistant Professor Joseph A. Roberts, Chair
Associate Professor Mark J. Carroll
Associate Professor Thomas R. Turner
Associate Professor Stephanie A. Yarwood

Dedication

I would like to dedicate this work to my fellow turfgrass managers in the Mid-Atlantic region. Your friendship and support has brought me continual enjoyment and success in my career. I hope my work may be beneficial now and in the future as we seek to maintain turfgrass in a responsible and sustainable manner.

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List of Abbreviations[z]

Full Meaning	Abbreviation
Acibenzolar-S-methyl	ASM
Active ingredient	a.i.
Analyses of variance	ANOVA
Area under disease progress curve	AUDPC
Area under NDVI progress curve	AUNPC
Area under quality progress curve	AUQPC
Biochar incorporated	BIO-I
Biochar surface applied	BIO-S
Carbon Dioxide	CO_2
Celsius	C
Colony forming units	cfu’s
Day	d
Demethylation inhibitor	DMI
Dihydrogen Oxide	H_2O
Fluazinam 14 d	FZM
Fluazinam threshold	FZM-T
Fluxapyroxad 14 d	FXD
Fluxapyroxad threshold	FXD-T
Gram	g
Gray leaf resistance	GL
Hectare	ha
Honestly significant difference	HSD
Meter	m
Milliliter	mL
Millimeter	mm
Nitrogen	N
Non-treated	NON
Normalized difference vegetation index	NDVI
Organic biosolids compost incorporated	OBC-I
Organic biosolids compost surface applied	OBC-S
Potato dextrose agar	PDA
Salt tolerance and gray leaf resistance	SGL
Species	spp.
Standard fertilizer	SF
Standard fertilizer + vermicompost	SF + V

[z] This list is in alphabetical order and not in the order of use throughout the thesis text

Chapter 1. Review of the Literature: Dollar Spot Disease and Organic Inputs

General Introduction: Pathogen, Epidemiology, Host and Symptomology

Dollar spot (*Clarireedia* spp. C. Salgado-Salazar) is a common and widespread disease of turfgrass caused by four distinct species of the *Clarireedia* fungal genus: *Clarireedia bennettii*, *Clarireedia homoeocarpa*, *Clarireedia jacksonii*, and *Clarireedia monteithiana* (Salgado-Salazar et al., 2018). Symptoms of the disease were perhaps unknowingly first described by Piper and Coe (1919) during their investigation of *Rhizoctonia* spp. on golf course putting greens near Philadelphia. They noted scattered brown patches of variable size, ranging from a few inches to a foot or more in diameter. In the first official report on dollar spot disease, Dr. John Monteith referred to the disease as 'small brown-patch' and described symptoms as straw colored spots of definite size, no larger than a silver dollar (Monteith, 1927). Later, to avoid confusion with large brown patch, caused by *Rhizoctonia solani* Kühn, the common name was changed to dollar spot (Monteith and Dahl, 1932). Bennett initially proposed *Rhizoctonia monteithiana* as the causal agent of dollar spot (Bennett, 1935). However, further investigation led to *Sclerotinia homoeocarpa*'s adoption as the official name for dollar spot (Bennett, 1937). Bennett's classification of the fungus to *Sclerotinia* sp. Fuckel was based on the broad definition of the genus at that time, which included conidia-producing fungi (Walsh et al., 1999). As isolates were collected and categorized, four strain types were identified and described as follows: one 'perfect' strain (produced ascospores and conidia), one 'ascigerous' strain (produced ascospores and microconidia), and two ‘nonsporiferous’ strains (Bennett, 1937; Salgado-Salazar et al., 2018). Though strains differed greatly in mycelial color, sterility, production of ascospores, conidia and microconidia depending on the continent of origin, they were considered a single fungus. At the turn of the century, reclassification of the fungus to *Lanzia*, *Moellerodiscus*, or *Rutstroemia* was being considered due to *Clarireedia’s* differing morphology from that of other *Sclerotinia* spp. and exhibition of a stronger genetic relationship to the aforementioned fungal genera (Allen et al., 2005). In 2018, *S. homoeocarpa* was formally reclassified to the new genus *Clarireedia*, after modern DNA sequence techniques and data confirmed that the fungus was not a species of *Sclerotinia* nor of any known Rutstroemiaceae genus (Salgado-Salazar et al., 2018). With this reclassification also came new taxonomic designations for the new species, which are listed here with their respective geographic and host distributions: *C. homoeocarpa* comb. nov. and *C. bennettii* sp. nov. (United Kingdom, Festuca rubra), *C. jacksonii* sp. nov., and *C. monteithiana* sp. nov. (Global distribution, multiple warm and cool season hosts) (Salgado-Salazar et al., 2018).

Smiley et al. (2005) described lab cultures of *Clarireedia* as being characterized by rapid-growing, fluffy white mycelium that may turn various shades of tan or green with age. Additionally, such cultures will not form sclerotia, instead, forming plate-like black stroma 2-4 weeks after inoculation. *Clarireedia* may overwinter as remnant stromata from previous infections (Smiley et al., 2005) or as dormant mycelium in tissues and crowns of infected grass plants (Fenstermacher, 1980). Infection occurs by mycelial invasion into severed leaf tissue, stomata, or direct penetration (Endo, 1966). Toxins secreted by the pathogen can cause necrosis of plant tissues, stunting and thickening of roots, and loss of root hairs (Allen et al., 2005). Dispersion of the pathogen may be localized or widespread. Local distribution occurs as mycelium from diseased leaf tissue contacts and spreads to healthy leaf tissue. Widespread distribution occurs when infected grass clippings are physically transported by maintenance equipment, golf carts, and foot traffic (Smith, 1953). It has also been discovered that turfgrass seeds can be contaminated by *Clarireedia* and are a potential source of dollar spot inoculum (Rioux et al., 2014).

Temperature and humidity strongly influence the infection and spread of dollar spot. Bennett's initial examination on the influence of temperature on *Clarireedia* development revealed general minimum, ideal, and maximum temperature ranges of 5, 20 and >35 °C, respectively (Bennett, 1937). Endo (1966) found similar values (4.5, 26.8, >32 °C, respectively) in a separate trial conducted on potato dextrose agar. Based on these findings, the window for optimal development of dollar spot was regarded to be from late spring through late autumn when temperatures ranged from 15 to 27 °C (Smiley et al., 2005). Maximum pathogenicity was reported to occur at 21 to 27 °C with greater than 85% nighttime atmospheric humidity (Couch, 1995; Endo, 1966). More recently, during the development of the Smith-Kerns logistic-based dollar spot warning system, dollar spot growth was found to be very limited when relative humidity was below 70%. (Smith et al., 2018).

Clarireedia has a wide host range, afflicting nearly every species of turfgrass in the world (Smiley et al., 2005). In North America, all commonly cultivated species of turfgrass are susceptible to *Clarireedia*, however, levels of susceptibility vary by species and cultivar (Walsh et al., 1999). Among warm-season turf types, bermudagrass (*Cynodon dactylon* L. Pers.) and seashore paspalum (*Paspalum vaginatum* Swarz.) are the most susceptible species. Of common cool-season turf types, perennial ryegrass (*Lolium perenne* L.) and tall fescue (*Festuca arundinacea* Schreb.) are regarded as the least susceptible while annual bluegrass (*Poa annua* L.) and creeping bentgrass (*Agrostis stolonifera* L.) are regarded as the most susceptible to *Clarireedia*.

Creeping bentgrass is one of the most popular cool-season turf types for use on golf courses in the transition zone of the United States (Vargas, 2005). Characterized as an allotetraploid, creeping bentgrass is thought to be native to Western Europe and was introduced to North America during colonization (Casler, 2003). The United States Golf Association Green Section collected and maintained selections of bentgrass types they deemed suitable for use on golf courses, which helped to promote the species widespread use as golf course turf (Duich, 1985). Susceptibility to *Clarireedia* also varies between bentgrass cultivar: Where older cultivars (Seaside, Penncross) are highly susceptible to *Clarireedia*, many new cultivars of creeping bentgrass display improved resistance to dollar spot. Some modern cultivars even match the resistance capability of velvet and colonial bentgrasses, which have historically been regarded as having better resistance to *Clarireedia* (Weible et al., 2012). Though newer cultivars have improved resistance to the disease, no modern bentgrass cultivar is considered highly resistant to dollar spot (Allen et al., 2005).

Symptoms of *Clarireedia* first appear on individual leaf blades of turfgrass as chlorotic lesions. As the disease progresses, lesions may take on a water-soaked appearance and ultimately become tan or completely bleached in color. Infection severity on individual leaf blades can range from one single lesion, to multiple lesions, to blighting of the entire leaf. Individual lesions may take on a characteristic hourglass shape with tan to red-brown margins, especially on large, coarse leaves (Smiley et al., 2005). Symptom progression of *Clarireedia* varies according to turf species and management regime. On turfgrass mown at or below ~1.25 cm, *Clarireedia* produces tan-colored, circular, recessed patches which range in size from several grass blades and topping out at the size of a silver dollar coin (5.0- to 7.5-cm diameter) (Smith, 1953). During severe outbreaks, individual infection centers may combine to form large asymmetrical patches (Smiley et al., 2005). Individual infection centers on turfgrass maintained at a higher height of cut (> 1.25 cm) are generally larger (2- to 15-cm diameter) and can also coalesce into large, irregular patches (15 cm to 3 meters diameter) (Allen et al., 2005; Smiley et al., 2005). During periods of high humidity or extended leaf wetness, *Clarireedia* produces a cottony network of aerial mycelia on diseased turf, which dissipates as the canopy dries (Smiley et al., 2005). This mycelial growth is sometimes misidentified as originating from other turfgrass pathogens (*Pythium*, *Rhizoctonia*) (Smiley et al., 2005) or as spider webs (Walsh et al., 1999).

Chemical Fungicide Use

Applications of chemical fungicides have been the most successful method to treat dollar spot of turfgrass. The first fungicides used to effectively control dollar spot were cadmium-based products (Fenstermacher, 1980). While these heavy-metal based fungicides are no longer used, numerous other fungicides are currently labeled for control of dollar spot. These include, but are not limited to: benzimidazoles, carboximides, demethylation inhibitors (DMI), dicarboxamides, one dinitro-aniline, dithiocarbamates, nitriles, and succinate dehydrogenase inhibitors (Allen et al., 2005). Because dollar spot occurrence can be widespread, chronic and severe in nature, multiple applications of fungicides may be required to maintain adequate control. At last estimate, managers were spending more for the chemical control of dollar spot than any other disease in a turfgrass setting (Vargas, 2005).

The continuous and repeated use of fungicides to control dollar spot has allowed fungicide resistant *Clarireedia* populations to develop (Vargas, 2005). Following approximately 20 years of use, *Clarireedia* insensitivity to cadmium and mercury based fungicides was first documented in the late 1960's (Cole et al., 1968). Benzimidazole-type systemic fungicides labeled for the control of dollar spot entered the market the 1960s and reports of dollar spot resistance came less than a decade after their use (Warren et al., 1974). In 1983, Detweiler and others (1983) documented *Clarireedia* resistance to the dicarboxamide iprodione, approximately 11 years after it was introduced; Similarly, Golembiewski and others (1995) reported DMI-resistant *Clarireedia* on golf courses in Michigan and Ohio, again coming approximately 11 years after this group of fungicides were released to the turf market. This trend toward *Clarireedia* resistance to fungicides may likely continue if selection pressure is increased by continually using only one compound (Latin, 2017). To minimize resistance, it is imperative to continually explore and employ non-chemical options for the control of dollar spot.

Impact of Fertility

While multiple biotic and abiotic factors strongly influence *Clarireedia* development and severity on turfgrass, the effect of fertility is perhaps one of the most important factors to consider when evaluating non-chemical control options for dollar spot. Plant nutrition is an important component of disease control practice (Cook, 1961; Huber and Gillespie, 1992). Nitrogen (N) in particular, is perhaps the most vital nutrient for turfgrass growth and managing disease (Beard, 1982; Watschke, 1995). Nitrogen is a molecular constituent of plant proteins, nucleic acids, hormones, and chlorophyll (Carrow et al., 2001; Pessarakli, 2014). At proper levels within the plant, N improves turfgrass vigor and bolsters resistance and recovery from disease (Watschke et al., 2013). Where N is deficient, turf can become weakened and disposed to increased injury from pathogens (Walters and Bingham, 2007). While deficiencies in the other macro and micronutrients can leave plants weakened and more predisposed to disease injury, there is little documentation that those nutrients alone have direct correlation to disease severity on turfgrass as does N (Watschke, 1995).

Clarireedia incidence and severity on turfgrass is often directly related to N fertility, doing the most damage to turfgrass that is undernourished (Watschke, 1995). Endo (1966) was one of the first to document that turfgrass lacking adequate N fertility could be predisposed to *Clarireedia* infection, as N-stressed plants developed senescent tissue which *Clarireedia* could then use as source for growth. Around the same time, Cook (1964) and Markland (1969) successfully used applications of fertilizer with high levels of available N to reduce dollar spot injury on cool season grasses. Markland (1969) determined that disease reduction came because of vigorous turf growth in response to increased N. Rapid increases in turf growth cause infected or necrotic tissue to be mown off more quickly (Couch, 1995), thereby masking or eliminating symptoms of dollar spot. As such, maintaining adequate to high N fertility during periods of peak dollar spot activity is now regarded as a primary method of control (Smiley et al., 2005). Even so, golf course managers may choose to apply minimal rates of N to reduce organic matter accumulation (Dernoeden, 2012), reduce annual bluegrass encroachment in bentgrass putting greens (McCarty, 1999), and increase ball roll distance (Hartwiger et al., 2001).

Nitrogen Carriers

Nitrogen carriers may be subdivided into two general forms: quickly available or slowly available. Quickly available fertilizers contain N as NO_3 or NH_4 and are manufactured artificially from petroleum, natural gas, or atmospheric N (Turner and Hummel, 1992). They are characterized by having high solubility, rapid availability, and minimal temperature dependency (Blume et al., 2009). Quickly available fertilizers are the predominant choice among turfgrass managers, due to their versatility and low cost per unit of N (Turgeon, 1996). They have also been shown to be effective at suppressing dollar spot (Landschoot and McNitt, 1997). Inorganic salts, urea, and ureaformaldehyde are types of quickly available N sources.

Slow release fertilizers contain N in an insoluble form, or as an impermeably coated water-soluble source. Natural organic fertilizers are manufactured from plant and animal residues and are characterized as having low solubility, availability that is dependent on temperature and microbial action, and a high cost per unit of N (Turgeon, 1996). One other important distinguishing feature of natural organic fertilizers is the effect they can have on increasing soil microbial activity. Due to composition, natural organic fertilizers either contain the microorganisms that biologically control plant pathogens (Liu et al., 1995), or they stimulate soil microbial activity so that plant pathogen activity is suppressed (Davis and Dernoeden, 2002). For these reasons, organic fertilizers and amendments have been extensively studied for use as biological control agents for dollar spot (Boulter et al., 2000; Davis and Dernoeden, 2002; Landschoot and McNitt, 1997; Liu et al., 1995; Markland et al., 1969; Nelson and Craft, 1991).

Biological Control Agents

Soil environments are the most complex habitats on earth, estimated to contain one-third of all living organisms: A single gram of soil is estimated to contain 10^9 bacterial and archaeal cells along with kilometers of fungal hyphae (Paul, 2014). Most of these microorganisms are in constant conflict for resources and have developed mechanisms by which they can coexist with or dominate other organisms (Hibbing et al., 2010). Fungi and bacteria that are known to be antagonistic toward foliar and root-based plant pathogens are referred to as biocontrol agents. Pathogen suppression by biocontrol agents is often directly related to microbial activity that coincides with critical pathogen lifecycles (Cook and Baker, 1983), occurring (but is not limited to) though the following mechanisms: Antibiosis, mycoparasitism, and plant defense activation (Nelson, 1997).

Antibiosis

Competition among microbes may occur indirectly or directly and is often over nutritional resources. Competing bacteria are known to maximize nutrient uptake by producing antimicrobial compounds (toxins, antibiotics, volatiles) which inhibit or eliminate the growth of competing microbes (Hibbing et al., 2010). With respect to turfgrass, certain species of *Pseudomonas* have been shown to produce antibiotics that suppress *Pythium* and *Rhizoctonia* diseases (Nelson, 1997).

In *in vitro* studies, *Enterobacter cloacae* Jordan was shown to be suppressive to *Pythium ultimum* Trow and *Rhizoctonia solani* through the production of ammonia (Howell et al., 1988). *Bacillus subtillis* Ehrenberg is frequently used as a biocontrol agent thanks to its ability to colonize roots, form a protective biofilm and secrete antibiotic compounds (Bais et al., 2004). Fungal species belonging to the genus *Trichoderma* were some of the first soil microbes to be evaluated as biological controls. A detailed evaluation of *Trichoderma's* antagonistic effects on *Rhizoctonia solani* revealed the production of a 'lethal principle' that was toxic to the pathogen (Weindling, 1932; Weindling, 1934).

Mycoparasitism

Mycoparasitism is the process by which fungal hyphae bind to, degrade, penetrate and inhibit the cell walls of a target fungal pathogen (Chet, 1987; Nelson, 1997). In addition to documenting an antibiotic effect, Weindling (1934) also noted that *Trichoderma* hyphae suppressed growth of *R. solani.* Bacteria have also been documented to be parasitic toward pathogenic fungi: *Serratia marcescens*'s Bizio effectiveness as a biocontrol agent for *Magnaporthe poae* Landschoot & N. Jackson is attributed to the production of chitinase enzymes, which inhibit chitin-containing fungal pathogens (Kobayashi and Nour, 1996).

Plant defense activation

Plants possess an assortment of defense mechanisms which may be expressed in response to an internal or external threat (Taiz et al., 2014). Induced resistance, occurring as either systemic acquired resistance or induced systemic resistance, takes place when plant defensive capabilities are enhanced after being triggered by environmental or biological stimuli (Vallad and Goodman, 2004). Each form of induced resistance is distinguished by the elicitor involved and regulatory pathways signaled (Vallad and Goodman, 2004).

Systemic acquired resistance may be activated when plants are exposed to elicitor microbes or chemicals, which trigger a buildup of pathogenesis related proteins or salicylic acid to reduce symptoms of disease (Sticher et al., 1997). In turfgrass, acibenzolar-S-methyl [(ASM) Actigard, Syngenta Corp., Basel, Switzerland] is applied as plant defense activator to induce systemic acquired resistance. Lee et al. (2003) reported a 38% reduction of dollar spot infection centers on a creeping bentgrass green when applying ASM as a spray on 14-d intervals. Zhang et al. (2005) also reported a 27% reduction of dollar spot on a creeping bentgrass green by applying ASM similarly.

Induced systemic resistance is activated when plant growth-promoting rhizobacteria which elicit defense response through jasmonate and ethylene regulated pathways (Vallad and Goodman, 2004). The rhizobacteria *Bacillus* spp. are one of the most common groups known to elicit plant defense response through mutualistic relationships (van Loon and Glick, 2004). *Bacillus* spp. have been reported to aid in the control diseases of turfgrass as well: Marvin et al. (2012) reported that *Bacillus licheniformis* used in combination with quarter rates of synthetic fungicides provided dollar spot control comparable to full rates of synthetics on bentgrass putting greens.

Ultimately, the degree to which a biological control can effectively suppress plant pathogens depends upon its ability to colonize and thrive in the rhizosphere (Nelson, 1997). One method to maximize the success of biocontrol agents may be to apply mixtures of microbes with differing modes of action and colonization abilities (Whipps, 2001). Enhanced microbial activity may also result in an increased availability of nutrients, which may stimulate plants to more rapid recovery from disease (Boulter et al., 2000). The deployment of biocontrol agents falls into two general categories: Application as an organic amendment or as an inundative inoculant (Walsh et al., 1999).

Natural Organic Amendments and Fertilizers

Organic amendments and fertilizers have long been evaluated for their ability to control soil borne pathogens by stimulation or enhancement of resident soil microbe populations (Cook and Baker, 1983; Hoitink and Fahy, 1986). Some of the most common types of amendments and fertilizers speculated to limit turfgrass pathogens are biosolids, organic waste composts, plant and animal meals, activated sewage sludge, and natural organic fertilizers. Other forms of organic amendments, such as biochar and vermicompost, are available for use on turfgrass but have not been evaluated for disease control.

Sewage Sludge

Activated sewage sludge is a granular fertilizer composed of processed sewage materials (Anderson, 1959). It was one of the first organic fertilizers extensively evaluated for disease control on turfgrass. Initial reports from Davis and Engel (1951) noted reduced large brown patch on creeping bentgrass after applying sewage sludge. In evaluations for snow mold treatment, Watson (1956) reported an increase in fungicide effectiveness when it was combined with activated sewage sludge. Wells and Robinson (1954) documented reductions in damage from cottony blight on ryegrass plots treated with heavy rates of activated sewage sludge, compared to other organic and inorganic nitrogen sources. Cook and others (1964) were one of the first to compare sewage sludge to conventional fertility sources for control of dollar spot on bentgrass, where they documented significant reductions in disease severity post sewage sludge application and no reductions from inorganic nitrogen sources. Markland (1969) also showed activated sewage sludge as useful for significantly reducing dollar spot, though he hypothesized that increased presence and uptake of heavy metals from the product could have also inhibited fungal growth of *Clarireedia*. Turner and Hummel (1992) agreed, hypothesizing that the presence of cadmium in early formulations of sewage sludge would have contributed to its effectiveness at suppressing dollar spot.

Composts

Composts are derived from the microbial decomposition of biodegradable organic materials and wastes (Boulter et al., 2002). When applied, they can directly impact soil health by increasing organic matter, cation exchange capacity, water holding capacity, and by lowering bulk density (Doran, 1995; Drinkwater et al., 1995). In turn, plant productivity is enhanced by the increased availability of water and nutrients (Doran and Zeiss, 2000). Composts may also be used as fertilizers; however, they require soil microbe activity for nutrient release (Hargreaves et al., 2008).

Composts were first applied to turfgrass as topdressings or by being mixed into sand topdressings (Fitts, 1925). Topdressing is a cultural practice where a thin layer of soil or sand is applied evenly across a turfgrass canopy (Turgeon, 1996). Composts were also the early organic component of choice for root zone mixes when constructing putting greens (Hummel, 1993). Though their use as a primary fertility source on turfgrass has been eclipsed by less expensive and more potent synthetic alternatives, they have consistently garnered the interest of research scientists looking for alternative sources of disease control.

Nelson and Craft (1991; 1992) conducted multiple studies that evaluated microbial inoculants, organic fertilizers and composts for the suppression of various turfgrass pathogens. In their earlier work, sand topdressings amended with cornmeal (which had previously been inoculated with strains of *Enterobacter cloacae*) were used to suppress dollar spot development of bentgrass putting greens (Nelson and Craft, 1991). Though excellent suppression of dollar spot was observed within the first month of application, the topdressing treatments were sometimes less effective after subsequent applications in the first and second year. In the second trial, sand topdressings amended with composts or organic fertilizers were evaluated for effect on dollar spot (Nelson and Craft, 1992). This study found that compost prepared from turkey litter, biosolids, and uncomposted blends of plant and animal meals were consistently suppressive to dollar spot on creeping bentgrass across the 3-year trial. While the researchers could not pinpoint the mechanism by which *E. cloacae* suppressed dollar spot, they hypothesized that suppression came from direct competition with pathogen growth.

In a greenhouse trial, Peacock and Daniel (1992) evaluated a natural organic fertilizer amended with a confidential blend of *Bacillus spp., Trichoderma viride* Pers., actinomycetes, and enzymes, compared to the same non-amended fertilizer alone, and to urea for impact on brown patch incidence. During and after the 72-day study, no added benefit to disease suppression was detected from the addition of organic materials.

Liu et al. (1995) conducted an evaluation of organic amendments (animal meal, plant meal, a blend of plant and animal meal, biosolids) and conventional fertility sources (Ammonium nitrate, Sulfur-coated Urea) for dollar spot suppression on a Penncross creeping bentgrass putting green. When averaging dollar spot infection centers per treatment over the three-year trial, the researchers found that blended meal products (Ringer brand) significantly reduced dollar spot incidence compared to the other organic fertility treatments, while ammonium nitrate was the most effective fertility source for reducing dollar spot incidence. The researchers hypothesized that nitrogen was the likely suppressive factor: plots that received higher rates of N minimized disease expression compared to treatments receiving lower rates of N.

A short time later, Landschoot and McNitt (1997) evaluated natural organic and synthetic organic N fertilizers, as well as N availability as factors related to dollar spot suppression on creeping bentgrass. Their results were similar to those documented by Liu et al. (1995) in that synthetic organic N fertilizers provided equal or better control of dollar spot on creeping bentgrass than natural organic N sources. Landschoot and McNitt (1997) were also able to demonstrate a correlation between dark green turf and disease suppression, indicating a potential connection between N availability and dollar spot suppression.

Davis and Dernoeden (2002) evaluated nine different standardized N-sources for impact on dollar spot development, N in foliar tissue, and soil microbial activity (as well as other factors). The study was fertilized for seven continuous years, with data collected in the final three. At the conclusion of the study, the researchers found only one organic N source (Ringer Lawn Restore, poultry-meal based) to reduce dollar spot in all three years of the trial, when pressure was low to moderate. They concluded that reductions likely resulted from increased N-availability rather than enhanced microbial activity, pointing out that no organic N source consistently reduced dollar spot incidence when compared with synthetic organic N-sources during the trial.

Vermicompost

Vermicompost is a homogenized, stabilized, organic compost derived from the breakdown of organic wastes via earthworm activity. Vermicompost possesses high porosity, high rates of mineralization, and has a low carbon to nitrogen ratio (Dominguez, 2004). As with other types of compost, applications of vermicompost have been linked to improvements to physical soil structure (Kahsnitz, 1992), increased availability of nutrients (Gilot, 1997), and enhancement of the soil microbiota (Domínguez et al., 2010). In some of the first work done on the suppressive properties of vermicompost, root rot of tomato caused by *Phytophthora nicotianae* var. *nicotianae* Breda de Haan and club root disease of cabbage caused by *Plasmodiophora brassicae* Woronin were suppressed by vermicompost-supplemented substrates (Szczech et al., 1993). There are many additional documented instances of disease suppression from vermicomposts in agriculture (Domínguez et al., 2010), with suppression primarily attributed to antibiosis, induced resistance, and outright competition (Litterick et al., 2004). To date, there is no peer-reviewed literature on the use of vermicompost to suppress diseases of turfgrass.

Biochar

Biochar is a carbon-rich soil amendment derived from the slow pyrolysis of organic biomass (Lehmann and Joseph, 2015). Biochar has been described as a means to improve soil fertility (Van Zwieten et al., 2010), bolster soil microbial population abundance (Jin, 2010), and sequester carbon in soils (Lehmann and Joseph, 2015). It has also been linked to the enhanced productivity of agricultural crops in a variety of pot and field experiments (Asai et al., 2009; Major et al., 2010). Initial reports on the impact of biochar on plant resistance to pathogens suggests that biochar-amended soils may suppress soil pathogens to the same degree and in the same fashion as compost-amended soil: Matsubara et al. (2002) reported an increased tolerance to Fusarium root rot by asparagus seedlings (*Asparagus officinalis* L.) grown in biochar-amended soil. Elad et al. (2010) showed improved sweet pepper (*Capsicum annuum*) cv. Maccabi (Hazera Genetics, Ltd.) and tomato (*Lycopersicum esculentum*) cv. 1402 (Hazera Genetics, Ltd., Brurim M.P. Shikmim, Israel) resistance to *Botrytis cinerea* Pers. (gray mold) and *Leveillula taurica* [(Lév.) G. Arnaud] (powdery mildew) in a biochar-amended medium, proposing that suppression was achieved through induced or systemic-acquired resistance. Later, many in this group of researchers would demonstrate improved broad-spectrum resistance against *B. cinerea*, *Colletotrichum acutatum* J.H. Simmonds and *Podosphaera apahanis* Wallr. by strawberries (*Fragaria* x *ananassa* Duchesne) grown in a biochar-amended potting mix. The researchers confirmed that biochar addition stimulated the expression of five different plant defense-related genes (*FaPR1*, *Faolp2*, *Fra a3*, *Falox*, and *FaWRKY1*) (Harel et al., 2012). To date, only a handful of studies detail the impact of biochar amendments to turfgrass. In each study, the addition of biochar to sand-based root zones had positive effects on creeping bentgrass growth and root zone water retention compared to non-treated controls (Brockhoff et al., 2010; Vaughn et al., 2018; Vaughn et al., 2015)

Inundative Inoculants

Inundative inoculants are antagonistic microbes that are mass-produced and applied to rapidly control the target pathogen (Nelson, 1997). Biological fungicides are a form of inundative inoculant which contains naturally occurring, antagonistic fungi and bacteria that are suppressive to foliar and root-based plant pathogens. Applications of biological fungicides are made to increase the populations and suppressive actions of resident microbes in a turfgrass system (Nelson and Burpee, 1994). The first biocontrol agent registered for the control of dollar spot on turfgrass was Biotrek 22G (*Trichoderma harzianum*) (Harman and Lo, 1996). While the product was touted as being effective for control of dollar spot (up to 71% reduction in active disease and up to 30 days of delayed development), similar results were never realized for others who trialed the product (Nelson and Craft, 1999, Vincelli and Doney, 1997). This variability is attributed to the sensitivity of biocontrol agents to environmental factors such as temperature, moisture, light and cultural practices (Nelson and Burpee 1994). Nelson and Craft (1999) hypothesized that improved product formulations and application methods compatible with management practices would improve efficacy of biological fungicides, yet nearly 2 decades later, significant hurdles still hinder widespread adoption of these materials.

Currently, biological fungicides are not widely used in the turfgrass industry due issues with cost and efficacy, especially compared to conventional fungicides (Vincelli and Clarke, 2017). The following list comprises biological fungicides that are currently marketed and labeled for the suppression of dollar spot: Actinovate SP (*Streptomyces lydicus* WYEC 108, Novozymes BioAg Inc., Milwaukee, WI), Companion (*Bacillus subtilis* GB03, Growth Products, White Plains, NY), EcoGuard (*Bacillus licheniformis*, Lebanon Seaboard Corporation, Lebanon, PA), Rhapsody (*Bacillus subtilis* QST 713, Bayer Crop Science, Triangle Park, NC), TurfShield Plus (*Trichoderma harzianum* Rifai strain T-22, *Trichoderma virens* strain G-41, Bioworks Inc., Victor, NY), and ZeroTol 2.0 (BioSafe Systems, East Hartford, CT).

Liquid compost extracts

Liquid compost extracts are derived from the filtration of mixtures of water and compost. Identified early as having potential for the biocontrol of pathogens in organic management systems (McQuilken et al., 1994) their popularity has greatly increased since the 1990s. Early studies on compost extract effect in agricultural settings showed that they provided inhibition of *B. cinerea* development on bean leaves (*Phaseolas vulgaris* L. cv. Groffy) (McQuilken et al., 1994). Studies on compost tea to suppress turfgrass disease has been limited and success variable: In a one-year study, mild suppression of microdochium patch (*Microdochium nivale* [Fries] Samuels & Hallett) was observed on putting greens, but no reduction in anthracnose severity or turf health and color compared to control plots after applying compost tea derived from wood chips, grass clippings, horse bedding and horse manure (Conforti et al., 2002). Hsiang and Tian (2007) reported that they achieved dollar spot control similar to chlorothalonil with a 'mushroom' compost tea extract, while most others provided significantly less suppression. No mechanism of suppression was mentioned in either study.

Ultimately, the degree of effective disease control from biocontrol agents varies greatly, with success being highly dependent upon the target pathogen, the biocontrol agent used, and environmental conditions (Bonanomi et al., 2007; Hoitink and Fahy, 1986). Though a great deal of the literature in review demonstrates that targeted applications of biocontrol agents may be effective at suppressing or reducing disease activity to acceptable thresholds, few reports were based on more than two years of accumulated data. Many of the studies are also focused on finding one principal biological control agent for a specific plant pathogen, when the evidence indicates that pathogen activity and severity is influenced and regulated by the interplay of multiple abiotic and microbial factors (Schroth and Hancock, 1981).

Summary and Thesis Overview

Dollar spot is a common turfgrass disease caused by the fungal pathogens belonging to the newly described genus *Clarireedia*. Symptoms of the disease manifest as localized spots that appear as sunken, withered, and bleached and are approximately the size of a dollar coin. The pathogen exhibits a wide host range; nearly all species of turfgrass are susceptible to the disease, including two of the most common cool-season types used for tee and fairway height turf in the Mid-Atlantic region: annual bluegrass and creeping bentgrass. While not overtly challenging to diagnose and treat, dollar spot is known to produce multiple infection cycles per growing season. Maintaining complete control of the pathogen is often an intensive and costly endeavor where multiple fungicide applications are required throughout the growing season. As concerns over pesticide usage on turfgrass have steadily increased in the past few decades, the development of alternative management tools becomes more and more important.

The use of organic fungicides and amendments has long been considered as one promising method of alternative dollar spot management. These products are designed and deployed to suppress pathogen activity through microbial suppression mechanisms. While early studies on the subject have showed that, in some cases, organic biocontrols can be effective at suppressing dollar spot, there remain more questions than answers on the topic of organic pest management.

First, it remains unclear as to the ideal method of application or incorporation of organic biocontrols. Can organic fungicides be used in a manner similar to conventional fungicides? How will the sustained addition of organic fertilizers or biocontrols to integrated pest management systems impact the visual quality and playability of the turf, or will they permit a reduction in conventional pesticide applications? Many are also interested in new types of composts and extracts that show promise as biological controls for plant pathogens. There is also increasing interest on how these organic management strategies affect microbial communities in the soil, such as beneficial plant-microbial symbiosis or antagonistic effects between individual microbes.

This thesis describes three field trials; one was initiated in 2016 and two were initiated in 2017. There is little to no previous research attempting to determine the effectiveness of organic fertilizer applied in conjunction with programmed rotations of organic fungicides to reduce the incidence and severity of dollar spot. Past research indicates that most forms of organic fertility have no greater influence on dollar spot development than synthetic sources (Davis and Dernoeden, 2002; Landschoot and McNitt, 1997). Additionally, organic fungicides are considered ineffective at controlling dollar spot when used alone (Vincelli and Clarke, 2017; Vincelli and Doney, 1997). It has not been evaluated whether combining organic fertility and organic fungicide sources provides any additional degree of pathogen control. In 2016, an experiment was initiated to evaluate the effect of using programmed rotations of organic fertilizers in combination with organic fungicides to control dollar spot on a perennial ryegrass fairway. An additional experiment in 2017 was designed to replicate the previous trial to elucidate the effect of organic fungicides when used in an alternated rotation with conventional fungicides (Chapter 2).

Previous research has shown that in certain situations, organic composts and amendments can effectively reduce the incidence and severity of dollar spot (Boulter et al., 2002; Nelson and Craft, 1991). Since that time, biochar and vermicompost have been introduced to the turfgrass market and each has demonstrated potential as a biocontrol for plant pathogens (Domínguez et al., 2010; Elad et al., 2010). A third experiment was initiated in 2017 to evaluate various composts for their influence on the development and severity of dollar spot, as well as for impact on residual fungicide efficacy (Chapter 3). Research presented in this thesis will further the work of developing suitable biological control tools for dollar spot management on cool-season golf course tees and fairways. While these practices are not expected to provide complete season-long control of the dollar spot pathogen, the combination of these practices along with additional cultural practices might reduce the reliance turfgrass managers have on chemical fungicides to control dollar spot.

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Chapter 2. Effects of Nitrogen Fertilizer Source and Fungicide Source on Dollar Spot Disease of Perennial Ryegrass Golf Course Fairways

Abstract

Dollar spot (*Clarireedia* spp. C. Salgado-Salazar) is a serious disease of cool-season turfgrass, which may require multiple fungicide applications to control. Reports of fungicide resistance have generated interest in alternative management practices to reduce dependence on chemical fungicides. Separate 2-yr field studies evaluated the effects of fertilizer source and fungicide source on dollar spot severity of perennial ryegrass (*Lolium perenne* L.) across two locations in central Maryland. The location 1 study utilized a 2 x 4 factorial, randomized complete block design of treatments, which were comprised of fertilizer source factor (fish meal based vs sulfur coated urea) and fungicide source factor (biological, alternated conventional and biological, conventional, and none). The location 2 study utilized a 2 x 5 factorial, randomized complete block design of treatments, which were comprised of fertilizer source factor (Fish meal based vs Sulfur Coated Urea) and disease control factor (biological, alternated conventional and biological, conventional, extended interval conventional, and none). Turfgrass was visually rated for disease development (dollar spot infection centers) and quality (1-9 rating scale; 9 = best) throughout each growing season. Fertilizer source did not impact dollar spot or turf quality in either location or year of the trial. Of the fungicide programs tested, the conventional fungicide program was the most effective program to reduce dollar spot. The alternated conventional and biological fungicide program was statistically similar to conventional when comparing area under the disease progress curve (AUDPC)

values. The biological fungicide program reduced AUDPC compared to non-treated, but not to the extent of the other fungicide programs. When using a standard 14 d fungicide program, these results support the incorporation of biological fungicides into a conventional fungicide program during times of low to moderate disease pressure.

Introduction

Dollar Spot (*Clarireedia* spp. C. Salgado-Salazar) is one of the most common and widespread foliar diseases of cool-season turfgrass. Symptoms of *Clarireedia* spp. first manifest as small (< 1 cm) lesions with individual leaf blades appearing water soaked or bleached. Lesions may also be accompanied by an aerial mycelium during humid periods. If left unchecked, infection centers on closely mown turf may grow to approximately 1-5 cm, wherein the infected turf becomes completely necrotic and recessed (Smiley et al., 2005). Multiple infection cycles may occur in a single growing season, making complete control of the pathogen an intensive and costly endeavor (Vargas, 2005).

Historically, chemical fungicides have been the most effective tool to manage dollar spot (Walsh et al., 1999) though their continual use has allowed resistant dollar spot populations to develop. Benzimidazoles (Warren et al., 1974), dicarboxamides (Detweiler et al., 1983), and demethylation inhibitors (Golembiewski et al., 1995) have all been implicated in resistance events. Efforts to minimize dependence on chemical fungicides have encouraged the development of integrated management strategies, which utilize a suite of non-chemical cultural practices to mitigate dollar spot incidence. Some of the cultural practices commonly employed to reduce dollar spot incidence include minimizing periods of leaf wetness (Williams et al., 1996), minimizing drought stress (Couch, 1995), and maintaining adequate nitrogen (N) fertilization (Smiley et al., 2005).

Supplying turfgrass with adequate N fertility is regarded as one of the most important cultural control measures for dollar spot. Nitrogen is necessary for the production of the carbohydrates, cellulose, hormones and other constituents of host resistance (Huber, 1980). Where N is deficient, dollar spot incidence and severity increases as N-stressed turfgrass is more likely to develop senescent tissue, acting as a substrate for *Clarireedia* spp. growth (Watschke, 1995). The effects of N fertility on dollar spot suppression are well documented. Increases in N fertility correlate with reduced dollar spot incidence (Cook et al., 1964; Davis and Dernoeden, 2002; Landschoot and McNitt, 1997; Liu et al., 1995; Markland et al., 1969; Nelson and Craft, 1991; Nelson and Craft, 1992). The effect that N source has on dollar spot is still unclear. Natural organic sources of have been suggested to provide the added benefit of supplying additional soil microorganisms (Liu et al., 1995), or stimulating microbe activity (Davis and Dernoeden, 2002) so that dollar spot is suppressed. In previous studies, natural organic sources of N were reported to have reduced dollar spot equivalent to that of a chemical fungicide (Nelson and Craft, 1992). In other studies, disease reductions were not favored by synthetic or natural organic sources (Davis and Dernoeden, 2002, Landschoot and McNitt, 1997).

Interest has also grown in the use of biological fungicides for dollar spot suppression. Biofungicides are inundative inoculants, usually comprised of mass-produced bacteria or fungi that are known to suppress foliar and root-based plant pathogens (Nelson, 1997). Applications of biofungicide are thought to inhibit plant pathogens through many modes of action, including competition of resources, production of antibiotics, mycoparasitism, rhizosphere competence, and induced host resistance (Cook and Baker, 1983; Nelson, 1997; Walsh et al., 1999). Strains of *Pseudomonas* spp. (Hodges et al., 1994), *Fusarium* spp., *Acremonium* spp., *Rhizoctonia* spp. (Goodman and Burpee, 1991), and *Trichoderma* spp. (Grebus et al., 1995) have shown moderate ability to control the dollar spot pathogen in laboratory settings. When microbial antagonists have been examined in field studies, results have been mixed.

Goodman and Burpee (1991) reported seeing dollar spot reductions of 79% and 66% after applying a sand-cornmeal topdressing infested with *Fusarium heterosporum* Nees & T. Nees and *Acremonium* sp. respectively, compared to non-treated. Lo et al. (1997) reported a sevenfold reduction of dollar spot disease from weekly applications of a combination of *Trichoderma harzianum* Rifai 1295-22 and a surfactant compared to water treatment in a greenhouse study. Nelson and Craft (1991) also used cornmeal-sand topdressings infested with *Enterobacter cloacae* (Jordan) Hormaeche and Edwards EcET-501 to reduce dollar spot disease by as much as 63% compared to non-treated plots. When microbial inoculants were applied as inundative inoculants in large-scale fungicide evaluations, their level of dollar spot control was similar to non-treated turf (Kaminski and Putman, 2007; Latin, 2008).

Previous research has focused largely on the singular ability of either a fertility source or biofungicide applied across a growing season to control disease. When comparing this approach to conventional management systems, fertilizers and chemical fungicides are applied in concert across a growing season to provide multiple modes of action against turfgrass pests as well as to prevent resistance development. The practice of applying various biofungicides in a programmed rotation, or alternating their use with conventional fungicides across a growing season has not been studied; furthermore, it is unknown whether the combination of a natural organic fertility source can enhance the effect of a biological fungicide. The objective of this research was to evaluate the impact of fertility source alone and when combined with programmed rotations of biofungicides on dollar spot development, turfgrass health, and soil microbial populations on a golf course fairway.

Materials and Methods

General Management Practices

Separate two-year studies were conducted from 2016 to 2018 on mature mixed perennial ryegrass (*Lolium perenne* L.) and annual bluegrass (*Poa annua* L.) fairways in two locations: Needwood Golf Course in Derwood, MD (Location 1) and at the Paint Branch Turfgrass Research Facility in College Park, MD (Location 2). Plots were mowed 3 times wk-1 at a bench height of 12 mm with clippings returned to the surface. The trial area was irrigated as needed to prevent visual signs of drought stress. Numerous cultivars are present in location 1 due to yearly overseeding with blended perennial ryegrass cultivars. During our trial, location 1 was reseeded with perennial ryegrass (33% Apple SGL, Stellar 3GL and Grand Slam Gold respectively) in two directions using a Redexim Speedseed overseeder

(Redexim North America, Valley Park, MO) in September of 2016. Stellar 3GL was the predominant cultivar in location 2.

Treatment Design

The trial at location 1 was initiated in 2016 and utilized a 2 x 4 factorial arrangement of treatments in a randomized complete block design. Individual plots measured 1.8 x 1.8 m. Main plot treatments consisted of an organic fertilizer (9-0-5 Dr. Earths Super Lawn Fertilizer; Dr. Earth Inc., Winters, CA) and synthetic fertilizer (43-0-0 polymer coated sulfur coated urea; Growmark FS, LLC, Milford, DE). Fertility treatments were applied during the growing season, beginning 11 May 2016 and 3 May 2017 and ending 25 August 2016 and 23 August 2017. The two fertilizer treatments were applied at a rate of 25.8 kg N ha^{-1} every 28 days during the trial period, totaling 129 kg N ha^{-1} yr^{-1}. In 2016, annual weeds within organic fertility main plots were treated pre-emergently with liquid corn gluten (Green it; Environmental Factor Inc., Ajax, Ontario) at a rate of 103 kg a.i. ha^{-1}. Annual weeds within synthetic fertility plots were treated pre-emergently with Dithiopyr (Dimension EG; Dow AgroSciences, Indianapolis, IN) at a rate of 0.56 kg ha^{-1}. Pre-emergent treatments were applied using a CO_2-pressurized system equipped with Tee Jet AI9508E nozzle calibrated to deliver each treatment rate in H_2O at 815 liters ha^{-1} on 27 April 2016. Due to the inability of liquid corn gluten to suppress annual weeds in 2016 and subsequent interference with disease ratings, the entire trial area was treated with Dithiopyr (Dimension EG; Dow AgroSciences, Indianapolis, IN) at a rate of 0.56 kg ha^{-1} on 19 April 2017 and again on 3 June 2017. Fungicide treatments consisted of the following 14-d fungicide programs: biological (biological fungicides), hybrid (alternate applications of biological and conventional fungicides), conventional (conventional fungicides), and non-treated, which are further defined in Table 1. Each fungicide treatment was applied every 14 days during the trial period using a CO_2-pressurized system equipped with Tee Jet AI9508E nozzle calibrated to deliver each treatment rate in H_2O at 815 liters ha^{-1}. Fertilizer and fungicide treatments were applied every 28 d and 14 d respectively, from 11 May to 9 September 2016 and 3 May to 7 September 2017, with applications occurring between 1100 and 1400 h after the turf was mowed.

The trial at location 2 was initiated in 2017 and utilized a 2 x 5 factorial arrangement of treatments in a randomized complete block design. For this trial, an extra fungicide treatment (i.e., 28 d interval) was added to elucidate the effect of the conventional fungicides within the hybrid program. Protocol for plot size and fertilizer treatments were identical to location 1. Annual weeds within the trial area were treated pre-emergently with dithiopyr (Dimension EG; Dow AgroSciences, Indianapolis, IN) at a rate of 0.56 kg ha^{-1}. Pre-emergent treatments were applied using a Toro Multi Pro® (The Toro Company, Bloomington, MN) equipped with Tee Jet AIC11008 nozzle calibrated to deliver each treatment rate in H_2O at 815 liters ha^{-1} on 1 May 2017 and 26 April 2018. Sub-plot treatments consisted of the following fungicide programs: biological (biological fungicides), hybrid (alternate applications of biological and conventional fungicides), conventional (conventional fungicides), extended (conventional fungicides applied every 28 d) and non-treated, which are further defined in Table 2. Biological, hybrid, and conventional fungicide treatments were applied every 14 days, while extended fungicide treatments were applied every 28 days during the trial period using a CO2-pressurized system equipped with Tee Jet AI9508E nozzle calibrated to deliver each treatment rate in H_2O at 815 liters ha^{-1}.

Data Collection and Analysis.

Data on turfgrass quality and disease severity were taken every 14 days during the trial period. Dollar spot severity was determined by visually counting foci within each plot. Visual ratings for turf quality were taken using a 1 to 9 rating scale (incorporates turfgrass color, density, uniformity, and disease) where 6 represented the minimum acceptable turf quality and 9 represented the best. Canopy reflectance was quantified by measuring normalized difference vegetation index (NDVI) with a turfgrass chlorophyll meter (FieldScout CM 1000; Spectrum Technologies Inc., Aurora, IL) at an approximate height of 1 meter. This meter calculates an index value range from 0 to 999, where 999 indicates greener color (Spectrum Technologies, 2018).

Data on soil microbial community structure were taken at the conclusion of each trial period. In September of each trial season, one rhizosphere sample was collected from each sub-plot of the respective trial locations. Soil was immediately placed in a sealed 50 mL centrifuge tube, transported to the lab on ice, and then stored at -40 °C. Phospholipid fatty acid analysis (PLFA) was performed using previously published methods (Buyer and Sasser, 2012). Approximately 1.0 g of lyophilized soil was extracted using 19:0 phosphatidylcholine as internal standard. Phospholipids were purified and transesterified using solid-phase extraction to form fatty acid methyl esters. Identification and quantification of the fatty acids by gas chromatography was done using an Agilent (Agilent Technologies, Wilmington, DE)

6890 GC equipped with flame ionization detector, autosampler, and split-splitless inlet. Agilent ChemStation and MIS Sherlock (MIDI Inc., Newark, DE) software controlled this system.

Respective ratings were transformed into yearly summative assessments using the area under progression curve for disease, quality, and NDVI (AUDPC, AUQPC, AUNPC respectively) (Madden et al., 2007). The data collected were subjected to ANOVA using the Mixed procedure in the Statistical Analysis System software v. 9.4 (SAS Institute, Cary, NC). Means were separated using Tukey's honest significant difference at the 0.05 probability level.

Results

Dollar Spot Severity

Dollar spot developed naturally in both years at both locations of the trial. Analysis showed dollar spot data was significant by location and year. As such, results will be presented individually throughout.

Location 1

2016. Fertilizer source did not impact dollar spot disease development, and results were consistent across all fungicide levels. Fungicide programs affected dollar spot infection on 5 of 10 individual rating dates and when comparing AUDPC values (Table 3). Plots managed with the conventional and hybrid programs had less dollar spot compared with plots managed with the biological and control programs; However, the hybrid program did not reduce dollar spot infection late in the growing season, as shown by the 11 August rating date. The biological program did not reduce dollar spot compared with non-treated control on individual rating dates, but was significantly better when comparing seasonal AUDPC values.

2017. Overall, dollar spot pressure was greater in 2017. Fertilizer source affected dollar spot disease development on 2 of 10 individual rating dates and when comparing AUDPC values (Table 4). During periods of high disease pressure, synthetically fertilized plots had less dollar spot than organically fertilized plots as indicated by the 28 June and 13 July rating dates. Synthetically fertilized plots had less incidence of seasonal dollar spot infection than organically fertilized plots. Fungicide programs affected dollar spot infection on 6 of 10 individual rating dates and when comparing AUDPC values (Table 4). As in the previous year, plots managed with the conventional and hybrid fungicide programs reduced dollar spot more significantly than biological and non-treated. The hybrid program was less effective than conventional late in the season, as shown by the 26 July rating date. The biological program offered no reduction in dollar spot compared to non-treated control. A fertilizer by fungicide interaction, observed on the 13 July rating date, indicated that organically fertilized plots treated with biological and no fungicide had more dollar spot incidence than synthetically fertilized plots treated with biological and no fungicide (Table 5).

Location 2

2017. Fertilizer source affected dollar spot infection on 2 of 9 individual rating dates (Table 6). Plots fertilized with organic fertilizer had slightly less dollar spot than synthetically fertilized plots on 19 July and 2 August rating dates. Fungicide programs affected dollar spot infection on 6 of 9 individual rating dates and when comparing AUDPC values (Table 6). On the 24 May rating date a significant fungicide effect was detected but Tukey's honestly significant difference test showed no difference between treatments. On subsequent rating dates, plots managed with the conventional, hybrid, and extended programs had less dollar spot incidence compared with plots managed with the biological and control programs. The extended program was less effective than conventional, as shown by the 5 July and 19 July rating. Conventional, hybrid, and extended fungicide programs were statistically similar when comparing AUDPC values. The biological program did reduce dollar spot compared to non-treated on 2 early rating dates (24 May and 8 June), and when comparing seasonal AUDPC values.

2018. Fertilizer source significantly affected dollar spot infection on 3 of 10 rating dates (Table 7). Synthetically fertilized plots had less dollar spot than organically fertilized plots on 6 June and 29 August, while the inverse was true on 15 August rating date. Fungicide programs significantly affected dollar spot infection on 6 of 10 rating dates and when comparing AUDPC values (Table 7). Plots managed with the conventional, hybrid, and extended fungicide programs consistently reduced dollar spot compared to non-treated. The hybrid program was significantly better than the extended program on the 19 July rating date. The biological program reduced dollar spot to the same degree as conventional, hybrid and extended programs, on the 6 June, 20 June, and 15 August rating dates, but were not as effective on the 5 July and 19 July rating dates. When comparing seasonal AUDPC values, all fungicide programs reduced disease compared to non-treated control, however, the biological program was not as effective as the conventional and hybrid programs. A fertilizer by fungicide interaction was detected on the 15 August rating date, which indicated that synthetically fertilized plots treated with conventional fungicide had more dollar spot than organically fertilized treated with conventional fungicide on this date (Table 8).

Turfgrass Quality

Location 1

2016. Fertilizer treatments significantly impacted turfgrass quality on 2 of 10 rating dates and when comparing AUQPC values (Table 9). Applications of organic fertilizer had higher turf quality than synthetically fertilized for each significant date and for AUQPC values. Fungicide programs significantly affected quality on 7 of 10 rating dates and when comparing AUQPC values (Table 9). Plots managed with the conventional and hybrid fungicide programs had better turf quality than biological and control during periods of high disease pressure, and when comparing AUQPC values. Turf quality on plots managed with the biological fungicide program were no different from non-treated control for all significant rating dates and when comparing AUQPC values.

2017. Fertilizer treatments had no effect on turf quality (Table 10). Fungicide programs significantly affected quality on 6 of 10 rating dates and when comparing AUQPC values (Table 10). The conventional fungicide program provided the highest quality turf on the 26 July and 23 August rating dates and when comparing AUQPC. The hybrid fungicide program matched the conventional program on 3 of 7 significant rating dates, but not when comparing AUQPC. The biological program was again, no better than non-treated control for all significant rating dates and seasonally.

Location 2

2017. Fertilization source did not affect turf quality in 2017 (Table 11). Fungicide programs had a significant effect on quality on 7 of 10 rating dates and when comparing AUQPC values (Table 11). The conventional, hybrid, and extended fungicide programs provided the highest quality turf during periods of high dollar spot pressure and when comparing AUQPC values. The biological program was no better than non-treated control for all significant rating dates and when comparing AUQPC.

2018. Fertilizer source significantly affected turf quality on 1 of 10 rating dates (Table 12). Synthetically fertilized plots had higher quality than organic on the 6 June rating date. Fungicide programs affected turf quality on 9 of 10 rating dates and when comparing AUQPC values (Table 12). The conventional, hybrid, and extended fungicide programs provided the highest quality turf on the majority of rating dates and when considering seasonal AUQPC values. The biological fungicide program was better than non-treated on 3 of 10 significant rating dates, but not when comparing AUQPC.

Turf Color – NDVI

Location 1

2016. Fertilization did not have an effect on NDVI (Table 13). Fungicide source had a significant effect on NDVI values on 6 of 8 individual rating dates and when comparing AUNPC values (Table 13). In general, plots treated with conventional and hybrid fungicide programs had the highest NDVI values across individual rating dates and when comparing AUNPC values. A significant fertilizer by fungicide interaction was detected on the 11 May rating date, however, Tukey's honestly significant difference test showed no difference between treatments (Table 14).

2017. Fertilization did not have an effect on NDVI values (Table 15). Fungicide programs affected NDVI values on 7 of 9 rating dates and when comparing AUNPC (Table 15). Again, conventional and hybrid fungicide treatments generally had the highest NDVI values across individual rating dates. When comparing AUNPC values, conventional was significantly better than all other treatments. The biological fungicide program was marginally better than non-treated on individual rating dates, and no different when comparing AUNPC values.

Location 2

2017. Fertilizer source was significant on 1 of 7 rating dates (Table 16). Plots treated with organic fertilizer had slightly higher NDVI values on the 4 May rating date. Fungicide source was significant on 5 of 7 rating dates and when comparing AUNPC values (Table 16). In general, the conventional, hybrid, and extended programs consistently returned the highest NDVI values, however, on 2 of 5 significant rating dates, the programs were no different from non-treated. When comparing AUNPC values, conventional and hybrid were better than biological and non-treated. A significant fertilizer by fungicide interaction was detected on 1 September, indicating that the biological fungicide program NDVI values were significantly less than conventional and extended when plots were treated with organic fertilizer (Table 17).

2018. Fertilizer source was significant on 4 of 9 significant rating dates, and when comparing AUNPC (Table 18). Main plots treated with synthetic fertilizers had higher NDVI values on 3 of 4 significant rating dates and when comparing AUNPC values. Fungicide program was significant on 8 of 9 rating dates and when comparing AUNPC values (Table 18). In general, the conventional and hybrid fungicide programs returned the highest NDVI values on significant rating dates. When comparing AUNPC values, conventional, hybrid, and extended were better than organic and non-treated.

PLFA Analysis

Location 1

2016. No treatment effect on fatty acid biomarker groups in was detected (Table 19).

2017. A fungicide effect on the gram-negative and total biomass groups was detected (Table 20). Gram-negative bacteria and total microbial biomass concentrations were significantly higher in non-treated plots than in plots treated with biological fungicides.

Location 2

2017. No fertilizer effect was observed at this location (Table 21). We observed a significant effect from fungicide factor on AM Fungi concentrations, as well as on the ratio of gram-negative to gram-positive bacteria. Greater concentrations of AM Fungi were returned by the hybrid fungicide program than the biological, extended and non-treated programs. The hybrid program had a lower bacterial ratio compared to the biological and non-treated fungicide programs.

Discussion

Disease pressure was estimated during the trial period using the Smith-Kerns weather-based dollar spot warning system (Smith et al., 2018). The risk of dollar spot differed by year, but not location (Figure 1): In 2016, the model predicted 66 days over the action threshold (20%). In 2017 the model predicted 93 days over the action threshold and in 2018 predicted 110 days over the action threshold.

Fertilizer effect on dollar spot. Fertilizer only impacted dollar spot development in one year across both locations. In 2017 at location 1, organically fertilized plots had significantly more dollar spot incidence compared to synthetically fertilized plots on 2 of 10 individual rating dates and when comparing AUDPC values. This difference may be attributed to an increase of annual bluegrass presence within organically fertilized plots in 2017. As previously mentioned, the use of liquid corn gluten as a pre-emergent herbicide for organic fertilizer plots was discontinued due to uncontrolled crabgrass (*Digitaria* spp. Haller), goosegrass (*Eleusine indica* L. Gaertn.) and annual bluegrass infestation. It is likely that increased annual bluegrass within the organically fertilized plots served as primary inoculum for dollar spot, leading to higher incidence on organic fertilizer plots as annual bluegrass is regarded as more susceptible to dollar spot than perennial ryegrass (Smiley et al., 2005). Furthermore, elevated disease pressure in 2017 may have exacerbated dollar spot infection of annual bluegrass.

In general, there were no other consistent differences between fertilizer sources when considering disease incidence. There was no indication that biological fungicide effectiveness was enhanced by an organic fertilizer source and vice versa. When an interaction between treatment factors was detected at location 2 on the 15

July 2017, fertilizer source had no effect on plots receiving biological fungicides. These results are similar to previous studies which standardized N treatment rates and found that, in general, organic fertilizers offered no consistent advantage over synthetic fertilizers in regard to dollar spot reduction (Davis and Dernoeden, 2002; Landschoot and McNitt, 1997). Our study supports the practice of continually applying N (25.8 kg N ha^{-1} every 28 d) during the growing season as it assists in mitigating initial infection and hastening recovery (Couch, 1995; Markland et al., 1969).

Fungicide effect on dollar spot. The conventional fungicide program was the most consistent treatment for reducing dollar spot in all years and locations of the study. The hybrid and extended fungicide programs trended similar to the conventional program early in the season and were similar when comparing AUDPC values, though they tended to lose effectiveness during periods of high disease pressure. The similarity between the conventional, hybrid and extended programs is likely due to a combination of conventional fungicide residual efficacy and intermittent disease activity. Previous work has shown that conventional fungicides can have residual activity that extends beyond the label rate, especially when penetrant fungicides are used (Latin, 2006). The residual activity of conventional fungicides used in the hybrid and extended programs may have helped to minimize dollar spot infection beyond the 14 d application interval. It is also possible that dollar spot was not active for portions of the growing season. Although the general window for dollar spot infection is broad, falling anywhere between late spring through late autumn, disease pressure during this period may not be constant (Smiley et al., 2005). Ryan et al. (2012) reported that dollar spot exhibited “peak and valley” patterns of infection, wherein multiple intense periods of infection occur during the trial season with latent periods in between. A similar intermittent pattern was evident when evaluating dollar spot risk for the trial period, as estimated by the Smith-Kerns risk model (Figure 1). Ultimately, it is likely that a combination of the two factors contributed to the similarity between the conventional, hybrid, and extended programs. When reduced efficacy occurred in the hybrid and extended fungicide programs, it typically occurred late June and July, when environmental conditions were more conducive to dollar spot infection. Previous reports indicate that fungicide efficacy is negatively impacted by prolonged periods of environmental conditions that favor dollar spot growth (i.e. high humidity, excessive rainfall) (Latin, 2006; Sigler et al., 2000). During these periods in our research, dollar spot activity likely exceeded the ability of biological fungicide or conventional residual efficacy to suppress disease.

The biological fungicide program was the least effective fungicide program for dollar spot control in all locations and years of the study. Biofungicide efficacy and reliability generally correlate to elevated population densities of inoculant(s) contained within trade formulations (Nelson et al., 1994). Previous studies have shown that biological inoculants were most effective when applied at higher rates of cells/ml, or when high population rates were maintained over time with multiple applications (Lo et al., 1997; Vargas et al., 1998). In our trial, biofungicide applications were made using only one active ingredient at the high label rate, on a strict 14 d application interval. Future work that evaluates biofungicides applied at shorter intervals and/or in tank mixes with other biological or conventional fungicides as directed by the product label may provide better levels of dollar spot control. Using shorter application intervals during periods of elevated disease activity helps to maintain microbe population levels required for a suppressive effect (Nelson et al., 1994).

While the biofungicide program was less effective than other fungicide treatments when comparing AUDPC values for all years and locations, results indicate it may be possible to substitute a biological for conventional in periods of low to moderate disease pressure. At location 2, biological reduced dollar spot incidence to the same degree as conventional on the 8 June 2017 and 6 June, 20 June 2018 dates respectively. Additionally, on the 19 July 2018 rating date at location 2 we observed significantly less dollar spot on hybrid treated plots than extended. Dollar spot pressure during these periods was low to moderate, as shown by the Smith-Kerns risk model values (Figure 1) and when evaluating disease incidence on plots not treated with fungicide.

Fertilizer effect on turf quality. In general, fertility treatments alone were not a sufficient method to maintain acceptable turf quality (≥6). In seasons when turf quality started at or above the level of acceptability, they became unacceptable (<6) from July through September for both treatments. While we did observe a significantly higher quality from organically fertilized turf at location 1 in 2016, the effect was not consistent across years or locations.

Fungicide effect on turf quality. Conventional fungicides were the most consistent treatment to provide acceptable turf quality across trial locations and years.

The hybrid and extended management programs largely matched conventional, though they tended to falter late in the season when disease pressure was highest. The biological fungicide program was unable to provide acceptable turf quality in periods when dollar spot was active. This pattern is similar to what we observed for dollar spot development, and is likely due to many of the same factors of influence discussed earlier. A similar study reported that biological pesticides were ineffective at providing high quality turf during in periods of elevated environmental stress during summer months (Rossi and Grant, 2009). Unacceptable turf quality may have also been impacted by the types of grasses used in our trial area. Perennial ryegrass and annual bluegrass are cool-season grasses known primarily for their ability to rapidly germinate and establish (Christians et al., 2016). Currently, they are rarely used alone for fairway turf, due to their disease susceptibility and inability to quickly recover from severe damage (Christians et al., 2016). As dollar spot infection increased in our plots, infected areas were generally left void for the remainder of the season. Turf quality ratings in similar studies were consistently acceptable when creeping bentgrass was used in experimental plots (Davis and Dernoeden, 2002). In our study, the trial area was treated as a low maintenance site and therefore cultural practices to alleviate stress and promote recovery were limited. Future work to combine the use of organic and/or biological fungicides would likely benefit from enhanced cultural management, which can improve turf quality.

PLFA biomarkers. Results from our analysis of PLFA microbial biomarkers indicated no significant fertilizer effect on community populations. While soil microbe communities may be impacted by a wide variety of physical, chemical, and biological factors (Marschner et al., 2001), soil type, plant cover, soil pH, and time are considered to be the strongest drivers of change for microbial communities (Bossio et al., 1998). Though previous studies have shown fertilizers to effect change on soil microbes, it was most often in long-term trials where soil organic carbon was drastically increased via organic inputs (Geisseler and Scow, 2014). Short term effects from mineral fertilizers are reported to be less pronounced, or altogether absent, which may help explain the lack of meaningful change from treatments in this trial (Stark et al., 2007). Although we also observed a few differences in fungicidal source effects on our PLFA biomarker groups, it is difficult to quantify the magnitude of the significant differences because of the lack of correlation or meaningful change in treatment effectiveness. Previous research indicates that soil microbes are very resilient to fungicidal effects in golf course and agricultural systems (Bending et al., 2007; Harman et al., 2006). When changes do occur, they are short-lived and populations of bacteria and fungi appear to quickly recover from negative effects (Doherty et al., 2017). In cases where significant long term changes to microbial biomass were reported after application of fungicide, the soil had no previous exposure to pesticides (Muñoz-Leoz et al., 2011). Similar studies also found no link between disease suppression and microbial activity (Davis and Dernoeden, 2002). In previous studies which attributed dollar spot reduction to organic fertilizers enhancing microbial activity, differences between N rate and source were not accounted for, which may have confounded results (Liu et al., 1995; Nelson and Craft, 1991). While it is possible that fungicide applications in this trial were effecting short-term change, sampling methods were not designed to measure those changes. Analysis of PLFA microbial biomarkers is an effective way to observe broad changes in overall structure of resident microbial communities (Buyer and Sasser, 2012), but it may not account for changes in microbe diversity, as many of the same fatty acids are shared between organisms profiled (Bossio et al., 1998). Future work that attempts to correlate soil microbes and disease activity may be more successful at documenting change if populations are sampled on a more frequent basis.

Conclusion

In summary, our short-term trial shows that a natural organic fertility source is no different than a synthetic fertility source at reducing the incidence and severity of dollar spot or increasing turfgrass quality on a predominantly perennial ryegrass fairway. Additionally, there was no enhancement of fungicide treatments by organic fertility. With respect to fungicide treatments, the conventional program was the most effective treatment to reduce dollar spot and provide acceptable turf quality. A hybrid program, which utilized 50% fewer synthetic fungicides than conventional, provided similar disease reduction and turf quality in periods of low to moderate disease pressure. While the biological fungicide program was also somewhat effective for dollar spot control in periods of low to moderate pressure, it was less effective than conventional and hybrid when comparing AUDPC values. The impact of treatments on turf quality mirror treatment effect on disease incidence. There was no association between the use of organic fertilizers and fungicides and the enhancement of soil microbes during the trial period. When using a standard 14 d fungicide program, these results support the incorporation of biological fungicides into a conventional fungicide program during times of low to moderate disease pressure.

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Table 1. Fungicides used per treatment for dollar spot disease caused by *Clarireedia* spp. on a perennial ryegrass fairway in location 1, 2016 and 2017.

Treatment[z]	Fungicides used
Biological	2.78 x 10^{11} CFU ha^{-1} *Bacillus subtilis* GB03, (Companion; Growth Products, Ltd., White Plains, NY), 47.6 L a.i. ha^{-1} Mineral Oil, (Civitas, Intelligro, Ontario, Canada), 4.6 x 10^{10} CFU ha^{-1} *Trichoderma harzianum* Rifai strain T-22, 2.4 x 10^{10} CFU ha^{-1} *Trichoderma virens* strain G-41, (TurfShield Plus WP; BioWorks Inc., Victor, NY), 4.2 x 10^{13} CFU ha^{-1} *Bacillus subtilis* QST 713, (Rhapsody; Bayer CropScience, Research Triangle Park, NC), 2.78 x 10^{11} CFU ha^{-1} *Bacillus subtilis* GB03, (Companion; Growth Products, Ltd., White Plains, NY), 47.6 L a.i. ha^{-1} Mineral Oil, (Civitas, Intelligro, Ontario, Canada), 4.6 x 10^{10} CFU ha^{-1} *Trichoderma harzianum* Rifai strain T-22, 2.4 x 10^{10} CFU ha^{-1} *Trichoderma virens* strain G-41, (TurfShield Plus WP; BioWorks Inc., Victor, NY), 4.2 x 10^{13} CFU ha^{-1} *Bacillus subtilis* QST 713, (Rhapsody; Bayer CropScience, Research Triangle Park, NC), 2.78 x 10^{11} CFU ha^{-1} *Bacillus subtilis* GB03, (Companion; Growth Products, Ltd., White Plains, NY)
Hybrid	0.99 kg a.i. ha^{-1} *Propiconazole*, (Banner Maxx II; Syngenta, Greensboro, NC), 2.78 x 10^{11} CFU ha^{-1} *Bacillus subtilis* GB03, (Companion; Growth Products, Ltd., White Plains, NY), 0.76 kg a.i. ha^{-1} *Penthiopyrad* (Velista; Syngenta, Greensboro, NC), 47.6 L a.i. ha^{-1} Mineral Oil, (Civitas, Intelligro, Ontario, Canada), 0.3 kg a.i. ha^{-1} Azoxystrobin + 7.2 g a.i. ha^{-1} Acibenzolar (Heritage Action; Syngenta, Greensboro, NC), 4.2 x 10^{13} CFU ha^{-1} *Bacillus subtilis* QST 713, (Rhapsody; Bayer CropScience, Research Triangle Park, NC), 0.15 kg a.i. ha^{-1} Fluxapyroxad, (Xzemplar; BASF, Research Triangle Park, NC), 4.6 x 10^{10} CFU ha^{-1} *Trichoderma harzianum* Rifai strain T-22, 2.4 x 10^{10} CFU ha^{-1} *Trichoderma virens* strain G-41, (TurfShield Plus WP; BioWorks Inc., Victor, NY), 4.4 kg a.i. ha^{-1} *Boscalid* (Emerald; BASF, Research Triangle Park, NC)
Conventional	0.99 kg a.i. ha^{-1} *Propiconazole*, (Banner Maxx II; Syngenta, Greensboro, NC), 3 kg a.i. ha^{-1} *Iprodione* (Ipro 2SE; Makhteshim Agan of North America Inc., Raleigh, NC), 0.76 kg a.i. ha^{-1} *Penthiopyrad* (Velista; Syngenta, Greensboro, NC), 6.8 kg a.i. ha^{-1} *Chlorothalonil* + 13.79 g ha^{-1} *Acibenzolar-S-methyl ester* (Daconil Action; Syngenta, Greensboro, NC), 0.3 kg a.i. ha^{-1} Azoxystrobin + 7.2 g a.i. ha^{-1} Acibenzolar (Heritage Action; Syngenta, Greensboro, NC), 24.4 kg a.i. ha^{-1} *Vinclozolin* (Curalan EG; BASF, Research Triangle Park, NC), 0.15 kg a.i. ha^{-1} Fluxapyroxad, (Xzemplar; BASF, Research Triangle Park, NC), 0.8 kg a.i. ha^{-1} *Tebuconazole* (Torque; Nufarm Americas Inc., Dayton, NJ) , 4.4 kg a.i. ha^{-1} *Boscalid* (Emerald; BASF, Research Triangle Park, NC)
Non-treated	-

[z] Treatments applied on a 14-day interval beginning 11 May 2016 and ending 9 September 2016 and 3 May 2017 and ending 7 September 2017.

Table 2. Fungicides used per treatment for dollar spot disease caused by *Clarireedia* spp. on a perennial ryegrass fairway in location 2, 2017 and 2018.

Treatment[z]	Fungicides used
Biological	2.78 x 10^{11} CFU ha^{-1} *Bacillus subtilis* GB03, (Companion; Growth Products, Ltd., White Plains, NY), 47.6 L a.i. ha^{-1} Mineral Oil, (Civitas, Intelligro, Ontario, Canada), 4.6 x 10^{10} CFU ha^{-1} *Trichoderma harzianum* Rifai strain T-22, 2.4 x 10^{10} CFU ha^{-1} *Trichoderma virens* strain G-41, (TurfShield Plus WP; BioWorks Inc., Victor, NY), 4.2 x 10^{13} CFU ha^{-1} *Bacillus subtilis* QST 713, (Rhapsody; Bayer CropScience, Research Triangle Park, NC), 2.78 x 10^{11} CFU ha^{-1} *Bacillus subtilis* GB03, (Companion; Growth Products, Ltd., White Plains, NY), 47.6 L a.i. ha^{-1} Mineral Oil, (Civitas, Intelligro, Ontario, Canada), 4.6 x 10^{10} CFU ha^{-1} *Trichoderma harzianum* Rifai strain T-22, 2.4 x 10^{10} CFU ha^{-1} *Trichoderma virens* strain G-41, (TurfShield Plus WP; BioWorks Inc., Victor, NY), 4.2 x 10^{13} CFU ha^{-1} *Bacillus subtilis* QST 713, (Rhapsody; Bayer CropScience, Research Triangle Park, NC), 2.78 x 10^{11} CFU ha^{-1} *Bacillus subtilis* GB03, (Companion; Growth Products, Ltd., White Plains, NY)
Hybrid	0.99 kg a.i. ha^{-1} *Propiconazole*, (Banner Maxx II; Syngenta, Greensboro, NC), 2.78 x 10^{11} CFU ha^{-1} *Bacillus subtilis* GB03, (Companion; Growth Products, Ltd., White Plains, NY), 0.76 kg a.i. ha^{-1} *Penthiopyrad* (Velista; Syngenta, Greensboro, NC), 47.6 L a.i. ha^{-1} Mineral Oil, (Civitas, Intelligro, Ontario, Canada), 0.3 kg a.i. ha^{-1} Azoxystrobin + 7.2 g a.i. ha^{-1} Acibenzolar (Heritage Action; Syngenta, Greensboro, NC), 4.2 x 10^{13} CFU ha^{-1} *Bacillus subtilis* QST 713, (Rhapsody; Bayer CropScience, Research Triangle Park, NC), 0.15 kg a.i. ha^{-1} Fluxapyroxad, (Xzemplar; BASF, Research Triangle Park, NC), 4.6 x 10^{10} CFU ha^{-1} *Trichoderma harzianum* Rifai strain T-22, 2.4 x 10^{10} CFU ha^{-1} *Trichoderma virens* strain G-41, (TurfShield Plus WP; BioWorks Inc., Victor, NY), 4.4 kg a.i. ha^{-1} *Boscalid* (Emerald; BASF, Research Triangle Park, NC)
Conventional	0.99 kg a.i. ha^{-1} *Propiconazole*, (Banner Maxx II; Syngenta, Greensboro, NC), 3 kg a.i. ha^{-1} *Iprodione* (Ipro 2SE; Makhteshim Agan of North America Inc., Raleigh, NC), 0.76 kg a.i. ha^{-1} *Penthiopyrad* (Velista; Syngenta, Greensboro, NC), 6.8 kg a.i. ha^{-1} *Chlorothalonil* + 13.79 g ha^{-1} *Acibenzolar-S-methyl ester* (Daconil Action; Syngenta, Greensboro, NC), 0.3 kg a.i. ha^{-1} Azoxystrobin + 7.2 g a.i. ha^{-1} Acibenzolar (Heritage Action; Syngenta, Greensboro, NC), 24.4 kg a.i. ha^{-1} *Vinclozolin* (Curalan EG; BASF, Research Triangle Park, NC), 0.15 kg a.i. ha^{-1} Fluxapyroxad, (Xzemplar; BASF, Research Triangle Park, NC), 0.8 kg a.i. ha^{-1} *Tebuconazole* (Torque; Nufarm Americas Inc., Dayton, NJ) , 4.4 kg a.i. ha^{-1} *Boscalid* (Emerald; BASF, Research Triangle Park, NC)
Extended[y]	0.99 kg a.i. ha^{-1} *Propiconazole*, (Banner Maxx II; Syngenta, Greensboro, NC), 0.76 kg a.i. ha^{-1} *Penthiopyrad* (Velista; Syngenta, Greensboro, NC), 0.3 kg a.i. ha^{-1} Azoxystrobin + 7.2 g a.i. ha^{-1} Acibenzolar (Heritage Action; Syngenta, Greensboro, NC), 0.15 kg a.i. ha^{-1} Fluxapyroxad, (Xzemplar; BASF, Research Triangle Park, NC), 4.4 kg a.i. ha^{-1} *Boscalid* (Emerald; BASF, Research Triangle Park, NC)
Non-treated	-

[z] Treatments applied every 14d starting 28 April 2017 ending 1 September 2017 and 9 May 2018 ending 12 September 2018.

[y] Treatments applied every 28d starting 28 April 2017 ending 1 September 2017 and 9 May 2018 ending 12 September 2018.

Table 3. Influence of fertilizer and fungicide applications on dollar spot disease caused by *Clarireedia* Spp. on a perennial ryegrass fairway at location 1, 2016.

	Evaluation date										
Treatment (level)	11 May	19 May	1 June	15 June	30 June	14 July	26 July	11 Aug	25 Aug	9 Sept	AUDPC[z]
Fertilizer[y]	--Infection centers per plot--										
Organic	0.06	0.13	0.5	0.94	4.44	9.19	12.75	12.38	2.81	0.31	620
Synthetic	0.13	0.19	0.56	1.56	4.13	10.31	14.94	11.94	3.38	0.31	673
Fungicide program[x]											
Biological	0.0	0.1	0.6	1.63ab[w]	7.63a	15a	21.5a	10.13ab	3.5	0.4	857b
Hybrid	0.0	0.0	0.3	0.5b	0.0b	1.5b	4.75b	18.0a	1.0	0.5	386c
Conventional	0.1	0.3	0.4	0.38b	0.0b	1.88b	3.0b	1.5b	1.25	0.4	124c
Non-treated	0.3	0.3	0.9	2.5a	9.5a	20.63a	26.13a	19.0a	6.63	0.0	1219a
Source of variation											
Fertilizer	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fungicide	NS	NS	NS	**	***	***	***	**	NS	NS	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Area under disease progression curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[x] Fungicide treatments were applied on a 14-day interval beginning 11 May and ending 9 September.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

, *, NS refer to the 0.01, 0.001 significance levels and non-significant, respectively.

Table 4. Influence of fertilizer and fungicide applications on dollar spot disease caused by *Clarireedia* Spp. on a perennial ryegrass fairway at location 1, 2017.

	Evaluation date										
Treatment (level)	3 May	17 May	31 May	14 June	28 June	13 July	26 July	11 Aug	23 Aug	7 Sept	AUDPC[z]
Fertilizer[y]	---Infection centers per plot---										
Organic	0.0	0.88	1.06	9.44	28.63a[x]	35.25a	52.81	0.25	15.88	0.0	2064a
Synthetic	0.0	0.56	0.75	5.25	18.31b	18.5b	37.44	0.06	19	0.0	1426b
Fungicide program[w]											
Biological	0.0	1.8a	1.75	16.63a	47.13a	55.25a	51.0a	0.0	21.13ab	0.0	2765a
Hybrid	0.0	0.4a	0.5	0.5bc	0.63b	3.5b	49.38a	0.5	12.75bc	0.0	997b
Conventional	0.0	0.4a	0.0	0.25c	0.25b	0.38b	0.0b	0.0	3.75c	0.0	68b
Non-treated	0.0	0.4a	1.38	12.0ab	45.88a	48.38a	80.13a	0.13	32.13a	0.0	3149a
Source of variation											
Fertilizer	NS	NS	NS	NS	**	***	NS	NS	NS	NS	*
Fungicide	NS	*	NS	***	***	***	***	NS	***	NS	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS

[z] Area under disease progression curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 3 May, 31 May, 28 June, 26 July, and 23 August at a rate of 25.8 kg N ha^{-1}.

[x] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[w] Fungicide treatments were applied on a 14-day interval beginning 3 May and ending 7 September.

*, **, ***, NS refer to the 0.05, 0.01, 0.001 significance levels and non-significant, respectively.

Table 5. Fertilizer by fungicide treatment means for dollar spot at location 1, 2017.

	Evaluation date
Treatment (level)	13 July
Fertilizer^z x Fungicide^y	-----Infection centers per plot-----
Organic x Biological	71.75a^x
Organic x Hybrid	4.0c
Organic x Conventional	0.0c
Organic x Non-treated	65.25a
Synthetic x Biological	38.75b
Synthetic x Hybrid	3.0c
Synthetic x Conventional	0.75c
Synthetic x Non-treated	31.5b

[z] Fertilizer treatments were applied on 3 May, 31 May, 28 June, 26 July, and 23 August at a rate of 25.8 kg N ha^{-1}.

[y] Fungicide treatments were applied on a 14-day interval beginning 3 May and ending 7 September.

[x] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

Table 6. Influence of fertilizer and fungicide applications on dollar spot disease caused by *Clarireedia* Spp. on a perennial ryegrass fairway at location 2, 2017.

	Evaluation date									
Treatment (level)	24 May	8 June	21 June	28 June	5 July	19 July	2 Aug	16 Aug	1 Sept	AUDPC[z]
Fertilizer[y]	--Infection centers per plot--									
Organic	0.75	12.5	46.75	47.4	61.55	29.3b[x]	0.25b	0.0	0.35	2043
Synthetic	0.9	11.35	43.45	42.9	51.95	35.3a	1.6a	0.0	0.4	1966
Fungicide program[w]										
Biological	1.5	4.38b	58.75b	65.88ab	87.0ab	52.13a	0.0	0.0	0.25	3766b
Hybrid	0.25	3.5b	34.13bc	29.5bc	19.75c	20.0bc	1.38	0.0	0.63	1110c
Conventional	0.0	2.63b	8.13c	5.88c	8.88c	12.63c	0.38	0.0	0.25	436c
Extended	0.25	6.25b	20.75c	22.25c	57.5b	28.38b	2.0	0.0	0.75	1488c
Non-treated	2.13	42.88a	103.75a	102.25a	110.63a	48.38a	0.88	0.0	0.0	4221a
Source of variation										
Fertilizer	NS	NS	NS	NS	NS	**	**	NS	NS	NS
Fungicide	**	***	***	***	***	***	NS	NS	NS	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Area under disease progression curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 4 May, 8 June, 5 July, 2 August, and 1 September at a rate of 25.8 kg N ha^{-1}.

[x] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[w] Fungicide treatments were applied on a 14-day or 21-day interval beginning 4 May and ending 1 September.

, *, NS refer to the 0.01, 0.001 significance levels and non-significant, respectively.

Table 7. Influence of fertilizer and fungicide applications on dollar spot disease caused by *Clarireedia* Spp. on a perennial ryegrass fairway at location 2, 2018.

	Evaluation date									
Treatment (level)	9 May	24 May	6 June	20 June	5 July	19 July	2 Aug	15 Aug	29 Aug	AUDPC[z]
Fertilizer[y]	--Infection centers per plot--									
Organic	0.0	5.2	17.15a[x]	9.55	27.45	24.45	16.95	2.75b	2.65a	1486
Synthetic	0.05	5.45	10.5b	6.35	23.15	26.75	15.7	5.3a	0.7b	1314
Fungicide program[w]										
Biological	0.0	7.63ab	7.25b	9.75b	45.38a	37.5a	4.13	3.13b	1.63	1643b
Hybrid	0.0	3.25b	7.75b	1.63b	2.00b	6.38c	24.25	4.88ab	3.0	832c
Conventional	0.0	2.88b	11.5b	3.13b	8.75b	12.13bc	15.25	3.25b	0.25	717c
Extended	0.13	2.00b	14.88ab	2.75b	15.63b	21.75b	19.37	2.63b	1.63	1125bc
Non-treated	0.0	10.88a	27.75a	22.5a	54.75a	50.25a	18.63	6.25a	1.88	2684a
Source of variation										
Fertilizer	NS	NS	*	NS	NS	NS	NS	***	**	NS
Fungicide	NS	**	***	***	***	***	NS	***	NS	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	*	NS	NS

[z] Area under disease progression curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 9 May, 6 June, 5 July, 2 August, and 29 August at a rate of 25.8 kg N ha^{-1}.

[x] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[w] Fungicide treatments were applied on a 14-day or 21-day interval beginning 9 May and ending 29 August.

$^{*, **, ***, NS}$ refer to the 0.05, 0.01, 0.001 significance levels and non-significant, respectively.

Table 8. Fertilizer by fungicide treatment means for dollar spot at location 2, 2018.

Treatment (level)	Evaluation date 15 Aug
Fertilizer[z] x Fungicide[y]	---Infection centers per plot---
Organic x Biological	3.25bc[x]
Organic x Hybrid	4.5abc
Organic x Conventional	0.75c
Organic x Extended	1.0c
Organic x Non-treated	4.25abc
Synthetic x Biological	3.0bc
Synthetic x Hybrid	5.25ab
Synthetic x Conventional	5.75ab
Synthetic x Extended	4.25abc
Synthetic x Non-treated	8.25a

[z] Fertilizer treatments were applied on 9 May, 6 June, 5 July, 2 August, and 29 August at a rate of 25.8 kg N ha^{-1}.

[y] Fungicide treatments were applied on a 14-day interval beginning 9 May and ending 29 August.

[x] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

Table 9. Influence of fertilizer and fungicide applications on turfgrass quality of a perennial ryegrass fairway at location 1, 2016.

	Evaluation date										
Treatment (level)	11 May	19 May	1 June	15 June	30 June	14 July	26 July	11 Aug	25 Aug	9 Sept	AUQPC[z]
Fertilizer[y]	----------Turfgrass quality[x]----------										
Organic	6.66	6.84a[w]	6.72	6.53	6.13	5.63	5.63	5.0a	4.69	4.31	706a
Synthetic	6.31	6.13b	6.22	6.28	5.91	5.53	5.34	4.5b	4.38	4.19	665b
Fungicide program[v]											
Biological	6.56	6.44	6.12	6.06ab	5.44b	4.94b	4.56b	4.0b	3.56b	3.13c	612b
Hybrid	6.5	6.56	6.75	6.88a	6.81a	6.31a	6.44a	5.56a	5.38a	4.88b	761a
Conventional	6.69	6.63	6.75	7.13a	7.0a	6.94a	6.81a	6.06a	5.88a	5.75a	804a
Non-treated	6.19	6.31	6.25	5.56b	4.81b	4.13b	4.13b	3.38b	3.31b	3.25c	565b
Source of variation											
Fertilizer	NS	**	NS	NS	NS	NS	NS	**	NS	NS	**
Fungicide	NS	NS	NS	**	***	***	***	***	***	***	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Area under quality progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[x] Quality ratings based on 1–9 scale (incorporates turfgrass color, density, uniformity, and disease percent) where 6 represented the minimum acceptable turf quality and 9 represented the best.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[v] Fungicide treatments were applied on a 14-day interval beginning 11 May and ending 9 September.

, *, NS refer to the 0.05, 0.01, 0.001 significance levels and non-significant, respectively.

Table 10. Influence of fertilizer and fungicide applications on turfgrass quality of a perennial ryegrass fairway at location 1, 2017.

	Evaluation date										
Treatment (level)	3 May	17 May	31 May	14 June	28 June	13 July	26 July	11 Aug	23 Aug	7 Sept	AUQPC[z]
Fertilizer[y]	--Turfgrass quality[x]--										
Organic	5.44	5.88	5.78	5.84	5.72	5.63	4.81	5.5	4.41	6.03	610
Synthetic	5.38	5.53	5.5	5.72	5.78	5.53	4.94	5.28	4.19	6.09	597
Fungicide program[w]											
Biological	5.13	5.31b[v]	5.44	5.38bc	4.88b	4.13c	3.88c	3.93b	2.94c	5.0b	516c
Hybrid	5.5	5.63ab	5.81	5.94ab	6.31a	6.31a	5.06b	6.25a	4.75b	6.69a	639b
Conventional	5.69	6.25a	5.88	6.63a	6.81a	6.88a	7.13a	7.13a	6.38a	7.31a	727a
Non-treated	5.31	5.53ab	5.44	5.19c	5.0b	5.0b	3.44c	4.25b	3.13c	5.25b	532c
Source of variation											
Fertilizer	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fungicide	NS	**	NS	***	***	***	***	***	***	***	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Area under quality progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 3 May, 31 May, 28 June, 26 July, and 23 August at a rate of 25.8 kg N ha^{-1}.

[x] Quality ratings based on 1–9 scale (incorporates turfgrass color, density, uniformity, and disease percent) where 6 represented the minimum acceptable turf quality and 9 represented the best.

[w] Fungicide treatments were applied on a 14-day interval beginning 3 May and ending 7 September.

[v] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

, *, NS refer to the 0.01, 0.001 significance levels and non-significant, respectively.

Table 11. Influence of fertilizer and fungicide applications on turfgrass quality of a perennial ryegrass fairway at location 2, 2017.

	Evaluation date										
Treatment (level)	28 Apr.	4 May	24 May	8 June	28 June	5 July	19 July	2 Aug	16 Aug	1 Sept	AUQPC^{z}
Fertilizer^{y}	---Turfgrass quality^{x}---										
Organic	5.43	5.98	5.93	5.38	5.58	5.05	5.18	5.18	4.65	4.83	672
Synthetic	5.5	5.83	5.8	5.4	5.68	5.28	5.05	5.4	4.78	4.55	674
Fungicide program^{w}											
Biological	5.44	5.78	5.69	5.44ab^{v}	4.88b	4.44bc	4.13c	4.06c	3.56c	4.25bc	599c
Hybrid	5.56	5.81	5.63	5.5a	6.06a	6.13a	5.81a	6.0ab	5.13ab	5.06ab	723ab
Conventional	5.31	5.88	6.123	5.69a	6.69a	6.25a	6.19a	6.38a	5.81a	5.5a	755a
Extended	5.25	6.0	6.06	5.44ab	5.94a	5.0b	5.19b	5.56b	5.19a	4.69abc	691b
Non-treated	5.75	6.06	5.81	4.88b	4.56b	4.0c	4.25c	4.44c	3.88bc	3.94c	595c
Source of variation											
Fertilizer	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fungicide	NS	NS	NS	**	***	***	***	***	***	***	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Area under quality progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[x] Quality ratings based on 1–9 scale (incorporates turfgrass color, density, uniformity, and disease percent) where 6 represented the minimum acceptable turf quality and 9 represented the best.

[w] Fungicide treatments were applied on a 14-day or 21-day interval beginning 11 May and ending 9 September.

[v] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

$^{**, ***, NS}$ refer to the 0.01, 0.001 significance levels and non-significant, respectively.

Table 12. Influence of fertilizer and fungicide applications on turfgrass quality of a perennial ryegrass fairway at location 2, 2018.

	Evaluation date										
Treatment (level)	9 May	24 May	6 June	20 June	5 July	19 July	2 Aug.	15 Aug	29 Aug	12 Sept.	AUQPC[z]
Fertilizer[y]	---------------------------Turfgrass quality[x]---------------------------										
Organic	6.52	5.38	5.8b[w]	6.63	5.93	5.88	5.07	4.53	4.27	4.38	684
Synthetic	6.52	5.2	6.23a	6.75	6.05	5.78	5.37	4.08	4.27	4.3	693
Fungicide program[v]											
Biological	6.56	5.06a	5.81bc	6.38b	5.25c	5.13c	5.24a	3.81ab	3.31b	3.56b	635b
Hybrid	6.5	5.44a	6.25ab	7.25a	7.31a	7.06a	5.49a	4.19ab	4.38ab	4.5ab	742a
Conventional	6.5	5.44a	6.75a	7.19a	6.5b	6.5ab	5.85a	5.25a	5.61a	5.69a	772a
Extended	6.5	5.5a	5.75bc	7.13a	6.31b	6.13b	5.5a	4.69ab	4.54ab	4.44ab	714a
Non-treated	6.56	5.0a	5.5c	5.5c	4.56c	4.31d	4.0b	3.56b	3.5b	3.5b	577b
Source of variation											
Fertilizer	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS
Fungicide	NS	*	***	***	***	***	***	*	**	**	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Area under quality progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 9 May, 6 June, 5 July, 2 August, and 29 August at a rate of 25.8 kg N ha^{-1}.

[x] Quality ratings based on 1–9 scale (incorporates turfgrass color, density, uniformity, and disease percent) where 6 represented the minimum acceptable turf quality and 9 represented the best.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[v] Fungicide treatments were applied on a 14-day or 21-day interval beginning 9 May and ending 29 August.

*, **, ***, NS refer to the 0.05, 0.01, 0.001 significance levels and non-significant, respectively.

Table 13. Influence of fertilizer and fungicide applications on normalized difference vegetation index, NDVI of a perennial ryegrass fairway at location 1, 2016.

	Evaluation date								
Treatment (level)	11 May	1 June	15 June	30 June	26 July	11 Aug.	25 Aug.	9 Sept.	AUNPC[z]
Fertilizer[y]	--------------------------------------Normalized difference vegetation index[x]--------------------------------------								
Organic	0.83	0.80	0.82	0.81	0.86	0.80	0.84	0.80	100
Synthetic	0.83	0.80	0.82	0.81	0.85	0.79	0.84	0.77	99
Fungicide program[w]									
Biological	0.83	0.80	0.84a[v]	0.80ab	0.84bc	0.79a	0.81b	0.72b	99b
Hybrid	0.83	0.80	0.83a	0.83a	0.87ab	0.82a	0.87a	0.81ab	102a
Conventional	0.84	0.80	0.83a	0.83a	0.88a	0.83a	0.88a	0.85a	103a
Non-treated	0.82	0.79	0.79b	0.77b	0.82c	0.73b	0.80b	0.76ab	96b
Source of variation									
Fertilizer	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fungicide	NS	NS	***	***	***	***	***	**	***
Fertilizer x Fungicide	*	NS	NS	NS	NS	NS	NS	NS	NS

[z] Area under NDVI progression curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[x] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[w] Fungicide treatments were applied on a 14-day interval beginning 11 May and ending 9 September.

[v] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

$^{*, **, ***, NS}$ refer to the 0.05, 0.01, 0.001 significance levels and non-significant, respectively.

Table 14. Fertilizer by fungicide treatment means for normalized difference vegetation index, NDVI at location 1, 2016.

	Evaluation date
Treatment (level)	11 May
Fertilizer[z] x Fungicide[y]	---Normalized difference vegetation index[x]---
Organic x Biological	0.85a[w]
Organic x Hybrid	0.83a
Organic x Conventional	0.83a
Organic x Non-treated	0.83a
Synthetic x Biological	0.82a
Synthetic x Hybrid	0.83a
Synthetic x Conventional	0.85a
Synthetic x Non-treated	0.82a

[z] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[y] Fungicide treatments were applied on a 14-day interval beginning 11 May and ending 9 September.

[x] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

Table 15. Influence of fertilizer and fungicide applications on normalized difference vegetation index, NDVI of a perennial ryegrass fairway at location 1, 2017.

	Evaluation date									
Treatment (level)	3 May	17 May	31 May	14 June	28 June	9 July	26 July	11 Aug.	23 Aug.	AUNPC[z]
Fertilizer[y]	---------------------------------------Normalized difference vegetation index[x]--------------------------------------									
Organic	0.80	0.83	0.86	0.87	0.86	0.78	0.86	0.82	0.92	106
Synthetic	0.80	0.83	0.86	0.87	0.84	0.79	0.86	0.82	0.92	107
Fungicide program[w]										
Biological	0.79	0.83	0.84b[v]	0.87bc	0.83b	0.77bc	0.84b	0.81bc	0.90b	105c
Hybrid	0.81	0.83	0.85b	0.87b	0.87a	0.79b	0.88a	0.84ab	0.93a	108b
Conventional	0.80	0.84	0.87a	0.90a	0.86ab	0.85a	0.88a	0.85a	0.93a	110 a
Non-treated	0.80	0.83	0.85b	0.85c	0.83ab	0.74c	0.83b	0.79c	0.91b	104c
Source of variation										
Fertilizer	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fungicide	NS	NS	***	***	**	**	**	***	***	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Area under NDVI progression curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 3 May, 31 May, 28 June, 26 July, and 23 August at a rate of 25.8 kg N ha^{-1}.

[x] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[w] Fungicide treatments were applied on a 14-day interval beginning 3 May and ending 7 September.

[v] Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

, *, NS refer to the 0.01, 0.001 significance levels and non-significant, respectively.

Table 16. Influence of fertilizer and fungicide applications on normalized difference vegetation index, NDVI of a perennial ryegrass fairway at location 2, 2017.

	Evaluation date							
Treatment (level)	28 April	4 May	8 June	21 June	19 July	2 Aug	1 Sept	AUNPC[z]
Fertilizer[y]	-----------------------------Normalized difference vegetation index[x]------------------------							
Organic	0.79	0.81a[w]	0.82	0.85	0.83	0.80	0.82	103
Synthetic	0.80	0.80b	0.83	0.85	0.82	0.80	0.83	103
Fungicide program[v]								
Biological	0.79	0.80	0.81b	0.84bc	0.79b	0.77b	0.81b	101c
Hybrid	0.79	0.81	0.84a	0.85ab	0.84a	0.81ab	0.83a	104a
Conventional	0.79	0.80	0.84a	0.87a	0.86a	0.82a	0.84a	105a
Extended	0.79	0.79	0.83ab	0.86ab	0.83a	0.80ab	0.83a	103ab
Non-treated	0.81	0.81	0.82ab	0.83c	0.79b	0.79ab	0.82ab	102bc
Source of variation								
Fertilizer	NS	*	NS	NS	NS	NS	NS	NS
Fungicide	NS	NS	**	***	***	**	***	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	*	NS

[z] Area under NDVI progression curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[x] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[v] Fungicide treatments were applied on a 14-day or 21-day interval beginning 11 May and ending 9 September.

$^{*, **, ***, NS}$ refer to the 0.05, 0.01, 0.001 significance levels and non-significant, respectively.

Table 17. Fertilizer by fungicide treatment means for normalized difference vegetation index, NDVI at location 2, 2017.

	Evaluation Date
Treatment (level)	1 September
Fertilizer^z x Fungicide^y	---Normalized difference vegetation index^x---
Organic x Biological	0.80b^w
Organic x Hybrid	0.83ab
Organic x Conventional	0.84a
Organic x Extended	0.83a
Organic x Non-treated	0.82ab
Synthetic x Biological	0.82ab
Synthetic x Hybrid	0.83a
Synthetic x Conventional	0.83ab
Synthetic x Extended	0.83a
Synthetic x Non-treated	0.82ab

[z] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[y] Fungicide treatments were applied on a 14-day or 21-day interval beginning 11 May and ending 9 September.

[x] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[w] Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

Table 18. Influence of fertilizer and fungicide applications on normalized difference vegetation index, NDVI of a perennial ryegrass fairway at location 2, 2018.

	Evaluation date									
Treatment (level)	9-May	24-May	6-June	20-June	5-July	19-July	2-Aug	15-Aug	29-Aug	AUNPC[z]
Fertilizer[y]	---------------------------------Normalized difference vegetation index[x]---------------------------------									
Organic	0.80	0.68b[w]	0.76b	0.84b	0.80	0.85a	0.84	0.77	0.80	89.57b
Synthetic	0.80	0.70a	0.77a	0.84a	0.81	0.84b	0.85	0.79	0.80	90.45a
Fungicide program[v]										
Biological	0.80	0.66b	0.75b	0.83b	0.80ab	0.84ab	0.83b	0.75b	0.80ab	88.42b
Hybrid	0.79	0.72a	0.77ab	0.85a	0.82ab	0.86a	0.85ab	0.79ab	0.80ab	91.13a
Conventional	0.80	0.72a	0.80a	0.85a	0.80ab	0.86a	0.86a	0.81a	0.83a	91.84a
Extended	0.80	0.71a	0.77ab	0.84a	0.82a	0.85ab	0.85ab	0.79ab	0.80ab	90.83a
Non-treated	0.80	0.66b	0.74b	0.82b	0.78b	0.83b	0.83b	0.76ab	0.78b	87.82b
Source of variation										
Fertilizer	NS	*	*	*	NS	*	NS	NS	NS	*
Fungicide	NS	***	**	***	**	**	**	*	*	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Area under NDVI progression curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[x] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[v] Fungicide treatments were applied on a 14-day or 21-day interval beginning 9 May and ending 29 August.

$^{*, **, ***, NS}$ refer to the 0.05, 0.01, 0.001 significance levels and non-significant, respectively.

Table 19. Concentration (nmol/g soil dry weight) of fatty acid biomarkers following seasonal treatments at location 1, 2016.

	Fatty acid biomarker group							
Treatment (level)	General	AM Fungi	G -	Eukaryote	Fungi	G +	Actino	Protozoa
Fertilizer^{z}	----------nmol/g dry weight^{y}----------							
Organic	288.71	48.82	173.25	27.60	25.28	228.46	33.54	6.46
Synthetic	314.54	57.38	191.41	30.90	28.03	230.96	43.68	7.34
Fungicide program^{x}								
Biological	294.40	54.00	182.11	28.95	25.86	231.97	38.75	6.71
Hybrid	275.39	42.21	167.66	26.88	22.82	221.89	39.43	5.89
Conventional	318.92	56.79	194.59	31.99	28.93	242.79	35.25	7.91
Non-treated	317.79	59.40	184.97	29.19	29.03	222.26	41.01	7.08
Source of variation								
Fertilizer	NS	NS	NS	NS	NS	NS	NS	NS
Fungicide	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	NS

[z] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[y] Reported as a ratio of nmol/g dry weight.

[x] Fungicide treatments were applied on a 14-day interval beginning 11 May and ending 9 September.

[NS] represents non-significant.

Table 19 (cont'd). Concentration (nmol/g soil dry weight) of fatty acid biomarkers following seasonal treatments at location 1, 2016.

	Fatty acid biomarker group		
Treatment (level)	G - / G +	Fungi/Bacteria	Total biomass
Fertilizer[z]	---nmol/g dry weight[y]---	---nmol/g dry weight[x]---	---nmol/g dry weight[w]---
Organic	1.23	0.05	832.13
Synthetic	1.15	0.06	904.24
Fungicide program[v]			
Biological	1.20	0.05	862.74
Hybrid	1.25	0.05	802.15
Conventional	1.17	0.06	917.11
Non-treated	1.14	0.06	890.73
Source of variation			
Fertilizer	NS	NS	NS
Fungicide	NS	NS	NS
Fertilizer x Fungicide	NS	NS	NS

[z] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[y] Ratio of gram-negative bacteria over gram-positive bacteria in units of nmol/g on a dry weight basis.

[x] Ratio of fungi over the sum of gram-positive, gram-negative and actino bacteria in units of nmol/g on a dry weight basis.

[w] Sum of all PLFA biomarkers in units of nmol/g on a dry weight basis.

[v] Fungicide treatments were applied on a 14-day interval beginning 11 May and ending 9 September.

[NS] represents non-significant.

Table 20. Concentration (nmol/g soil dry weight) of fatty acid biomarkers following seasonal treatments at location 1, 2017.

	Fatty acid biomarker group							
Treatment (level)	General	AM Fungi	G -	Eukaryote	Fungi	G +	Actino	Protozoa
Fertilizer[z]	---------------------------nmol/g dry weight[y]---------------------------							
Organic	478.54	60.28	237.52	36.58	53.50	249.53	69.08	10.67
Synthetic	508.25	58.83	241.96	32.67	58.06	238.85	70.29	10.00
Fungicide program[x]								
Biological	424.19	47.57	209.32b[w]	32.93	51.42	211.26	64.61	9.42
Hybrid	514.1	62.67	252.12ab	33.39	55.27	256.45	70.23	10.75
Conventional	475.56	60.51	229.44ab	32.07	54.06	230.95	63.13	9.40
Non-treated	559.75	67.47	268.09a	40.11	62.37	278.10	80.77	11.77
Source of variation								
Fertilizer	NS[v]	NS	NS	NS	NS	NS	NS	NS
Fungicide	NS	NS	*	NS	NS	NS	NS	NS
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	NS

[z] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[y] Reported as a ratio of nmol/g dry weight.

[x] Fungicide treatments were applied on a 14-day interval beginning 11 May and ending 9 September.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[*,NS] refer to the 0.05 significance level and non-significant, respectively.

Table 20 (cont'd). Concentration (nmol/g soil dry weight) of fatty acid biomarkers following seasonal treatments at location 1, 2017.

	Fatty acid biomarker group		
Treatment (level)	G - / G +	Fungi/Bacteria	Total biomass
Fertilizer[z]	---nmol/g dry weight[y]---	---nmol/g dry weight[x]---	---nmol/g dry weight[w]---
Organic	1.00	0.09	1195.71
Synthetic	0.94	0.10	1218.92
Fungicide program[v]			
Biological	0.96	0.10	1050.73b[U]
Hybrid	0.99	0.09	1254.97ab
Conventional	0.94	0.10	1155.13ab
Non-treated	0.99	0.09	1368.43a
Source of variation			
Fertilizer	NS	NS	NS
Fungicide	NS	NS	*
Fertilizer x Fungicide	NS	NS	NS

[z] Fertilizer treatments were applied on 3 May, 31 May, 28 June, 26 July, and 23 August at a rate of 25.8 kg N ha^{-1}

[y] Ratio of gram-negative bacteria over gram-positive bacteria in units of nmol/g on a dry weight basis.

[x] Ratio of fungi over the sum of gram-positive, gram-negative and actino bacteria in units of nmol/g on a dry weight basis.

[w] Sum of all PLFA biomarkers in units of nmol/g on a dry weight basis.

[v] Fungicide treatments were applied on a 14-day interval beginning 3 May and ending 7 September.

[u] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[*,NS] refer to the 0.05 significance level and non-significant, respectively.

Table 21. Concentration (nmol/g soil dry weight) of fatty acid biomarkers following seasonal treatments at location 2, 2017.

	Fatty acid biomarker group							
Treatment (level)	General	AM Fungi	Gram -	Eukaryote	Fungi	Gram +	Actino	Protozoa
Fertilizer[z]	---------------------------	--------------------------	--------------------------	-nmol/g dry weight[y]-	--------------------------	--------------------------	--------------------------	--------------------------
Organic	360.89	68.50	179.81	25.43	39.99	167.90	26.41	8.84
Synthetic	382.25	63.21	191.62	27.66	45.00	173.91	24.76	9.13
Fungicide program[x]								
Biological	367.32	58.77b[w]	180.51	24.46	39.09	169.93	26.72	8.63
Hybrid	395.23	84.83a	200.97	27.05	44.20	176.73	29.96	9.86
Conventional	411.68	75.07ab	206.03	31.46	51.01	184.27	24.80	9.84
Extended	332.40	52.13b	166.71	22.60	39.24	150.57	24.50	7.88
Non-treated	351.24	58.48b	174.36	27.13	38.95	173.02	21.95	8.72
Source of variation								
Fertilizer	NS	NS	NS	NS	NS	NS	NS	NS
Fungicide	NS	**	NS	NS	NS	NS	NS	NS
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS	NS	NS

[z] Fertilizer treatments were applied on 11 May, 1 June, 30 June, 26 July, and 25 August at a rate of 25.8 kg N ha^{-1}.

[y] Reported as a ratio of nmol/g dry weight.

[x] Fungicide treatments were applied on a 14-day or 21-day interval beginning 11 May and ending 9 September.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[**, NS] refer to the 0.01 significance level and non-significant, respectively.

Table 21 (cont'd). Concentration (nmol/g soil dry weight) of fatty acid biomarkers following seasonal treatments at location 2, 2017.

	Fatty acid biomarker group		
Treatment (level)	Gram-neg/Gram-pos	Fungi/Bacteria	Total biomass
Fertilizer^{z}	---nmol/g dry weight^{y}---	---nmol/g dry weight^{x}---	---nmol/g dry weight^{w}---
Organic	0.91	0.11	877.77
Synthetic	0.90	0.11	917.55
Fungicide program^{v}			
Biological	0.93a^{u}	0.10	875.43
Hybrid	0.86b	0.10	968.82
Conventional	0.88ab	0.12	994.17
Extended	0.88ab	0.11	793.48
Non-treated	0.97a	0.10	856.40
Source of variation			
Fertilizer	NS	NS	NS
Fungicide	*	NS	NS
Fertilizer x Fungicide	NS	NS	NS

[z] Fertilizer treatments were applied on 3 May, 31 May, 28 June, 26 July, and 23 August at a rate of 25.8 kg N ha^{-1}.

[y] Reported as a ratio of nmol/g dry weight of gram-negative bacteria over gram-positive bacteria.

[x] Reported as a ratio of nmol/g dry weight fungi over the sum of gram-positive, gram-negative and actino bacteria.

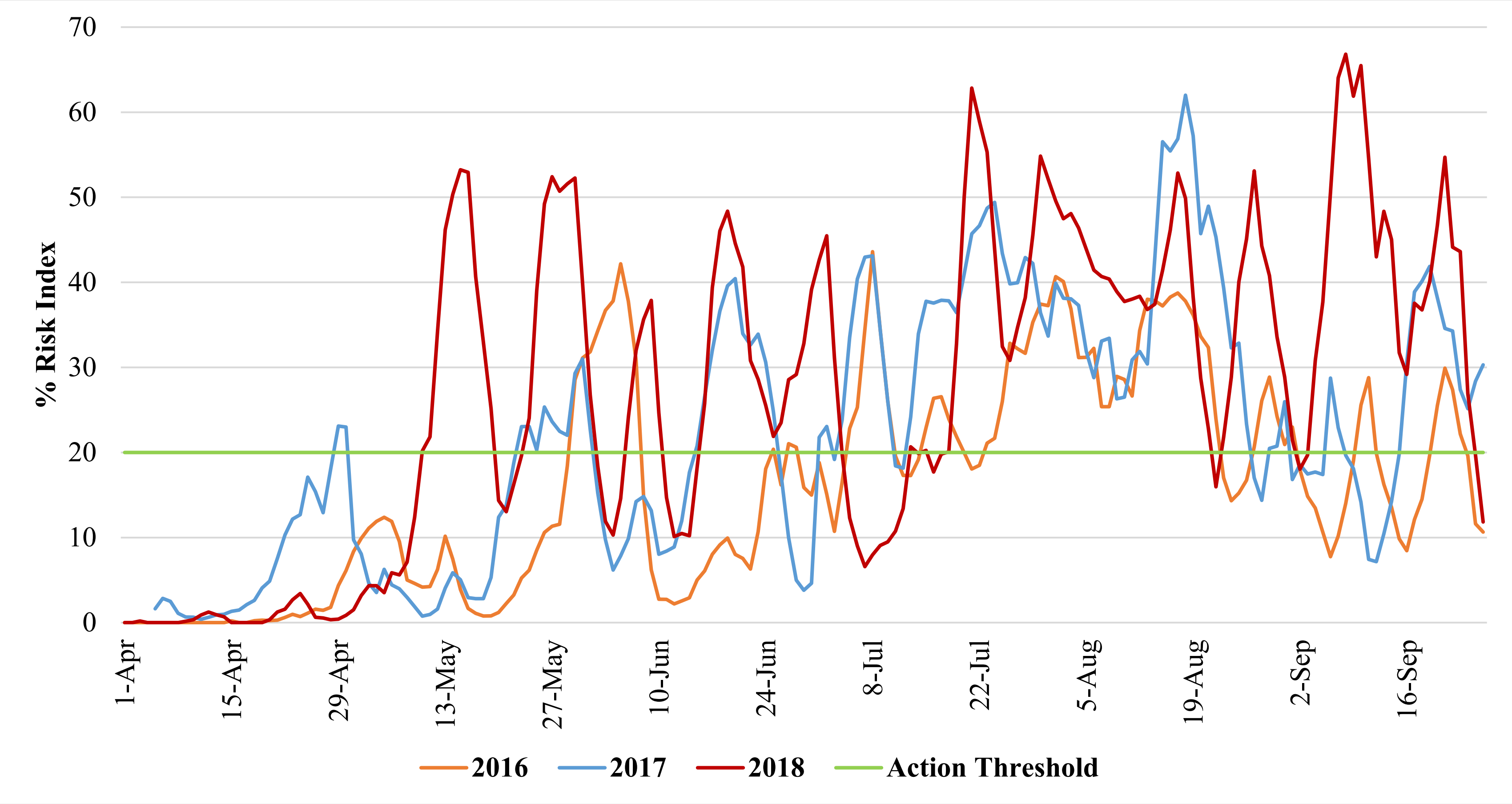
[w] Reported as nmol/g dry weight of all PLFA biomarkers.

[v] Fungicide treatments were applied on a 14-day interval beginning 3 May and ending 7 September.

[u] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[*,NS] refer to the 0.05 significance level and non-significant, respectively.

Figure 1. Dollar Spot Probability Chart for Derwood, MD According to the Smith-Kerns Index, 2016-2018.



Chapter 3: Effects of Organic Amendments on Dollar Spot Disease of Creeping Bentgrass Golf Course Fairways

Abstract

Dollar spot (*Clarireedia* spp.) is a common disease of turfgrass, which often requires multiple fungicide applications for control. Naturally suppressive organic amendments are an alternative management tool that merits further evaluation. A 2-yr trial was initiated in late 2016 on creeping bentgrass (*Agrostis stolonifera* L. cv. '007') maintained as a golf course fairway to evaluate fertility and fungicide source for impact on dollar spot development on newly established creeping bentgrass stand. Main-plot treatments were applied as soil incorporated organic biosolids compost (OBC-I), soil incorporated biochar + surface applied standard fertilizer (BIO-I), surface applied organic biosolids compost (OBC-S), surface applied biochar + standard fertilizer (BIO-S), surface applied standard fertilizer + vermicompost spray program (SF + V), surface applied standard fertilizer (SF), and non-treated (NON). Nitrogen fertility levels for all treatments were standardized at approximately 411 kg N ha^{-1} over the course of 2 years. Sub-plot fungicide treatments were applied as a 14 d fluazinam (FZM), FZM threshold, 14 d fluxapyroxad (FXD), FXD threshold, and none. Turfgrass was visually rated for disease development (dollar spot infection centers) and quality (1-9; 9 = best) throughout each growing season. Threshold treatments were made when >2 infection centers were counted on two of four replicates. During the trial period, the BIO-I, BIO-S, SF +V and SF treatments were the most consistent treatments for reducing dollar spot. When comparing area under the disease progress curve (AUDPC) values for dollar spot incidence in 2017, all

fertilizer treatments were better than non-treated, yet were similar to each other. In 2018, the BIO-I, BIO-S, SF + V and SF treatments were better than OBC-I, OBC-S and NON. The reduced effectiveness of OBC-I and OBC-S in the second year of the trial show that N availability was a major contributing factor for fertility-mediated disease reductions. All fungicide treatments effectively reduced dollar spot when applied at designated 14 d intervals. In 2017, all fertilizer treatments reduced the number of threshold sprays compared to NON, yet the same effects were not consistently observed in 2018. The results of this study suggest that fertilizers which supply adequate plant available nitrogen at a consistent rate of release, regardless of source, may be used as a cultural control method for mitigating dollar spot disease.

Introduction

Dollar spot (*Clarireedia spp*. C. Salgado-Salazar) is a foliar disease which affects nearly all types of species of turfgrass, and may be particularly severe on creeping bentgrass (*Agrostis stolonifera* L.) mowed at or under 12 mm (Salgado-Salazar et al., 2018). The disease first appears as a small (< 1 cm) lesions, which are tan or bleached in color. As the disease becomes more severe, lesions may spread to 1-5 cm in size and render turf completely sunken and necrotic. Aerial mycelium may be present when the pathogen is actively growing, particularly following periods of heavy rain and on mornings with high dew formation (Smiley et al., 2005). Dollar spot has a broad range of activity and can occur many times throughout a growing season (Ryan et al., 2012). Severe cases of dollar spot greatly reduce the overall playability and aesthetics of turfgrass, making control a necessary and expensive requirement for turfgrass managers (Vargas, 2005). Historically, applications of chemical fungicides have been the most effective method to manage dollar spot (Walsh et al., 1999). Growing concern over non-target effects, resistance, and an overall reliance on chemical fungicides have prompted some to develop alternative management strategies for dollar spot of turfgrass (Golembiewski et al., 1995; Nelson et al., 1994). Naturally suppressive organic amendments, such as natural organic fertilizers, composts, and extracts are an alternative management tool that merits further evaluation.

Organic amendments have long been evaluated for their ability to control soilborne pathogens by stimulation or enhancement of resident soil microbe populations (Hoitink and Fahy, 1986). Suppression is thought to occur when microbial activity inhibitory to the pathogen coincides with critical points in its lifecycle (Cook and Baker, 1983). This inhibitory activity may occur as one or as a combination of competition mechanisms which include (but are not limited to) antibiosis, mycoparasitism, competition of resources, and induced resistance. Antibiosis occurs when soil microbes (bacteria, fungi, etc.) produce antimicrobial compounds to eliminate or inhibit growth of competing microbes (Hibbing et al., 2010). Certain species of *Pseudomonas* have been shown to produce antibiotics that suppress *Pythium* and *Rhizoctonia* diseases of turfgrass (Nelson, 1997). Mycoparasitism occurs when fungal hyphae bind to, degrade, penetrate and inhibit the cell walls of a fungal pathogen (Chet, 1987). The effectiveness of *Serratia marcescens* Bizio as a biocontrol agent for *Magnaporthe poae* Landschoot & N. Jackson is attributed to the production of chitinase enzymes, which inhibit chitin-containing fungal pathogens (Kobayashi and Nour, 1996). Competition among microbes may occur indirectly or directly and is often over nutritional resources (Nelson, 1997). In studies using *Typhula phacorrhiza* Reichard, Burpee et al. (1987) found that pathogenic *Typhula* growth was significantly reduced when grown on media that was previously exposed to *T. phacorrhiza* and hypothesized that suppression occurred via nutrient competition. Induced resistance can occur as either systemic acquired resistance or induced systemic resistance and is initiated when plant defenses are enhanced by environmental or biological stimuli (Vallad and Goodman, 2004). In turfgrass, acibenzolar-S-methyl [(ASM), Actigard, Syngenta Corp., Basel, Switzerland] is applied as plant defense activator to induce systemic acquired resistance. In studies that evaluated ASM for use against dollar spot, a 38% reduction of dollar spot infection centers on a creeping bentgrass green was reported after applying ASM (Lee et al., 2003). Organic amendments may also indirectly suppress plant pathogens when the addition of N fertility (Turgeon, 1996) and/or improved physical soil characteristics (Doran, 1995) enhances plant growth and development.

Many researchers have studied the effect of organic soil amendments, more specifically those of composts, on the development and severity of turfgrass diseases. Davis (1951) first reported seeing reduced incidence of brown patch (*Rhizoctonia solani* J.G. Kühn) on creeping bentgrass (*Agrostis stolonifera* L.) that was treated with activated sewage sludge. The same product was also used to effectively treat Pythium blight [*Pythium aphanidermatum* (Edson) Fitzp]., (Wells and Robinson, 1954) and dollar spot (Cook et al., 1964), though later it was determined that the sewage sludge also had a fungicidal effect due to the presence of cadmium (Turner and Hummel, 1992). When Nelson and Craft (1991) evaluated multiple types of organic fertilizers, litters, manures, composts, and sludges for dollar spot control, they found that that sand topdressings amended with turkey litter compost, sewage sludge, and non-composted blends of plant and animal meal were as suppressive to dollar spot on creeping bentgrass as conventional fungicides. In a similar evaluation of various organic amendments, Liu et al. (1995) found blended meal products (Ringer brand) to be the most effective organic method to reduce dollar spot on creeping bentgrass, though the rate of N between amendments and fertilizers was not standardized in this trial. Davis and Dernoeden (2002) performed a similar evaluation with standardized N rates and found a poultry-meal based organic fertilizer (Ringer Lawn Restore) to suppress dollar spot in the spring months, when pressure was low to moderate. However, they concluded that the results were due to increased plant N-availability rather than enhanced microbial activity and pointed out that no organic N source consistently reduced dollar spot incidence when compared with synthetic organic N-sources during the trial. In an assessment of standard fertilizer, poultry meal, and granular humates applied at the establishment of creeping bentgrass, Kaminski and Dernoeden (2004) found no fertilizer or soil amendment effect dollar spot incidence.

Over the past decade, additional organic amendments have become commercially available to agriculture and turfgrass. Vermicompost is a granular compost derived from the breakdown of organic wastes via earthworm activity and exhibit high porosity, high rates of mineralization, and have low carbon:nitrogen ratios (Dominguez, 2004). Vermicompost applications been reported to improve the physical soil structure (Kahsnitz, 1992), increase the availability of nutrients (Gilot, 1997), and enhance soil microbiota (Domínguez et al., 2010). Szczech (1993) reported suppression of root rot of tomato caused by *Phytophthora nicotianae* var. *nicotianae* van Breda de Hann and clubroot disease of cabbage caused by *Plasmodiophora brassicae* Woronin after applying a granular vermicompost.

In general, vermicompost is applied to turfgrass as an extract or tea, which is derived from the filtration of vermicompost-water mixtures. Liquid compost extracts have been studied in agricultural settings and are reported to have many of the same biocontrol properties as granular composts (McQuilken et al., 1994). In turfgrass, Conforti et al. (2002) reported mild suppression of microdochium patch [*Microdochium nivale* (Fries) Samuels & Hallett] on golf course putting greens after applying a compost tea derived from plant and animal waste. Hsiang and Tian (2007) reported seeing dollar spot reductions similar to that of chlorothalonil fungicide on creeping bentgrass putting greens after using a 'mushroom' compost tea extract. The effect of vermicompost extract for control of dollar spot on golf course fairway turfgrass is unknown.

Biochars are carbon-rich amendments derived from the slow pyrolysis of organic biomass (Lehmann and Joseph, 2015). Applications of biochar have been reported to increase soil microbe populations (Jin, 2010) and to improve fertilizer use efficiency of wheat (Van Zwieten et al., 2010). Biochars have also been successfully used to suppress soil borne plant pathogens. Asparagus (*Asparagus officinalis* L.) seedlings grown in biochar-amended soil showed increased tolerance to fusarium root rot caused by *Fusarium solani* (Mart.) Sacc. f. sp. *phaseoli* (Burkholder) W. C.

Snyder and H. N. Hans (Matsubara et al., 2002). Elad et al. (2010) reported improved pepper and tomato resistance to gray mold caused by *Botrytis cinerea* Pers. and powdery mildew caused by *Leveillula taurica* (Lév.) G. Arnaud when the crops were grown in a biochar amended media. They hypothesized that suppression resulted from induced or systemic-acquired resistance. Later, Harel et al. (2012) would show that strawberries grown in a potting mix amended with biochar stimulated the expression of five defense genes (*FaPR1*, *Faolp2*, *Fra a3*, *Falox*, and *FaWRKY1*), thereby improving resistance against *Botrytis cinerea* Pers., anthracnose caused by *Colletotrichum acutatum* J.H. Simmonds, and strawberry powdery mildew caused by *Podosphaera apahanis* Wallr. Applications of biochar to turfgrass have been reported to positively affect the growth of creeping bentgrass and improve water retention in the root zones of golf course greens (Brockhoff et al., 2010; Vaughn et al., 2018; Vaughn et al., 2015). The direct effect of biochar on suppression of turfgrass pathogens also remains unknown.

To reduce dependence on conventional fungicides for dollar spot control, turfgrass managers require additional alternative management tools that are effective and practical to implement. Organic amendment applications are one such tool that warrants additional investigation. There have been no published studies assessing the effect of biochar or vermicompost on dollar spot development of creeping bentgrass. The objectives of this study were to evaluate three different compost sources (i.e., organic biosolids compost, biochar, and vermicompost extract) for their impact on dollar spot severity, fungicide efficacy, and turfgrass quality on a newly established creeping bentgrass fairway.

Materials and Methods

General Management Practices

A 2-yr field study was conducted from late 2016 to 2018 on a creeping bentgrass (cv. '007') fairway at the University of Maryland Paint Branch Turfgrass Research Facility located in College Park, MD. The monostand of bentgrass turf was established from seed on 16 October 2016. Turfgrass was mowed three times weekly at a bench height of 10 mm using a Jacobsen Greens King IV (Textron Inc., Providence, RI) triplex mower and clippings were usually returned. The site was irrigated as needed to prevent visual signs of drought stress using an overhead irrigation system. Annual weeds were suppressed with dithiopyr (Dimension EG; Dow AgroSciences, Indianapolis, IN) at a rate of 0.56 kg ha^{-1} on 1 May 2017 and 26 April 2018 using a Toro Multi Pro® 1750 (The Toro Company, Bloomington, MN) equipped with Tee Jet AIC11008 nozzle calibrated to deliver each treatment rate in H_2O at 815 liters ha^{-1}. Annual bluegrass *Poa annua* L. f. *reptans* (Hausskn) T. Koyama was controlled by treating the entire study area with amicarbazone (Xonerate 2SC; FMC, Philadelphia, PA) at a rate of 0.17 kg a.i. ha^{-1} on 21 April 2017 and 8 May 2018. This treatment was applied using a CO2-pressurized system equipped with Tee Jet 6502 nozzles calibrated to deliver each treatment rate in H_2O at 408 liters ha^{-1}. The rate of turf growth was controlled with applications of trinexapac-ethyl (Primo Maxx; Syngenta, Greensboro, NC) at 0.048 kg a.i. ha^{-1} as this is a common practice to control creeping bentgrass growth in this region. Pythium disease was prevented by treating the entire study area with potassium phosphite (Stress Master Si; Quest Products Corp, Linwood, KS) at 6.66 kg a.i. ha^{-1}.

Trinexapac-ethyl and potassium phosphite were applied in combination every 21 d from 26 May 2017 to 18 August 2017 and 22 May 2018 to 4 September 2018 using a Toro Multi Pro® 1750 (The Toro Company, Bloomington, MN) equipped with Tee Jet AIC11008 nozzle calibrated to deliver each treatment rate in H_2O at 815 liters ha^{-1}. The entire study area was vertically mown in two directions on 28 April 2017 and 2 May 2018 using a LESCO Renovator 021600 (LESCO Inc., Cleveland, OH). The dollar spot epiphytotic was arrested after treatments were suspended in 2017 to allow non-treated sub-plots to recover from late fall to early spring. Chlorothalonil (Daconil Ultrex; Syngenta, Greensboro, NC) was applied at 8.86 kg a.i. ha^{-1} with iprodione (Ipro 2SE; Makhteshim Agan of North America Inc., Raleigh, NC), applied at 3.05 kg a.i. ha^{-1} on 13 October 2017.

Treatment Design

This trial utilized a 7 x 5 split-plot arrangement of treatments in a randomized complete block design. Individual main plots measured 1.8 x 6.1 m. and were separated on all sides by a 0.3 m non-treated buffer. Main plot treatments consisted of soil incorporated organic biosolids compost (OBC) (1-1-0 Orgro Compost; Baltimore City Composting Facility, Baltimore MD) [OBC-I]; surface applied organic biosolids compost (OBC-S); soil incorporated biochar (2-2-2 Mirimichi Green Pro Soil Enhancer; Mirimichi Green Express, Castle Hayne, NC) + surface applied standard fertilizer (43-0-0 polymer coated sulfur coated urea; Growmark FS, LLC, Milford, DE) [BIO-I]; surface applied biochar + surface applied standard fertilizer [BIO-S]; surface applied standard fertilizer + vermicompost extract (0.48-0.01-0.016 Vermaplex; Southern Organics & Supply, Monroe, NC) spray program

[SF + V]; surface applied standard fertilizer (SF); and non-treated (NON). Analysis of organic biosolids compost, biochar, sulfur coated urea, and vermicompost were based on the published analysis provided by each respective producer.

Main plot treatments were initiated at trial establishment on 16 October 2016. All fertilizer (organic and synthetic) treatments were applied as identified through distributor analysis of N-P-K at their respective rates. Organic biosolids compost was applied to OBC-I at a rate of 411 kg N ha^{-1} and tilled into the surface to a depth of ±8 cm using a Barreto 1620B tiller (Barreto Manufacturing, Inc., La Grande, OR). Biochar was applied to BIO-I at a rate of 78 kg N ha^{-1} and worked into the surface with a hard landscape rake. Nitrogen was applied at a rate of 44 kg N ha^{-1} to OBC-S, BIO-S, and SF + V as sulfur coated urea and to SF as starter fertilizer (14-20-4 LESCO Professional Turf Fertilizer; LESCO Inc., Cleveland, OH) using a shaker jar. As N rates varied between treatments at trial establishment, subsequent N applications were designed to standardize N rate at the conclusion of the trial. The N rate applied to OBC-I at trial establishment (411 kg N ha^{-1}) was used to guide N applications for all other treatments. Under the assumption that N release from organic biosolids compost would be relatively constant during for the remainder of the trial (~205 kg N ha^{-1} yr^{-1}), other treatment application schedules attempted to match this N release rate. After subtracting the amount of N applied to each treatment at trial establishment, the following application schedule was created for the remaining fertilized treatments: organic biosolids compost was surface applied to OBC-S at a rate of 92 kg N ha^{-1} on 4 May and 14 August 2017 and 4 May and 7 September 2018; biochar was surface applied to BIO-S at a rate of 20 kg N ha^{-1} on 4

May and 14 August of 2017 and 4 May and 7 September 2018 with N applied as sulfur coated urea at a rate of 36 kg N ha^{-1} on 4 May, 5 June, 14 July and 21 August of 2017 and 4 May, 8 June, 20 July, and 7 September 2018; nitrogen was surface applied as sulfur coated urea to SF + V at a rate of 46 kg N ha^{-1} on 4 May, 5 June, 14 July and 21 August of 2017 and 4 May, 8 June, 20 July, and 7 September 2018. Vermicompost extract was applied as part of a foliar spray program: Microbac (Southern Organics & Supply, Monroe, NC) was applied at a rate of 9.35 L ha^{-1} in the spring when soil temperatures reached 14 °C and in the fall when soil temperatures dropped to 14 °C; Vermaplex (Southern Organics & Supply, Monroe, NC) was applied 14 d after the application of Microbac, at a rate of 9.35 L ha^{-1} on the initial application, at 4.68 L ha^{-1} every 14 d thereafter until July, when the rate returned to 9.35 L ha^{-1} until the end of the growing season. Nitrogen was surface applied as sulfur coated urea to SF at a rate of 46 kg N ha^{-1} on 4 May, 5 June, 14 July and 21 August of 2017 and 4 May, 8 June, 20 July, and 7 September 2018. Respective rates of phosphorus (P) and potassium (K) were also normalized between treatments and applied at the rates shown on Table 22. Compost treatments were applied by hand and evenly distributed over the turf canopy with a hard landscape rake. Granular fertilizer treatments were applied by hand using a shaker jar. Vermaplex treatments in 2017 were initiated on 26 April and ended 28 September. Treatments in 2018 were initiated on 1 May and ended 10 October. Treatments were applied using a CO2-pressurized system equipped with Tee Jet AI9508e nozzle calibrated to deliver each treatment rate in H_2O at 408 liters ha^{-1}.

Subplot treatments consisted of: 14 d fluazinam (Secure; Syngenta, Greensboro, NC)[FZM] at a rate 0.8 kg a.i. ha^{-1}; 14 d fluxapyroxad (Xzemplar; BASF, Research Triangle Park, NC)[FXD] at a rate of 0.15 kg a.i. ha^{-1}; Threshold (> 2 infection centers on 2 of 4 treatment replicates) fluazinam [Secure; Syngenta, Greensboro, NC][[FZM-T]] at a rate 0.8 kg a.i. ha^{-1}; Threshold (> 2 infection centers on 2 of 4 treatment replicates) fluxapyroxad [Xzemplar; BASF, Research Triangle Park, NC][[FXD-T]] at a rate of 0.15 kg a.i. ha^{-1}; and non-treated (None). All treatments were applied using a CO_2-pressurized system equipped with a Tee Jet AI11004 nozzle calibrated to deliver each treatment rate in H_2O at 408 liters ha^{-1}. In 2017, 14 d treatments were initiated on 19 May ending 31 August and threshold treatments were initiated on 26 May ending 18 Aug. In 2018, 14d treatments were initiated beginning 14 May ending 17 October and threshold treatments were initiated beginning 14 May ending 25 September.

The experimental area was inoculated on 15 May 2017 with rye grain (*Secale cereale* L.) infested with *Clarireedia jacksonii*. Isolate previously isolated from the Paint Branch Turfgrass Facility. The inoculum was prepared by mixing 250 ml rye grain, 2 tsp. Calcium carbonate powder, and 220 ml warm water in a flask. Ten 1 L mixtures were prepared and autoclaved for 45 minutes at 121° C. After autoclaving, mycelial plugs from *Clarireedia jacksonii* isolates were placed on sterilized rye grains and allowed to grow at 25°C for 21 days. The inoculated rye grains were then spread evenly by hand over the entire trial area and left on the surface for 3 d. After the trial area was mown with clippings collected, the remaining rye grains were removed with a vacuum.

Data Collection and Analysis

Data on turfgrass quality and disease severity for the entire trial area were taken every 14 days during the trial period. Threshold sub-plots were rated on a daily basis. Dollar spot severity was determined by visually counting infection centers within each plot. Visual ratings for turf quality (color, density, uniformity, and disease percent) were taken using a 1 to 9 rating scale where 6 represented the minimum acceptable turf quality and 9 represented the best. Canopy reflectance was quantified by measuring NDVI with a turfgrass chlorophyll meter (FieldScout CM 1000; Spectrum Technologies Inc., Aurora, IL). This meter calculates an index value range from -1.000 to 1.000, where 1.000 indicates greener color. Nutrient content within plant tissues was quantified twice per growing season by mowing main plots using a Toro® Greensmaster® 1600 (The Toro Company, Bloomington, MN) walk behind mower and collecting grass clippings in paper bags. The fresh clippings were weighed and then dried in an oven (Precision Thelco 18; Thermo Fisher Scientific, Waltham, MA) at 40 ° C for 72 h. The dried clippings were weighed and analyzed at Waypoint Analytical in Richmond, VA. Root area was quantified two times during each growing season. Samples were collected by harvesting two samples, measuring 2.5 cm in diameter and 15 cm in length, per sub-plot. Samples were wrapped tightly in paper towel and soaked in warm water for 24 h. After the soaking period, the samples were unwrapped, placed on a mesh sieve, and soil was gently washed from the roots using a garden hose with a nozzle. The washed samples were placed in a plastic bag and refrigerated at 4 ° C for approximately 1 week. After the refrigeration period, samples were pressed flat in paper towels, roots were untangled and then scanned to create a digital image. Images were loaded into Assess 2.0 (The American Phytopathological Society, St. Paul, MN) and the root area of each sample was measured.

Respective disease counts were transformed using the trapezoidal method of area under disease progression curve (AUDPC) to produce a summative rating of disease incidence during the trial period (Madden et al., 2007). Respective turf quality ratings were transformed using the area under quality progression curve (AUQPC) to produce a summative rating of turf quality during the trial period. Respective NDVI ratings were transformed using the area under NDVI progression curve (AUNPC) to produce a summative rating of NDVI values during the trial period. The data collected were subjected to ANOVA using the Mixed and Reg procedures in the Statistical Analysis System software v. 9.4 (SAS Institute, Cary, NC). Means were separated using Tukey's honest significant difference at the 0.05 probability level. A linear regression analysis was performed to determine whether dollar spot incidence could be associated with tissue nutrient content or root area. We fit a linear regression model using tissue nitrogen content, or root area as the independent variable and dollar spot incidence (AUDPC of rating dates before and after sampling) as the dependent variable.

Results

Dollar Spot Severity

Dollar spot severity was significantly impacted by fertilizer factor in 2017 (Table 23). Main plots treated with OBC-I, OBC-S and SF recovered more quickly from the initial onset of dollar spot than NON, as indicated by the 16 June rating date.

In general, the BIO-I, BIO-S, SF + V and SF treatments were consistently better than NON when disease pressure was high, as indicated by the 3 July, 14 July, 27 July and 10 August rating dates. When comparing AUDPC values to evaluate seasonal effectiveness, all fertility treatments were significantly better than NON, with no difference between the respective treatments.

Dollar spot severity was significantly impacted by fungicide factor in 2017 (Table 23). There were no significant differences between any fungicide treatments and all fungicide treatments were significantly better than NON on 7 of 8 rating dates and when comparing AUDPC values. A fertilizer by fungicide interaction, observed on 6 of 8 rating dates and in AUDPC values, indicated that non-fertilized main plots had more dollar spot incidence on non-treated subplots than fertilized main plots (Table 24).

While fertilizer significantly influenced dollar spot severity again in 2018, the overall effect was less pronounced than in the previous year (Table 25). Although not always statistically significant, OBC-S was generally the most effective fertility treatment early in the season, as indicated by the 14 May and 30 May rating dates. During the second period of elevated dollar spot activity, the BIO-I, BIO-S and SF + V treatments were more effective than other fertility treatments and NON, as indicated by the 27 June rating date. At the beginning of the third infection period, the BIO-I, BIO-S, SF + V and SF treatments were significantly better than all other treatments as indicated by the 7 August rating date. However, on the subsequent rating date (22 August), only BIO-I and BIO-S were more effective than NON. In the final late-season epidemic (3 October and 17 October), we found no difference between main plot treatments. When comparing seasonal AUDPC values, the BIO-I, BIO-S, and SF + V were the only treatments having significantly less dollar spot than NON.

Fungicide factor significantly affected dollar spot development in 2018 (Table 25). The only significant difference between 14 d fungicide treatments was observed on 22 August when the FXD treatment had significantly more dollar spot than other fungicide treatments. Fungicide treatments were similar for all other rating dates and when comparing AUDPC values. Significant treatment interactions were observed on 5 of 12 rating dates as well as seasonally, indicating that plots that were not fertilized or treated with organic biosolids compost had more dollar spot incidence on non-treated subplots than plots treated with standard fertility (Table 26).

Fertilizer Effect on Fungicide Efficacy

To quantify the fertilizer effect on threshold fungicide treatments, the total number of threshold fungicide sprays for each treatment was quantified across the season. The sum of days that a treatment remained disease free beyond the 14 day application interval was also calculated. In 2017, a strong fertilizer effect was observed on threshold subplot treatments (Table 27). The NON x FZM-T treatment required 7 total threshold sprays, and averaged 3.1 days of extended efficacy. In contrast, the BIO-I, BIO-S, SF + V, and SF treatments only required 4 total threshold sprays and averaged 14 days of extended efficacy. The NON x FXD-T treatment required 7 total sprays and averaged 2.4 days of extended efficacy, whereas the OBC-S, BIO-S, SF + V, and SF treatments required 4 total applications and averaged 14 days of extended efficacy.

In 2018, the effect of fertility on threshold fungicide timing was greatly reduced (Table 28). While NON x FZM-T again required 7 total threshold sprays, average efficacy increased to 7.7 days. Only the SF treatment differed, requiring 6 total threshold sprays with an average efficacy of 11.5 days. The NON x FXD-T treatment required 6 total threshold sprays and averaged 11.7 days of extended efficacy. OBC-S was the only treatment to improve on this number, requiring 5 total threshold sprays and averaging 15.2 days of extended efficacy.

Turf Quality

Turf quality was significantly impacted by fertilizer and fungicide factor on 12 of 12 rating dates and seasonally in 2017 (Table 29). Shortly after establishment in 2016, OBC-I plot quality was below that of all other treatments. However, by the beginning of 2017, OBC-I had the best turf quality of all treatments, as indicated by the 27 April 2017 rating date. From that date forward, all fertilized plots were better than NON and when comparing AUQPC values. On the 27 July rating date, quality for OBC-S was lower than all other fertility treatments, but still above the acceptability threshold (>6). At the end of the 2017 season, quality for all fertilized treatments was above the level of acceptability. Turf quality on plots treated with FZM and FXD was better than None on every rating date as well as seasonally. While both 14 d fungicide programs were similar when comparing seasonal AUDPC values, FZM was significantly better than FXD on the 3 July and 14 July rating dates. A fertilizer by fungicide interaction was observed on the 2 June rating date, indicating that non-fertilized plots had lower turf quality ratings for all sub-plot treatments than fertilized treatments (Table 30).

In 2018, turf quality was significantly affected by fertilizer on 12 of 12 rating dates and when comparing AUQPC values (Table 31). Early in the season, OBC-S plot quality was significantly better than all other treatments, though all fertilized treatments were still above the acceptable threshold (>6). In contrast to the previous year, OBC-I was less effective than other fertility treatments: OBC-I was similar to NON on 11 of 12 rating dates, with quality below the acceptable threshold on 3 of these dates. When comparing AUQPC values, OBC-I was less effective than other fertilizer treatments and similar to NON. Quality was affected by fungicide on 11 of 12 rating dates and when comparing AUQPC values. In general, all fungicide treatments provided turf quality that was above the acceptable range (>6) and better than None. Notably, quality on non-treated plots was often above the level of acceptability from 14 May to 25 July. We also observed a marked reduction in quality on FXD plots on the 22 August rating date. When comparing AUQPC values, FZM was better than FXD and FXD-T while all fungicide treatments were better than none. A fertilizer by fungicide interaction observed on 4 of 12 rating dates and in AUQPC values indicated that plots which were not fertilized or treated with OBC at establishment, had lower turf quality ratings for non-treated sub-plots than other fertilized treatments. (Table 32).

NDVI Values

On 6 of 7 rating dates in 2017, fertilized plots had higher NDVI values than NON (Table 33). When comparing AUNPC values, all fertilized treatments were better than NON. Fungicide significantly impacted NDVI values on 7 of 7 rating dates and when comparing AUNPC values. Initially, 14d treatments were better than threshold treatments and None, by virtue of being treated before inoculation. From the 27 July rating date throughout the season, all fungicide treatments were better than None. FZM had significantly higher NDVI values compared to all other treatments when comparing AUNPC values. A fertilizer by fungicide interaction, observed on 1 of 7 rating dates and in AUNPC values, indicated that plots which were not fertilized had lower NDVI values for each respective sub-plot treatment than other fertilized treatments (Table 34).

In 2018, the effect of fertility was less pronounced on NDVI values (Table 35). On the 14 May rating date, we observed that OBC-I and NON resulted in significantly lower NDVI values than other fertilized treatments. On subsequent rating dates, although generally higher, no fertility treatment was consistently better than NON. When comparing AUNPC values, BIO-I, BIO-S, OBC-S, SF + V, and SF were better than OBC-I and NON. Fungicide significantly affected NDVI values on 6 of 9 rating dates and when comparing AUNPC values. On the 14 May rating date, None was significantly better than FZM. On the 30 May rating date, FZM-T was significantly better than FXD. On the 11 July rating date, FZM was significantly better than FXD and None. On the 7 August rating date, both 14d treatments were better than both threshold and None. On the 22 August rating date, FZM was better than FXD and None. On the 5 September rating date, FZM was better than FXD-T and None. When comparing 2018 AUNPC values, FZM and FZM-T were significantly better than FXD and None. A fertilizer by fungicide interaction was observed on 3 of 9 rating dates in 2018 (Table 36). On the 27 June rating date, an interaction indicated that non-fertilized plots had lower NDVI values for FZM and

FXD-T sub-plot treatments than SF + V treatments. On the 11 July and 7 August rating dates, a significant interaction was detected, however, Tukey's honestly significant difference test showed no differences among treatments.

Root Area

In 2017, fertilizer factor affected root area on 2 of 2 rating dates (Table 37). In July, only samples taken from OBC-S had significantly greater root areas than NON and OBC-I, whereas all other treatments were statistically similar to both. In August, samples taken from BIO-I had greater root area than SF + V and NON, whereas all other treatments were statistically similar to both. No effect from fungicide factor was detected on either sampling date. On the August sampling date, a fertilizer x fungicide interaction was detected, however, Tukey's honestly significant difference test showed no differences among treatments (Table 38).

In 2018, fertilizer factor affected root area on 2 of 2 rating dates, while fungicide affected root area on 1 of 2 rating dates (Table 39). In August, samples taken from NON had significantly greater root area than BIO-I or BIO-S samples, whereas all other treatments were statistically similar to both. Fungicide had no effect on August 2018 samples. On the September 2018 sampling, a significant fertilizer effect was detected but Tukey's honestly significant difference test showed no differences among treatments. A fungicide effect was detected in the same month, wherein samples treated with FXD had greater root areas than None and all other treatments were statistically similar to both.

Linear regression analysis was used to calculate correlation (r) to determine the degree of association between root area and dollar spot incidence (Table 40). On

3 of 4 rating dates there was no significant correlation between root area and disease, indicating no relationship between the two variables. On 1 of 4 rating dates, there was a significant positive correlation between the two variables (r = 0.40).

Tissue Nitrogen Analysis

In 2017, fertilizer factor was significant for tissue N content on 2 of 2 sampling dates (Table 41). In July, the OBC-S treatment had significantly more N tissue content than OBC-I and NON, whereas all other treatments were statistically similar to both. In August, the OBC-I treatment had significantly more N tissue content than OBC-S and NON, whereas all other treatments were statistically similar to both.

In 2018, fertilizer factor was significant for tissue N content on 2 of 2 sampling dates (Table 41). On the July sampling date, a significant effect was detected, however, Tukey's honestly significant difference test showed no differences among treatments. On the September sampling date, only the BIO-I and BIO-S treatments had higher N tissue content than NON, while all other treatments were statistically similar to both.

Linear regression analysis was used to calculate correlation (r) to determine the degree of association between tissue nitrogen and dollar spot incidence (Table 42). On 1 of 4 rating dates there was no significant correlation between root area and disease, indicating no relationship between the two variables. On 3 of 4 rating dates, there were significant positive correlations between the two variables (r = 0.80, 0.44 and 0.54).

Discussion

The Smith-Kerns weather-based dollar spot warning system was used to estimate disease pressure during the trial period and found that dollar spot pressure differed by year (Figure 2) (Smith et al., 2018). In 2017, estimated risk was relatively low through the end of May before increasing gradually and remaining above the recommended action threshold of 20% until the end of August. In 2017, the total number of days above the action threshold was 93. In 2018, the estimated risk of dollar spot incidence was more sporadic and more severe than the previous year. High (> 50%) risk indices were observed on two occasions in May. Estimated risk continued to rise and fall sporadically until holding steadily above the action threshold from mid-July through the end of September. The total number of days recorded above the action threshold was 110.

Fertilizer Effect on Dollar Spot

Although year was significant in our analysis, an analysis of AUDPC values indicated significant interaction between treatments, which was consistent across both years. This interaction indicated that subplots not treated with fungicide positively amplified the relationship between fertilizer source and dollar spot incidence, while fungicides reduced dollar spot severity similarly across all fertilizer treatments. Therefore, fertilizer effect discussion will focus on the fertilizer x no fungicide interactions. In 2017 all fertilizer source treatments tested were effective at reducing dollar spot incidence compared to a non-treated control, while in 2018 organic biosolids compost treatments were less effective than biochar, vermicompost, and standard fertilizer treatments, while being statistically similar to non-treated. Reduced dollar spot suppression on plots treated with organic biosolids compost in the second year of the trial may have been due to diminished plant available N compared to other fertilizer sources. Slow N release characteristics are associated with organically composted wastes, which rely on mineralization from soil microbes to make N plant available (Turner and Hummel, 1992). The release characteristics of an organic N source can vary by parent material and maturity, but as a general rule, N availability from organic biosolids compost is estimated to fall within 10-15% in the first year after application and 5-7% in the second year after application (Hargreaves et al., 2008; Zhang et al., 2006). In contrast, the other fertilizer treatments evaluated in this trial utilized sulfur coated urea as the primary source of N, which is regarded to have a more controlled and sustained N release compared to compost (Turner and Hummel, 1992). Dollar spot incidence on turfgrass has been directly linked to plant N availability: turf lacking adequate N fertility is predisposed to increased infection from *Clarireedia* spp. (Davis and Dernoeden, 2002; Endo, 1996; Landschoot and McNitt, 1997; Watschke, 1995). Davis and Dernoeden (2002), reported that composted sewage sludge was not effective for the suppression of dollar spot compared to other sources of N. Our results showed positive reductions in the first year of incorporation, however, the organic biosolids compost we evaluated did not reduce disease compared to the non-treated in the second year of the trial.

Application methodology may have also contributed to the differences observed in 2018: the application interval for the standard fertilizer component of all other treatments (BIO-I, BIO-S, SF + V, SF) was more frequent than that of organic biosolids compost treatments (OBC-I, OBC-S) (4 vs 2 yr^{-1}). Currently, best management practices suggest applying N fertility at a light and frequent rate in order to maintain adequate levels of plant available N (Smiley et al., 2005; Vargas, 2005). Our results support current best management practices, although it is possible that increasing the frequency of compost topdressing applications would also improve dollar spot control to the level of other synthetic fertilizer treatments.

Fertilizer Effect on Fungicide Performance

In 2017, all fertilizer treatments reduced the total number of threshold fungicide sprays required to control dollar spot compared to the non-treated check (4 vs 7 respectively). Surprisingly, all treatments required the same general number of fungicide sprays (6-7) to control dollar spot in 2018. Multiple factors may have contributed to similarity of treatments in the second year, including N mineralization, annual bluegrass populations, and environmental pressures.

Nitrogen mineralization. Turfgrass quality in non-treated plots dramatically increased in year two of the trial. In 2017, symptoms of nutrient deficiency were readily apparent on non-fertilized turf. Non-fertilized turf quality was lower than fertilized turf on 10 of 10 rating dates and was below the level of acceptability (<6) on 9 of 10 rating dates (Table 29). Additionally, NDVI values were rated significantly lower than those of fertilized plots on 6 of 7 rating dates (Table 33). In 2018, an overall increase in turfgrass quality was observed in non-fertilized turf: non-fertilized turfgrass quality was as good as at least one other fertilizer treatment on 11 of 12 rating dates and was at or above the level of acceptability (≥6) on 5 of 12 rating dates. NDVI values for non-treated were similar to fertilized plots on 9 of 9 rating dates. This dramatic increase in turf quality and NDVI on non-fertilized plots in the second year of the trial may be due to increased plant available N from native soil organic matter mineralization. Soil temperature and moisture are known to have a significant effect on the rate of N mineralization from soil organic matter (Griffin, 2008). Elevated soil field capacity (55% vs 23% volumetric water content) has been reported to nearly double the expected level of N mineralization (Gilmour and Mauromoustakos, 2011). Though soil field capacity was not measured during the trial, precipitation totals were higher in 2018 than in 2017 (1152 vs 798 mm), increasing the likelihood that non-fertilized plots benefited from the provision of additional plant available N via mineralization.

Annual bluegrass presence. By the spring of 2017, it was apparent that annual bluegrass (*Poa annua* L.) had germinated along with creeping bentgrass in the trial area. While not quantified, observed visual differences indicated that non-fertilized check plots were infested to a greater degree than fertilized plots. Greater annual bluegrass encroachment in non-fertilized plots would not be surprising as fertilizer is commonly applied to turfgrass at establishment to promote turf vigor, density, and to minimize annual weed infestation (Christians et al., 2016; McCarty, 1999). Annual bluegrass is more susceptible to disease and may have increased the inoculum load for dollar spot in 2017 (Smiley et al., 2005). Herbicide applications targeting annual bluegrass were made, but appeared to be more effective late in 2017 and throughout 2018. Therefore, increased annual bluegrass populations in non-fertilized plots compared to fertilized plots likely contributed to the significant difference in AUDPC values and threshold treatment sprays in 2017.

Environment. The Smith-Kerns (2018) dollar spot prediction model indicated the overall risk of dollar spot was higher in the second year of the trial (Figure 10).

Although applications of N fertilizer are regarded as an effective cultural control for dollar spot, they are unlikely to provide acceptable disease control in the absence of a proper fungicide program, especially during prolonged periods of high disease pressure (Couch, 1995). While disease pressure was likely elevated due to higher precipitation in 2018, frequent precipitation events may have also impacted the residual efficacy of fungicides. It has been previously shown that increased frequency and intensity of rainfall can increase the amount of fungicide displaced from plant tissue, thereby decreasing fungicide effectiveness (Carroll et al., 1993; Carroll et al., 2001; Couch, 1985; Pigati et al., 2010). The suppressive effects of regular N fertilizer inputs may have been mitigated by elevated dollar spot pressure and fungicide degradation in 2018, helping to explain why fertilized treatments required the same amount of threshold sprays as non-treated the second year of the trial.

Conclusion

One of the primary purposes for this study was to compare dollar spot suppression from largely untested organic amendments. Turfgrass managers seeking to broaden their approach to integrated pest management stand to benefit from knowing if and how an organic amendment can be effectively used to control disease. Currently, the only fair comparison is to normalize N levels between treatments, which often requires the supplemental application of N; however, the results of this and similar studies indicate that frequent applications of N at moderate to high rates may mask the effects of organic amendments.

In the first year of this trial, all organic amendment treatments were successful in reducing dollar spot disease, but not different from a standard fertility treatment.

In the second year, organic biosolids compost treatments were less effective than biochar, vermicompost and standard fertility treatments. When N fertilizer sources are used as a cultural control for dollar spot, effectiveness appears to be conditional upon the consistency of N rate release from that product.

The long-term effects of organic amendment incorporation on dollar spot development are yet to be determined. The real test of whether organic amendments can provide enhanced disease suppression may come in subsequent years where no N is applied. It is also unclear whether the effect of these organic amendments would be more apparent if applied with lower rates of supplemental N. Future research utilizing this trial area may elucidate the long-term impact of organic amendments on dollar spot, independent of N fertility effects.

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Table 22. Phosphorus (P) and potassium (K) as applied in main plot treatments, 2017-2018.

	At Establishment (kg ha$^{-1)}$		Maintenance Applications (kg ha$^{-1)}$	
Treatment (level)	P	K	P	K
Fertilizer				
OBC-I[z]	411	0	0	78
BIO-I[y]	78	78	333	0
OBC-S[x]	0	0	44	78
BIO-S[w]	0	0	290	78
SF + V[v]	0	0	411	78
SF[u]	63	12	349	65
NON	-	-	-	-

[z] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[y] Biochar (BIO-I) was incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[x] Organic biosolids compost (OBC-S) surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[w] Biochar (BIO-S) surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[v] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018, vermicompost (V) applied every 14 d beginning 10 May 2017 and 18 May 2018.

[u] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018.

Table 23. Influence of fertilizer and fungicide applications on dollar spot disease caused by *Clarireedia* spp. on a '007' creeping bentgrass fairway, 2017.

	Evaluation date								
Treatment (level)	26 May	2 June	16 June	3 July	14 July	27 July	10 Aug	25 Aug	AUDPC[z]
Fertilizer	----------Infection centers per plot----------								
OBC-I[y]	26.8	18.5	1.0b[x]	5.0b	14.8ab	12.7bc	5.8ab	10.7ab	906b
BIO-I[w]	26.1	17.2	4.5ab	8.9b	15.4ab	4.3c	3.0b	6.5ab	814b
OBC-S[v]	35.2	27.0	2.6b	8.6b	19.1ab	18.7ab	9.2ab	12.1ab	1297b
BIO-S[u]	42.7	32.1	7.5ab	8.3b	14.5b	5.7c	3.2b	8.6ab	1089b
SF + V[t]	39.7	24.3	8.0ab	7.7b	13.0b	3.2c	2.2b	4.6b	896b
SF[s]	30.4	16.8	2.7b	4.0b	12.7b	2.3c	2.7b	4.9b	653b
NON	35.7	33.2	12.3a	19.7a	24.1a	27.3a	14.9a	12.1ab	1955a
Fungicide[r]									
FZM	0.0b	13.9b	1.0b	0.7b	0.0b	0.4b	0.2b	0.0b	47b
FXD	0.1b	5.5b	1.8b	2.4b	0.3b	6.1b	0.8b	0.0b	213b
FZM-T	61.8a	14.3b	1.7b	2.6b	0.4b	1.2b	1.0b	0.1b	463b
FXD-T	51.8a	15.7b	2.1b	3.3b	0.3b	2.3b	1.6b	0.14b	481b
None	55.1a	83.7a	20.9a	35.4a	80.2a	43.0a	25.5a	45.4a	4233a
Source of variation									
Fertilizer	NS	NS	**	***	**	***	**	*	***
Fungicide	***	***	***	***	***	***	***	***	***
Fertilizer x Fungicide	NS	NS	***	***	***	***	***	***	***

[z] Area under disease progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[x] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[w] Biochar (BIO-I) incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[v] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017.

[u] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017.

[t] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and vermicompost (V) applied every 14 d beginning 10 May 2017.

[s] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017.

[r] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[*, **, ***, NS] refer to the 0.05, 0.01, 0.001 significance levels and non-significant, respectively.

Table 24. Fertilizer by fungicide treatment means for dollar spot disease caused by *Clarireedia* spp. on a ‘007’ creeping bentgrass fairway, 2017.

	Evaluation Date						
Treatment (level)	16 June	3 July	14 July	27 July	10 Aug.	25 Aug.	AUDPC[z]
Fertilizer x Fungicide[y]	---Infection centers per plot---						
OBC-I[x] x FZM	0.75c[w]	0.75d	0.00d	0.00c	0.00c	0.00d	21e
OBC-I x FXD	0.00c	0.50d	0.50d	1.00c	0.25c	0.00d	42e
OBC-I x FZM-T	0.00c	3.25d	0.00d	1.00c	0.00c	0.00d	295e
OBC-I x FXD-T	0.00c	2.00d	0.00d	0.25c	0.00c	0.00d	242e
OBC-I x None	4.25c	18.5bcd	73.50bc	61.00b	28.75bc	53.25abc	3931bc
BIO-I[v] x FZM	1.00c	0.50d	0.00d	0.00c	0.25c	0.00d	33e
BIO-I x FXD	2.75c	1.75d	0.25d	1.25c	0.00c	0.00d	89e
BIO-I x FZM-T	0.75c	0.75d	0.25d	0.00c	0.00c	0.00d	308e
BIO-I x FXD-T	2.75c	4.50d	0.00d	0.50c	0.75c	0.00d	369e
BIO-I x None	15.00bc	36.75b	76.50bc	19.50c	13.75bc	32.50bcd	3274bc
OBC-S[u] x FZM	0.25c	1.00d	0.00d	0.25c	0.75c	0.00d	76e
OBC-S x FXD	0.50c	1.75d	0.50d	26.50bc	0.50c	0.00d	689de
OBC-S x FZM-T	2.25c	4.25d	1.50d	4.25c	3.25c	0.25d	604de
OBC-S x FXD-T	0.75c	2.75d	0.50d	2.25c	1.25c	0.25d	366e
OBC-S x None	9.25bc	33.00bc	93.00ab	60.25b	40.25ab	60.00ab	4748b
BIO-S[t] x FZM	3.00c	0.25d	0.00d	0.00c	0.00c	0.00d	56e
BIO-S x FXD	5.50c	0.50d	0.00d	0.50c	0.00c	0.00d	122e

[z] Area under disease progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[x] Organic biosolids compost (OBC-I) incorporated at 41000 $kg \cdot ha^{-1}$ into the top 8 cm of the rootzone on 16 October 2016.

[w] Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

[v] Biochar (BIO-I) incorporated at 3900 $kg \cdot ha^{-1}$ into the top 8 cm of the rootzone on 16 October 2016.

[u] Organic biosolids compost (OBC-S) surface applied at 10250 $kg \cdot ha^{-1}$ on 4 May, 21 August 2017.

[t] Biochar (BIO-S) surface applied at 975 $kg \cdot ha^{-1}$ on 4 May, 21 August 2017.

Table 24 (cont'd). Fertilizer by fungicide treatment means for dollar spot disease caused by *Clarireedia* spp. on a '007' creeping bentgrass fairway, 2017.

	Evaluation date						
Treatment (level)	16 June	3 July	14 July	27 July	10 Aug.	25 Aug.	AUDPC[z]
Fertilizer x Fungicide[y]	Infection centers per plot						
BIO-S[x] x FZM-T	0.75c[w]	1.00d	0.25d	0.50c	0.25c	0.00d	438e
BIO-S x FXD-T	7.00c	4.25d	0.00d	1.75c	0.50c	0.00d	853de
BIO-S x None	21.25bc	35.25b	72.00bc	25.75bc	15.00bc	43.00bc	3973bc
SF + V[w] x FZM	0.50c	0.25d	0.00d	0.25c	0.00c	0.00d	22e
SF + V x FXD	2.50c	2.00d	0.00d	0.25c	0.25c	0.00d	87e
SF + V x FZM-T	1.25c	0.75d	0.00d	0.25c	0.25c	0.00d	459e
SF + V x FXD-T	1.00c	2.25d	0.75d	0.00c	2.75c	0.00d	415e
SF + V x None	34.5ab	33.25b	64.00c	15.00c	7.50c	22.75cd	3498bc
SF[v] x FZM	1.25c	0.00d	0.00d	0.00c	0.25c	0.00d	29e
SF x FXD	1.25c	1.5d	0.25d	0.00c	0.00c	0.00d	55e
SF x FZM-T	1.50c	3.25d	0.25d	0.00c	0.50c	0.00d	411e
SF x FXD-T	1.00c	3.00d	0.00d	0.00c	3.50c	0.25d	352e
SF x None	8.25c	12.25bcd	63.00c	11.5c	9.25bc	24.00cd	2420cd
NON x FZM	0.25c	2.25d	0.00d	2.00c	0.25c	0.25d	91e
NON x FXD	0.00c	8.50cd	0.25d	13.00c	4.50c	0.00d	408e
NON x FZM-T	5.50c	4.75d	0.50d	2.50c	2.50c	0.25d	724de
NON x FXD-T	2.00c	4.50d	0.50d	11.25c	2.75c	0.50d	768de
NON x None	53.75a	78.50a	119.25a	107.75a	64.25a	82.25a	7786a

[z] Area under disease progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[x] Biochar (BIO-S) surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017.

[w] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and vermicompost (V) applied every 14 d beginning 10 May 2017.

[v] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017.

Table 25. Influence of fertilizer and fungicide applications on dollar spot disease caused by Clarireedia Spp. on a ‘007’ creeping bentgrass fairway, 2018.

	Evaluation date												
Treatment (level)	14 May	30 May	13 Jun	27 Jun	11 Jul	25 Jul	7 Aug	22 Aug	5 Sep	19 Sep	3 Oct	17 Oct	AUDPC[z]
Fertilizer	------------Infection centers per plot------------												
OBC-I[y]	2.9a[x]	12.4a	3.4	20.7a	0.6	0.1	16.9a	12.4a	16.6	0.0	6.7	10.1	1339a
BIO-I[w]	1.8ab	4.5ab	1.4	9.7bcd	1.0	0.0	2.6b	2.1cd	12.4	0.0	2.8	5.2	559c
OBC-S[v]	0.0b	2.1b	2.2	14.1abc	0.4	0.2	11.9ab	9.7abc	19.7	0.0	5.2	6.1	980abc
BIO-S[u]	0.8ab	5.1ab	2.0	6.8cd	1.5	0.1	3.5b	1.8d	5.0	0.0	2.3	6.1	441c
SF + V[t]	1.9ab	4.5ab	2.4	3.3d	0.5	0.0	3.9b	3.6bcd	11.5	0.0	2.1	6.3	503c
SF[s]	2.7a	6.1ab	2.8	9.7bcd	0.7	0.0	5.6b	5.8abcd	11.1	0.0	2.8	5.1	684bc
NON	2.2ab	12.1a	5.1	17.0ab	2.2	0.1	15.7a	11.0ab	13.6	0.0	4.7	8.1	1226ab
Fungicide[r]													
FZM	1.0c	6.4b	0.8b	0.4b	0.0b	0.0	0.0b	0.2b	0.2c	0.0	0.8b	2.1b	154b
FXD	1.0c	6.4b	1.3b	1.1b	0.0b	0.0	0.5b	17.2a	0.0c	0.0	3.0b	0.3b	439b
FZM-T	2.8a	2.5b	0.9b	4.0b	0.0b	0.1	3.7b	0.1b	14.7b	0.0	1.2b	0.3b	408b
FXD-T	2.3ab	4.0b	0.7b	2.0b	0.1b	0.0	6.1b	1.3b	6.1bc	0.0	1.2b	0.4b	327b
None	1.5bc	14.0a	10.0a	50.4a	4.7a	0.1	32.4a	14.3a	43.0a	0.0	12.6a	30.3a	2766a
Source of variation													
Fertilizer	**	**	NS	***	NS	NS	***	***	NS	NS	NS	NS	***
Fungicide	***	***	***	***	***	NS	***	***	***	NS	***	***	***
Fertilizer x Fungicide	NS	**	NS	***	NS	NS	***	***	**	NS	NS	NS	***

[z] Area under disease progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Organic biosolids compost (OBC-I) incorporated at 41000 $kg \cdot ha^{-1}$ into the top 8 cm of the rootzone on 16 October 2016.

[x] Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

[w] Biochar (BIO-I) incorporated at 3900 $kg \cdot ha^{-1}$ into the top 8 cm of the rootzone on 16 October 2016.

[v] Organic biosolids compost (OBC-S) surface applied at 10250 $kg \cdot ha^{-1}$ on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[u] Biochar (BIO-S) surface applied at 975 $kg \cdot ha^{-1}$ on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[t] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018, vermicompost (V) applied every 14 d beginning 10 May 2017 and 18 May 2018.

[s] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018.

[r] 14 d fungicide treatments were applied beginning 14 May and ending 17 October. Threshold treatments were initiated on 14 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[**, ***, NS] refer to the 0.01, 0.001 significance levels and non-significant, respectively.

Table 26. Fertilizer by fungicide treatment means for dollar spot disease caused by *Clarireedia* spp. on a '007' creeping bentgrass fairway, 2018.

	Evaluation date					
Treatment (level)	30 May	27 June	7 Aug	22 Aug	5 Sep	AUDPC[z]
Fertilizer x Fungicide[y]	----------------------------------Infection centers per plot----------------------------------					
OBC-I[x] x FZM	12.25a-e[w]	0.00f	0.00b	0.25e	0.50d	246cd
OBC-I x FXD	19.00abc	4.25f	0.50b	30.50ab	0.00d	1000bcd
OBC-I x FZM-T	4.50b-e	3.00f	8.50b	0.00e	20.25cd	568cd
OBC-I x FXD-T	7.75a-e	1.75f	15.00b	4.25de	0.00d	482cd
OBC-I x None	18.50a-d	94.5a	60.25a	27.00abc	62.00ab	4398a
BIO-I[v] x FZM	4.25b-e	0.00f	0.00b	0.50e	0.00d	114cd
BIO-I x FXD	1.25de	0.25f	1.50b	9.00cde	0.00d	216cd
BIO-I x FZM-T	1.50cde	16.00ef	2.75b	0.00e	10.75d	506cd
BIO-I x FXD-T	2.25cde	7.25ef	2.50b	0.75e	21.25cd	516cd
BIO-I x None	13.25a-e	24.75def	6.00b	0.25e	29.75bcd	1444bcd
OBC-S[u] x FZM	1.00de	1.00f	0.25b	0.25e	0.00d	56d
OBC-S x FXD	1.25de	0.75f	0.50b	9.00cde	0.25d	192cd
OBC-S x FZM-T	2.75b-e	1.25f	0.00b	0.00e	21.75cd	401cd
OBC-S x FXD-T	4.50b-e	2.25f	0.00b	0.00e	2.00d	164cd
OBC-S x None	1.00de	65.25bc	58.75a	39.25a	74.50a	4087a
BIO-S[t] x FZM	4.25b-e	0.25f	0.00b	0.00e	0.00d	137cd
BIO-S x FXD	4.00b-e	0.25f	0.50b	4.50de	0.00d	190cd

[z] Area under disease progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] FZM, FXD applied beginning 14 May and ending 17 October. Threshold treatments were initiated on 14 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[x] Organic biosolids compost (OBC-I) was incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[v] Biochar (BIO-I) was incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[u] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[t] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

Table 26 (cont'd). Fertilizer by fungicide treatment means for dollar spot disease caused by Clarireedia spp. on a '007' creeping bentgrass fairway, 2018.

	Evaluation date					
Treatment (level)	30 May	27 June	7 Aug	22 Aug	5 Sep	AUDPC[z]
Fertilizer x Fungicide[y]	--------------------------------Infection centers per plot--------------------------------					
BIO-S[x] x FZM-T	1.00de[w]	0.50f	7.75b	0.00e	5.50d	239cd
BIO-S x FXD-T	3.50b-e	0.25f	1.00b	0.75e	0.25d	115cd
BIO-S x None	12.75a-e	32.50de	8.25b	3.50de	19.00cd	1523bc
SF[w] + V x FZM	3.25b-e	0.75f	0.00b	0.25e	0.25d	140cd
SF + V x FXD	1.75cde	0.50f	0.25b	13.00b-e	0.00d	307cd
SF + V x FZM-T	4.00b-e	1.00f	2.50b	0.00e	9.00d	282cd
SF + V x FXD-T	3.75b-e	0.00f	1.50b	1.25e	17.50cd	383cd
SF + V x None	9.50a-e	14.25ef	15.25b	3.50de	30.50bcd	1405bcd
SF[v] x FZM	3.00b-e	0.25f	0.00b	0.00e	0.25d	78cd
SF x FXD	2.00cde	0.75f	0.00b	21.50a-d	0.00d	376cd
SF x FZM-T	0.50e	5.50f	4.00b	1.00e	19.50cd	480cd
SF x FXD-T	2.00cde	0.00f	6.50b	1.75e	2.00d	222cd
SF x None	23.00a	42.00cd	17.25b	4.75de	33.75bcd	2264b
NON x FZM	17.00a-e	0.25f	0.00b	0.25e	0.25d	305cd
NON x FXD	15.75a-e	1.25f	0.50b	33.00a	0.00d	794cd
NON x FZM-T	3.00cde	1.00f	0.50b	0.00e	16.25cd	377cd
NON x FXD-T	4.25b-e	2.75f	16.25b	0.25e	0.00d	409cd
NON x None	20.25ab	79.75ab	61.25a	21.75a-d	51.50abc	4243a

[z] Area under disease progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] FZM, FXD applied beginning 14 May and ending 17 October. FZM-T, FXD-T initiated on 14 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[x] Biochar (BIO-S) surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[w] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018, vermicompost (V) applied every 14 d beginning 10 May 2017 and 18 May 2018.

[v] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018.

Table 27. Fertilizer effect on threshold fungicide applications for dollar spot disease caused by Clarireedia Spp. on a '007' creeping bentgrass fairway, 2017.

Treatment (level)	Total Sprays	Enhanced efficacy days[z]
Fluazinam[y]		
OBC-I[x]	5	41
BIO-I[w]	4	56
OBC-S[v]	5	42
BIO-S[u]	4	56
SF + V[t]	4	56
SF[s]	4	56
NON	7	22
Fluxapyroxad[r]		
OBC-I	4	56
BIO-I	4	56
OBC-S	5	42
BIO-S	5	43
SF + V	4	56
SF	4	56
NON	7	17

[z] Sum of the number of days where treatment remained disease free, 14 d after a threshold spray application was made, 2017

[y] Treatment applied at 0.8 kg a.i. ha^{-1} when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[x] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[w] Biochar (BIO-I) incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[v] Organic biosolids compost (OBC-S) surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017.

[u] Biochar (BIO-S) surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017.

[t] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017, vermicompost (V) applied every 14 d beginning 10 May 2017.

[s] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017.

[r] Treatment applied at 0.15 kg a.i. ha^{-1} rate when > 2 infection centers were counted on 2 of 4 replicates, respectively.

Table 28. Fertilizer effect on threshold fungicide applications for dollar spot disease caused by Clarireedia Spp. on a ‘007’ creeping bentgrass fairway, 2018.

Treatment (level)	Total Sprays	Enhanced efficacy days[z]
Fluazinam[y]		
OBC-I[x]	7	56
BIO-I[w]	7	58
OBC-S[v]	7	48
BIO-S[u]	7	59
SF + V[t]	7	55
SF[s]	6	69
NON	7	54
Fluxapyroxad[r]		
OBC-I	6	67
BIO-I	6	71
OBC-S	5	76
BIO-S	6	68
SF + V	6	67
SF	6	75
NON	6	70

[z] Sum of the number of days where treatment remained disease free, 14 d after a threshold spray application was made, 2017

[y] Treatment applied at 0.8 kg a.i. ha^{-1} when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[x] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[w] Biochar (BIO-I) incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[v] Organic biosolids compost (OBC-S) surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[u] Biochar (BIO-S) surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[t] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 4 May 2018, vermicompost (V) applied every 14 d beginning 10 May 2017 and 18 May 2018.

[s] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018.

[r] Treatment applied at 0.15 kg a.i. ha^{-1} rate when > 2 infection centers were counted on 2 of 4 replicates, respectively.

Table 29. Influence of fertilizer and fungicide applications on turfgrass quality a ‘007’ creeping bentgrass fairway, 2016-2017.

	Evaluation date						
	2016		2017				
Treatment (level)	31 Oct	11 Nov	27 Apr	16 May	26 May	2 June	16 June
Fertilizer	----------Turfgrass quality[z]----------						
OBC-I[y]	2.5c[x]	3.3b	6.5a	5.1ab	5.3a	5.9a	5.9a
BIO-I[w]	4.4a	4.4a	4.3b	5.1ab	4.9a	5.3a	6.1a
OBC-S[v]	4.5a	4.5a	4.4b	5.5a	5.3a	6.0a	5.9a
BIO-S[u]	4.5a	4.5a	4.3b	5.0b	4.8a	5.2a	5.8a
SF + V[t]	4.5a	4.5a	4.1b	5.0b	4.9a	5.5a	6.1a
SF[s]	4.5a	4.5a	4.5b	5.0b	4.9a	5.4a	6.2a
NON	4.0b	4.3a	3.4c	3.5c	3.1b	3.8b	3.9b
Fungicide[r]							
FZM	4.2	4.3	4.5	4.9	5.0a	5.7a	5.9a
FXD	4.2	4.3	4.5	4.9	5.0a	5.5ab	5.7a
FZM-T	4.2	4.3	4.5	4.9	4.6b	5.4b	5.8a
FXD-T	4.2	4.3	4.5	4.9	4.5b	5.3b	5.7a
None	4.2	4.3	4.5	4.9	4.6b	4.6c	5.3b
Source of variation							
Fertilizer	***	***	***	***	***	***	***
Fungicide	NS	NS	NS	NS	***	***	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	*	NS

[z] Quality ratings based on 1–9 scale (incorporates turfgrass color, density, uniformity, and disease percent) where 6 represented the minimum acceptable turf quality and 9 represented the best.

[y] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[x] Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

[w] Biochar (BIO-I) incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[v] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017.

[u] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017.

[t] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and vermicompost (V) applied every 14 d beginning 10 May 2017.

[s] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017.

[r] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[*, ***, NS] refer to the 0.05, 0.001 significance levels and non-significant, respectively.

Table 29 (cont'd). Influence of fertilizer and fungicide applications on turfgrass quality a '007' creeping bentgrass fairway, 2017.

	Evaluation date					
Treatment (level)	3 July	14 July	27 July	10 Aug.	25 Aug.	AUQPC[z]
Fertilizer	-----------------------Turfgrass quality[y]-----------------------					
OBC-I[x]	6.2ab[w]	6.8a	7.1a	7.5a	7.4a	1628a
BIO-I[v]	6.4a	6.5abc	7.3a	7.4ab	7.2a	1528ab
OBC-S[u]	5.8b	6.1c	6.3b	7.0b	7.1a	1527b
BIO-S[t]	6.0ab	6.3bc	7.2a	7.5ab	7.2a	1543ab
SF + V[s]	6.2ab	6.6ab	7.4a	7.3ab	7.2a	1525b
SF[r]	6.3ab	6.6abc	7.4a	7.3ab	7.3a	1560ab
NON	4.1c	4.6d	4.9c	5.8c	6.2b	1226c
Fungicide[q]						
FZM	6.3a	6.8a	7.5a	7.7a	7.7a	15493a
FXD	6.0b	6.5b	7.3a	7.6a	7.7a	1533a
FZM-T	6.0b	6.6ab	7.2a	7.6a	7.5a	1528a
FXD-T	5.9b	6.5b	7.2a	7.5a	7.7a	1524a
None	5.2c	4.6c	4.9b	5.0b	4.7b	1393b
Source of variation						
Fertilizer	***	***	***	***	***	***
Fungicide	***	***	***	***	***	***
Fertilizer x Fungicide	NS	NS	NS	NS	NS	NS

[z] Area under quality progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Quality ratings based on 1–9 scale (incorporates turfgrass color, density, uniformity, and disease percent) where 6 represented the minimum acceptable turf quality and 9 represented the best.

[x] Organic biosolids compost (OBC-I) incorporated at 41000 $kg{\cdot}ha^{-1}$ into the top 8 cm of the rootzone on 16 October 2016.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[v] Biochar (BIO-I) incorporated at 3900 $kg{\cdot}ha^{-1}$ into the top 8 cm of the rootzone on 16 October 2016.

[u] Organic biosolids compost (OBC-S) was surface applied at 10250 $kg{\cdot}ha^{-1}$ on 4 May, 21 August 2017.

[t] Biochar (BIO-S) was surface applied at 975 $kg{\cdot}ha^{-1}$ on 4 May, 21 August 2017.

[s] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and vermicompost (V) applied every 14 d beginning 10 May 2017.

[r] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017.

[q] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[***,NS] refer to the 0.001 significance level and non-significant, respectively.

Table 30. Fertilizer by fungicide treatment means for turfgrass quality of a '007' creeping bentgrass fairway, 2017.

Treatment (level)	Evaluation date 2 June
Fertilizer x Fungicide[z]	---------------Turf quality[y]---------------
OBC-I[x] x FZM	6.25ab[w]
OBC-I x FXD	6.00a-e
OBC-I x FZM-T	6.00a-e
OBC-I x FXD-T	5.63a-g
OBC-I x None	5.38a-h
BIO-I[v] x FZM	5.63a-g
BIO-I x FXD	5.63a-g
BIO-I x FZM-T	5.38a-h
BIO-I x FXD-T	5.25a-i
BIO-I x None	4.63f-k
OBC-S[u] x FZM	6.38ab
OBC-S x FXD	5.88a-f
OBC-S x FZM-T	6.38ab
OBC-S x FXD-T	6.50a
OBC-S x None	4.88c-j
BIO-S[t] x FZM	5.38a-h
BIO-S x FXD	5.50a-h

[z] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[y] Quality ratings based on 1–9 scale (incorporates turfgrass color, density, uniformity, and disease percent) where 6 represented the minimum acceptable turf quality and 9 represented the best.

[x] Organic biosolids compost (OBC-I) was incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[v] Biochar (BIO-I) was incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[u] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017.

[t] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017.

Table 30 (cont'd). Fertilizer by fungicide treatment means for turfgrass quality of a '007' creeping bentgrass fairway, 2017.

	Evaluation date
Treatment (level)	2 June
Fertilizer x Fungicide[z]	---------------Turf quality[y]---------------
BIO-S[x] x FZM-T	5.38a-h[w]
BIO-S x FXD-T	5.13bii
BIO-S x None	4.38g-l
SF[v] + V x FZM	6.00a-d
SF + V x FXD	5.88a-f
SF + V x FZM-T	5.50a-h
SF + V x FXD-T	5.38a-h
SF + V x None	4.75e-j
SF[u] x FZM	6.00a-e
SF x FXD	5.50a-h
SF x FZM-T	5.38a-h
SF x FXD-T	5.50a-h
SF x None	4.75d-j
NON x FZM	4.25h-l
NON x FXD	4.00ijk
NON x FZM-T	3.63jk
NON x FXD-T	3.75jk
NON x None	3.38k

[z] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[y] Quality ratings based on 1–9 scale (incorporates turfgrass color, density, uniformity, and disease percent) where 6 represented the minimum acceptable turf quality and 9 represented the best.

[x] Biochar (BIO-S) surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[v] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018, vermicompost (V) applied every 14 d beginning 10 May 2017 and .

[u] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017.

Table 31. Influence of fertilizer and fungicide applications on turfgrass quality a '007' creeping bentgrass fairway, 2018.

	Evaluation date												
Treatment (level)	14 May	30 May	13 Jun	27 Jun	11 Jul	25 Jul	7 Aug	22 Aug	5 Sep	19 Sep	3 Oct	17 Oct	AUQPC[z]
Fertilizer	Turfgrass quality[y]												
OBC-I[x]	6.1c[w]	5.9b	6.7bc	6.6b	6.3bc	6.8bc	6.1bc	6.0c	6.0ab	6.0b	5.8b	6.4a	956b
BIO-I[v]	7.0b	6.2b	6.8ab	7.3a	6.9a	7.3ab	7.0a	6.4ab	6.3a	6.2b	6.4ab	6.8a	1038a
OBC-S[u]	8.0a	7.2a	7.2a	6.6b	6.7ab	7.2ab	6.9a	6.6a	6.2a	6.7a	6.3ab	6.8a	1058a
BIO-S[t]	7.0b	5.9b	6.7abc	7.2a	6.7ab	7.3ab	6.9a	6.5ab	6.5a	6.3ab	6.6a	6.9a	1036a
SF + V[s]	7.0b	6.3b	6.8ab	7.4a	7.0a	7.3ab	6.6ab	6.1bc	6.3a	6.2b	6.3ab	6.7a	1027a
SF[r]	7.0b	6.2b	6.7abc	7.3a	6.8ab	7.5a	6.5ab	5.9c	6.1ab	6.0b	6.4ab	6.7a	1015a
NON	6.0c	5.9b	6.3c	5.9c	6.1c	6.5c	5.8c	5.7c	5.5b	6.0b	5.8b	6.3a	922b
Fungicide[q]													
FZM	6.9	6.3a	6.8a	7.0a	6.8a	7.2a	7.0ab	6.8a	6.8a	6.8a	6.5a	7.0a	1055a
FXD	6.9	6.2a	6.7ab	7.0a	6.5bc	7.2a	7.1a	5.9c	6.4b	6.7a	6.5ab	6.9a	1029b
FZM-T	6.9	6.4a	6.9a	7.0a	6.8a	7.1a	6.7bc	6.7ab	6.2b	6.6ab	6.4ab	6.9a	1038ab
FXD-T	6.8	6.3a	6.8a	7.0a	6.6ab	7.2a	6.6c	6.5b	6.2b	6.3b	6.3b	6.8a	1023b
None	6.9	5.8b	6.5b	6.0b	6.4c	6.9b	5.3d	4.9d	5.0c	4.9c	5.5c	5.6b	892c
Source of variation													
Fertilizer	***	***	***	***	***	***	***	***	***	***	**	*	***
Fungicide	NS	***	***	***	***	***	***	***	***	***	***	***	***
Fertilizer x Fungicide	NS	NS	NS	***	NS	NS	***	**	***	NS	NS	NS	**

[z] Area under quality progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Quality ratings based on 1–9 scale (incorporates turfgrass color, density, uniformity, and disease percent) where 6 represented the minimum acceptable turf quality and 9 represented the best.

[x] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[v] Biochar (BIO-I) incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[u] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[t] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[s] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and vermicompost (V) applied every 14 d beginning 10 May 2017 and 18 May 2018.

[r] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018.

[q] FZM, FXD applied beginning 14 May and ending 17 October. FZM-T, FXD-T initiated on 14 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

*, **, ***, NS refer to the 0.05, 0.01, 0.001 significance level and non-significant, respectively.

Table 32. Fertilizer by fungicide treatment means for turfgrass quality of a ‘007’ creeping bentgrass fairway, 2018.

	Evaluation date				
Treatment (level)	27 June	7 Aug	22 Aug	5 Sep	AUQPC^{z}
Fertilizer x Fungicide^{y}	--------------------------------Turfgrass quality^{x}------------------------------				
OBC-I^{w} x FZM	6.50efg^{v}	6.50a-g	6.75a-d	7.00ab	1003d-i
OBC-I x FXD	6.50efg	6.50a-g	5.50f-k	6.38a-e	970g-k
OBC-I x FZM-T	6.50efg	6.50a-g	6.75a-d	6.25a-e	994e-j
OBC-I x FXD-T	6.63b-g	6.13bh	6.13b-h	6.50a-d	976f-k
OBC-I x None	4.88j	5.00hi	4.75jk	4.00h	838lm
BIO-I^{u} x FZM	7.50a	7.38abc	6.88abc	6.88abc	1080a-d
BIO-I x FXD	7.50a	7.50a	6.35a-g	6.38a-e	1065a-e
BIO-I x FZM-T	7.38abd	7.13a-d	6.75a-d	6.50a-d	1067a-e
BIO-I x FXD-T	7.25a-e	7.00a-e	6.50a-f	5.60def	1028a-h
BIO-I x None	6.63c-h	5.88e-i	5.50f-k	6.10a-f	948ijk
OBC-S^{t} x FZM	6.88a-f	7.38abc	7.25a	7.00ab	1112a
OBC-S x FXD	6.75a-g	7.38abc	6.35a-g	6.63a-d	1073a-e
OBC-S x FZM-T	6.88a-f	7.50a	7.25a	6.50a-d	1103ab
OBC-S x FXD-T	6.88a-f	7.50a	7.13ab	6.63a-d	1093abc
OBC-S x None	5.63ij	4.88hi	4.88ijk	4.25gh	911jkl
BIO-S^{s} x FZM	7.38abc	7.50a	6.88abc	7.00a	1073a-e
BIO-S x FXD	7.25a-e	7.38abc	6.10c-h	6.63a-d	1043a-g

^{z}Area under quality progress curve, generated using the trapezoidal method (Madden et al. 2007).

^{y}FZM, FXD applied beginning 14 May and ending 17 October. FZM-T, FXD-T initiated on 14 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

^{x}Quality ratings based on 1–9 scale (incorporates turfgrass color, density, uniformity, and disease percent) where 6 represented the minimum acceptable turf quality and 9 represented the best.

^{w}Organic biosolids compost (OBC-I) was incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

^{v}Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

^{u}Biochar (BIO-I) was incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

^{t}Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

^{s}Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

Table 32 (cont'd). Fertilizer by fungicide treatment means for turfgrass quality of a '007' creeping bentgrass fairway, 2018.

	Evaluation date				
Treatment (level)	27 June	7 Aug	22 Aug	5 Sep	AUQPC[a]
Fertilizer x Fungicide[y]	--------------------------------Turfgrass quality[x]-------------------------------				
BIO-S[w] x FZM-T	7.38abc[v]	6.88a-e	7.00abc	6.48a-d	1058a-f
BIO-S x FXD-T	7.38abc	7.00a-e	6.88abc	6.75a-d	1067a-e
BIO-S x None	6.63d-h	5.88d-i	5.38g-k	5.83b-f	941ijk
SF + V[u] x FZM	7.50a	6.75a-f	6.63a-e	6.75a-d	1073a-e
SF + V x FXD	7.50a	7.50a	5.63e-j	6.75a-d	1057a-f
SF + V x FZM-T	7.50a	7.00a-e	6.88abc	6.63a-d	1081a-d
SF + V x FXD-T	7.50a	6.0d-h	6.23b-h	5.85a-f	1015c-i
SF + V x None	7.13a-e	5.50ghi	4.88ijk	5.25efg	908kl
SF[t] x FZM	7.38a-d	7.38ab	7.00abc	6.88abc	1082a-d
SF x FXD	7.50a	7.50a	5.85d-i	6.38a-e	1060a-f
SF x FZM-T	7.38a-d	6.00d-h	6.10c-h	5.60def	1016c-i
SF x FXD-T	7.50a	6.13c-h	6.13b-h	6.38a-e	1022b-i
SF x None	6.50efg	5.50f-i	4.63jk	5.0fgh	897kl
NON x FZM	6.13fgi	6.13b-h	6.23b-h	6.00a-f	964g-k
NON x FXD	6.13fgi	6.13b-h	5.25h-k	5.88a-f	937ijk
NON x FZM-T	6.00gi	6.13b-h	6.00c-h	5.73c-f	949h-k
NON x FXD-T	6.13fgi	6.13b-h	6.38a-g	6.00a-f	957h-k
NON x None	4.88j	4.63i	4.50k	3.88h	803m

[z] Area under quality progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] FZM, FXD applied beginning 14 May and ending 17 October. FZM-T, FXD-T initiated on 14 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[x] Quality ratings based on 1–9 scale (incorporates turfgrass color, density, uniformity, and disease percent) where 6 represented the minimum acceptable turf quality and 9 represented the best.

[w] Biochar (BIO-S) surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[v] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[u] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018, vermicompost (V) applied every 14 d beginning 10 May 2017 and 18 May 2018.

[t] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018.

Table 33. Influence of fertilizer and fungicide applications on NDVI of a ‘007’ creeping bentgrass fairway, 2017.

	Evaluation date							
Treatment (level)	26 May	2 June	16 June	3 July	27 July	10 Aug.	25 Aug.	AUNPC[z]
Fertilizer	----------------------------Normalized difference vegetation index[y]----------------------------							
OBC-I[x]	0.84a[w]	0.84a	0.83a	0.85ab	0.88b	0.88a	0.86	237a
BIO-I[v]	0.84a	0.82ab	0.83a	0.86a	0.89ab	0.87a	0.86	240a
OBC-S[u]	0.85a	0.83ab	0.81b	0.83b	0.87c	0.88a	0.85	237a
BIO-S[t]	0.83a	0.79b	0.83a	0.85ab	0.88ab	0.88a	0.86	238a
SF + V[s]	0.83a	0.82ab	0.84a	0.86a	0.89ab	0.88a	0.86	242a
SF[r]	0.84a	0.83ab	0.84a	0.86a	0.89a	0.87a	0.85	241a
NON	0.74b	0.73c	0.74c	0.78c	0.84d	0.86b	0.85	228b
Fungicide[q]								
FZM	0.84a	0.83a	0.83a	0.85a	0.89a	0.89a	0.87a	239a
FXD	0.83ab	0.81bc	0.81bc	0.84ab	0.89a	0.89a	0.87a	238b
FZM-T	0.82bc	0.81b	0.82ab	0.84ab	0.88a	0.88a	0.87a	238b
FXD-T	0.81c	0.81bc	0.82ab	0.84ab	0.89a	0.88a	0.86a	238b
None	0.82bc	0.79c	0.80c	0.83b	0.84b	0.83b	0.81b	235c
Source of variation								
Fertilizer	***	***	***	***	***	***	NS	***
Fungicide	***	***	***	**	***	***	***	***
Fertilizer x Fungicide	NS	NS	NS	NS	**	NS	NS	*

[z] Area under NDVI progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[x] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[w] Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

[v] Biochar (BIO-I) incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[u] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017.

[t] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017.

[s] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and vermicompost (V) applied every 14 d beginning 10 May 2017.

[r] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017.

[q] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

*, **, ***, NS refer to the 0.05, 0.01, 0.001 significance level and non-significant, respectively.

Table 34. Fertilizer by fungicide treatment means for NDVI of a ‘007’ creeping bentgrass fairway, 2017.

	Evaluation date	
Treatment (level)	27 July	AUNPC[z]
Fertilizer x Fungicide[y]	Normalized difference vegetation index[x]	
OBC-I[w] x FZM	0.89abc[v]	238.50a-g
OBC-I x FXD	0.89a-d	237.68a-i
OBC-I x FZM-T	0.89a-d	236.98a-i
OBC-I x FXD-T	0.89a-d	237.56a-i
OBC-I x None	0.85fg	234.89dhi
BIO-I[u] x FZM	0.90ab	241.24a-e
BIO-I x FXD	0.90ab	240.34a-f
BIO-I x FZM-T	0.90ab	240.15a-f
BIO-I x FXD-T	0.90ab	240.38a-f
BIO-I x None	0.85efg	236.72b-i
OBC-S[t] x FZM	0.87a-g	237.69a-i
OBC-S x FXD	0.88a-f	237.85a-i
OBC-S x FZM-T	0.87b-g	237.48a-i
OBC-S x FXD-T	0.88a-g	237.63a-i
OBC-S x None	0.84g	235.44a-i
BIO-S[s] x FZM	0.90ab	239.04a-g
BIO-S x FXD	0.90ab	238.45a-g

[z] Area under NDVI progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[x] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[w] Organic biosolids compost (OBC-I) incorporated at 41000 $kg\cdot ha^{-1}$ into the top 8 cm of the rootzone on 16 October 2016.

[v] Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

[u] Biochar (BIO-I) incorporated at 3900 $kg\cdot ha^{-1}$ into the top 8 cm of the rootzone on 16 October 2016.

[t] Organic biosolids compost (OBC-S) was surface applied at 10250 $kg\cdot ha^{-1}$ on 4 May, 21 August 2017.

[s] Biochar (BIO-S) was surface applied at 975 $kg\cdot ha^{-1}$ on 4 May, 21 August 2017.

Table 34 (Cont'd). Fertilizer by fungicide treatment means for NDVI of a '007' creeping bentgrass fairway, 2017.

	Evaluation date	
Treatment (level)	27 July	AUNPC^{z}
Fertilizer x Fungicide^{y}	Normalized difference vegetation index^{x}	
BIO-S^{w} x FZM-T	0.89a-e^{v}	238.42a-g
BIO-S x FXD-T	0.89ad	238.06a-i
BIO-S x None	0.85d-g	235.97c-i
SF + V^{u} x FZM	0.90ab	242.83a-d
SF + V x FXD	0.90a	242.4a-d
SF + V x FZM-T	0.90ab	242.32a-d
SF + V x FXD-T	0.90ab	241.35a-e
SF + V x None	0.86c-g	239.03e-h
SF^{t} x FZM	0.90ab	241.75a-e
SF x FXD	0.90ab	241.54a-e
SF x FZM-T	0.90ab	241.37a-e
SF x FXD-T	0.90ab	241.41a-e
SF x None	0.87a-g	240.03a-f
NON x FZM	0.87b-g	230.78fgh
NON x FXD	0.85fg	227.85i
NON x FZM-T	0.86c-g	229.35ghi
NON x FXD-T	0.85d-g	228.89ghi
NON x None	0.77h	224.13j

[z] Area under NDVI progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[x] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[w] Biochar (BIO-S) surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017.

[v] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[u] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017, vermicompost (V) applied every 14 d beginning 10 May 2017.

[t] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017.

Table 35. Influence of fertilizer and fungicide applications on NDVI of a '007' creeping bentgrass fairway, 2018.

Treatment (level)	Evaluation date									
	14 May	30 May	13 Jun	27 Jun	11 Jul	25 Jul	7 Aug	22 Aug	5 Sep	AUNPC[z]
Fertilizer	------------------------------------Normalized difference vegetation index[y]------------------------------------									
OBC-I[x]	0.78c[w]	0.78ab	0.83a	0.86ab	0.82b	0.88	0.88ab	0.86	0.89	102.13b
BIO-I[v]	0.83b	0.80ab	0.85a	0.88a	0.85a	0.89	0.89ab	0.87	0.88	104.14a
OBC-S[u]	0.85a	0.81a	0.85a	0.86ab	0.83ab	0.89	0.89ab	0.86	0.88	103.70a
BIO-S[t]	0.83ab	0.77b	0.84a	0.88a	0.84a	0.89	0.89a	0.87	0.89	103.62a
SF + V[s]	0.84ab	0.80ab	0.85a	0.88a	0.85a	0.89	0.89ab	0.87	0.88	104.21a
SF[r]	0.83b	0.80ab	0.85a	0.88a	0.84a	0.89	0.89ab	0.87	0.88	103.71a
NON	0.78c	0.77b	0.83a	0.85b	0.82b	0.88	0.88b	0.86	0.89	101.77b
Fungicide[q]										
FZM	0.81b	0.79ab	0.84	0.87	0.84a	0.89	0.89a	0.87a	0.90a	103.78a
FXD	0.82ab	0.78b	0.84	0.87	0.83c	0.89	0.89a	0.86bc	0.89ab	103.19b
FZM-T	0.82ab	0.80a	0.84	0.87	0.84ab	0.89	0.88b	0.87ab	0.89ab	103.71a
FXD-T	0.82ab	0.79ab	0.84	0.87	0.83abc	0.88	0.88b	0.87ab	0.88b	103.32ab
None	0.83a	0.79ab	0.84	0.87	0.83bc	0.88	0.86c	0.86c	0.87c	102.63c
Source of variation										
Fertilizer	***	**	*	**	***	NS	*	NS	NS	***
Fungicide	*	*	NS	NS	***	NS	***	***	***	***
Fertilizer x Fungicide	NS	NS	NS	*	*	NS	**	NS	NS	NS

[z] Area under NDVI progress curve, generated using the trapezoidal method (Madden et al. 2007).

[y] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[x] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[w] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[v] Biochar (BIO-I) incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[u] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[t] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[s] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and vermicompost (V) applied every 14 d beginning 10 May 2017 and 18 May 2018.

[r] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018.

[q] FZM, FXD applied beginning 14 May and ending 17 October. FZM-T, FXD-T initiated on 14 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[*, **, ***, NS] refer to the 0.05, 0.01, 0.001 significance level and non-significant, respectively.

Table 36. Fertilizer by fungicide treatment means for NDVI of a ‘007’ creeping bentgrass fairway, 2018.

	Evaluation date		
Treatment (level)	27 June	11 Jul	7 Aug
Fertilizer x Fungicide[z]	---------------Normalized difference vegetation index[y]---------------		
OBC-I[x] x FZM	0.85bc[v]	0.82b-h	0.89a-f
OBC-I x FXD	0.86abc	0.81h	0.89a-f
OBC-I x FZM-T	0.87abc	0.82c-h	0.89a-f
OBC-I x FXD-T	0.86abc	0.81fgh	0.89a-f
OBC-I x None	0.85abc	0.82b-h	0.86fg
BIO-I[u] x FZM	0.89abc	0.86ab	0.90a
BIO-I x FXD	0.89abc	0.84a-h	0.90abc
BIO-I x FZM-T	0.88abc	0.85abc	0.88a-f
BIO-I x FXD-T	0.88abc	0.84a-g	0.89a-d
BIO-I x None	0.87abc	0.84a-h	0.87efg
OBC-S[t] x FZM	0.88abc	0.85a-f	0.89a-e
OBC-S x FXD	0.86abc	0.82e-h	0.89a-d
OBC-S x FZM-T	0.86abc	0.84a-g	0.89a-e
OBC-S x FXD-T	0.87abc	0.84a-h	0.90abc
OBC-S x None	0.86abc	0.83a-h	0.86fg
BIO-S[s] x FZM	0.88abc	0.85a-e	0.90abc
BIO-S x FXD	0.87abc	0.83a-h	0.9ab

[z] FZM, FXD applied beginning 14 May and ending 17 October. FZM-T, FXD-T initiated on 14 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[y] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[x] Organic biosolids compost (OBC-I) was incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[v] Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

[u] Biochar (BIO-I) was incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[t] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[s] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

Table 36 (Cont'd). Fertilizer by fungicide treatment means for NDVI of a '007' creeping bentgrass fairway, 2018.

	Evaluation date		
Treatment (level)	27 June	11 Jul	7 Aug
Fertilizer x Fungicide[z]	---------------Normalized difference vegetation index[y]--------------		
BIO-S[x] x FZM-T	0.89abc[v]	0.85a-e	0.89a-e
BIO-S x FXD-T	0.86abc	0.84a-g	0.89a-d
BIO-S x None	0.88abc	0.83a-h	0.87c-g
SF[u] + V x FZM	0.89a	0.85abc	0.9ab
SF + V x FXD	0.89abc	0.85a-f	0.91a
SF + V x FZM-T	0.87abc	0.86a	0.89a-f
SF + V x FXD-T	0.89ab	0.85a-d	0.88b-g
SF + V x None	0.88abc	0.84a-h	0.86fg
SF[t] x FZM	0.88abc	0.85abc	0.88a-f
SF x FXD	0.88abc	0.84a-h	0.9ab
SF x FZM-T	0.88abc	0.84a-g	0.87c-g
SF x FXD-T	0.89abc	0.85a-e	0.87c-g
SF x None	0.87abc	0.83a-h	0.87d-g
NON x FZM	0.85c	0.82e-h	0.89a-f
NON x FXD	0.85c	0.82e-h	0.88b-g
NON x FZM-T	0.85bc	0.81gh	0.88a-f
NON x FXD-T	0.85c	0.82d-h	0.87c-g
NON x None	0.86abc	0.83a-h	0.86g

[z] FZM, FXD applied beginning 14 May and ending 17 October. FZM-T, FXD-T initiated on 14 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[y] Calculated by measuring canopy reflectance and assigning an index value from -1.000 to 1.000, where 1.000 indicates greener color.

[x] Biochar (BIO-S) surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[v] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[u] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018, vermicompost (V) applied every 14 d beginning 10 May 2017 and 18 May 2018.

[t] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018.

Table 37. Influence of fertilizer and fungicide applications on roots of a ‘007’ creeping bentgrass fairway, 2017.

	Evaluation date	
Treatment (level)	6 June	11 July
Fertilizer	------------------------Root area (cm^2)	------------------------
OBC-I[z]	15.40b[y]	14.24ab
BIO-I[x]	20.48ab	18.34a
OBC-S[w]	20.87a	14.64ab
BIO-S[v]	20.07ab	13.59ab
SF + V[u]	20.63ab	11.77b
SF[t]	18.83ab	14.02ab
NON	15.40b	12.26b
Fungicide[s]		
FZM	20.20	12.91
FXD	19.65	13.61
FZM-T	20.43	15.30
FXD-T	19.05	15.09
None	18.13	13.70
Source of variation		
Fertilizer	*	**
Fungicide	NS	NS
Fertilizer x Fungicide	NS	*

[z] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[y] Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

[x] Biochar (BIO-I) incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[w] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017.

[v] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017.

[u] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and vermicompost (V) applied every 14 d beginning 10 May 2017.

[t] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017.

[s] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

$^{*,\ **,NS}$ refer to the 0.05, 0.01 significance level and non-significant, respectively.

Table 38. Fertilizer by fungicide treatment means for root area of a ‘007’ creeping bentgrass fairway, 2017.

	Evaluation date
Treatment (level)	11 July
Fertilizer x Fungicide[z]	---------------Root area (cm^2) ---------------
OBC-I[y] x FZM	8.68a[x]
OBC-I x FXD	12.94a
OBC-I x FZM-T	16.61a
OBC-I x FXD-T	14.50a
OBC-I x None	18.46a
BIO-I[w] x FZM	18.82a
BIO-I x FXD	17.58a
BIO-I x FZM-T	19.61a
BIO-I x FXD-T	16.43a
BIO-I x None	19.26a
OBC-S[v] x FZM	15.57a
OBC-S x FXD	17.68a
OBC-S x FZM-T	12.23a
OBC-S x FXD-T	16.63a
OBC-S x None	11.06a
BIO-S[t] x FZM	12.47a
BIO-S x FXD	12.40a

[z] FZM, FXD applied beginning 19 May and ending 25 August. FZM-T, FXD-T initiated on 26 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[y] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[x] Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

[w] Biochar (BIO-I) incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[v] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017.

[t] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017.

Table 38 (Cont'd). Fertilizer by fungicide treatment means for root area of a '007' creeping bentgrass fairway, 2017.

	Evaluation date
Treatment (level)	11 July
Fertilizer x Fungicide[z]	---------------Root area (cm^2) ---------------
BIO-S[y] x FZM-T	17.34a[x]
BIO-S x FXD	13.98a
BIO-S x None	11.75a
SF[w] + V x FZM	8.02a
SF + V x FXD	10.99a
SF + V x FZM-T	14.39a
SF + V x FXD	15.04a
SF + V x None	10.44a
SF[v] x FZM	12.98a
SF x FXD	14.82a
SF x FZM-T	16.22a
SF x FXD	13.19a
SF x None	12.88a
NON x FZM	13.83a
NON x FXD	8.88a
NON x FZM-T	10.67a
NON x FXD	15.87a
NON x None	12.08a

[z] FZM, FXD applied beginning 14 May and ending 17 October. FZM-T, FXD-T initiated on 14 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[y] Biochar (BIO-S) surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[x] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[w] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018, vermicompost (V) applied every 14 d beginning 10 May 2017 and 18 May 2018.

[v] Standard fertilizer (SF) surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018.

Table 39. Influence of fertilizer and fungicide applications on roots of a '007' creeping bentgrass fairway, 2018.

	Evaluation date	
Treatment (level)	7 August	4 September
Fertilizer	------------------------------Root area (cm^2) ------------------------------	
OBC-I[z]	14.70ab[y]	9.34a
BIO-I[x]	13.05b	8.32a
OBC-S[w]	14.44ab	8.28a
BIO-S[v]	12.95b	9.51a
SF + V[u]	15.13ab	10.51a
SF[t]	15.49ab	8.92a
NON	16.79a	11.79a
Fungicide[s]		
FZM	14.23	10.29ab
FXD	15.84	10.64a
FZM-T	14.43	9.64ab
FXD-T	14.31	8.79ab
None	14.44	8.27b
Source of variation		
Fertilizer	**	*
Fungicide	NS	*
Fertilizer x Fungicide	NS	NS

[z] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[y] Means followed by the same letter are not significantly different according to Tukey's HSD (0.05).

[x] Biochar (BIO-I) incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[w] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[v] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[u] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and vermicompost (V) applied every 14 d beginning 10 May 2017 and 18 May 2018.

[t] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018.

[s] FZM, FXD applied beginning 14 May and ending 17 October. FZM-T, FXD-T initiated on 14 May and reapplied when > 2 infection centers were counted on 2 of 4 replicates, respectively.

[*, **, NS] refer to the 0.05, 0.01 significance level and non-significant, respectively.

Table 40. Correlation (r) and levels of significance between dollar spot (AUDPC[z]) and root area (cm^2), 2017-2018.

Date	(r)[y]	Significance
2017		
6 June	0.02	NS
3 July	0.40	*
2018		
7 August	0.06	NS
4 September	0.21	NS

[z] Area under disease progress curve, generated using the trapezoidal method (Madden et al. 2007). Values generated from dollar spot incidence on rating date immediately before and after sample date.

[y] Correlation for disease ratings and root area generated from main plot + all sub-plot treatments, respectively.

[*, NS] refer to the 0.05 significance level, and non-significant respectively.

Table 41. Influence of fertilizer applications on tissue nitrogen content of a ‘007’ creeping bentgrass fairway, 2017-2018.

	Evaluation date			
	2017		2018	
Treatment (level)	19 July	17 August	9 July	7 September
Fertilizer	------------------------------------Tissue nitrogen (%) ------------------------------------			
OBC-I[z]	5.09b[y]	4.23a	3.47a	4.78ab
BIO-I[x]	5.62a	3.99ab	3.67a	4.91a
OBC-S[w]	4.18c	3.77b	3.68a	4.82ab
BIO-S[v]	5.31ab	4.05ab	3.79a	5.0a
SF + V[u]	5.59a	3.98ab	3.78a	4.84ab
SF[t]	5.53ab	4.06ab	3.75a	4.87ab
NON	4.18c	3.79b	3.48a	4.68b
Source of variation				
Fertilizer	***	**	*	**

[z] Organic biosolids compost (OBC-I) incorporated at 41000 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[y] Means followed by the same letter are not significantly different according to Tukey’s HSD (0.05).

[x] Biochar (BIO-I) incorporated at 3900 kg·ha^{-1} into the top 8 cm of the rootzone on 16 October 2016.

[w] Organic biosolids compost (OBC-S) was surface applied at 10250 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[v] Biochar (BIO-S) was surface applied at 975 kg·ha^{-1} on 4 May, 21 August 2017 and 4 May, 7 September 2018.

[u] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and vermicompost (V) applied every 14 d beginning 10 May 2017 and 18 May 2018.

[t] Standard fertilizer (SF) was surface applied at 46 kg N ha^{-1} every 28 d beginning 4 May 2017 and 4 May 2018.

*, **, *** refer to the 0.05, 0.01, 0.001 significance level, respectively.

Table 42. Correlation (r) and levels of significance between dollar spot (AUDPC^z) and tissue nitrogen (%), 2017-2018.

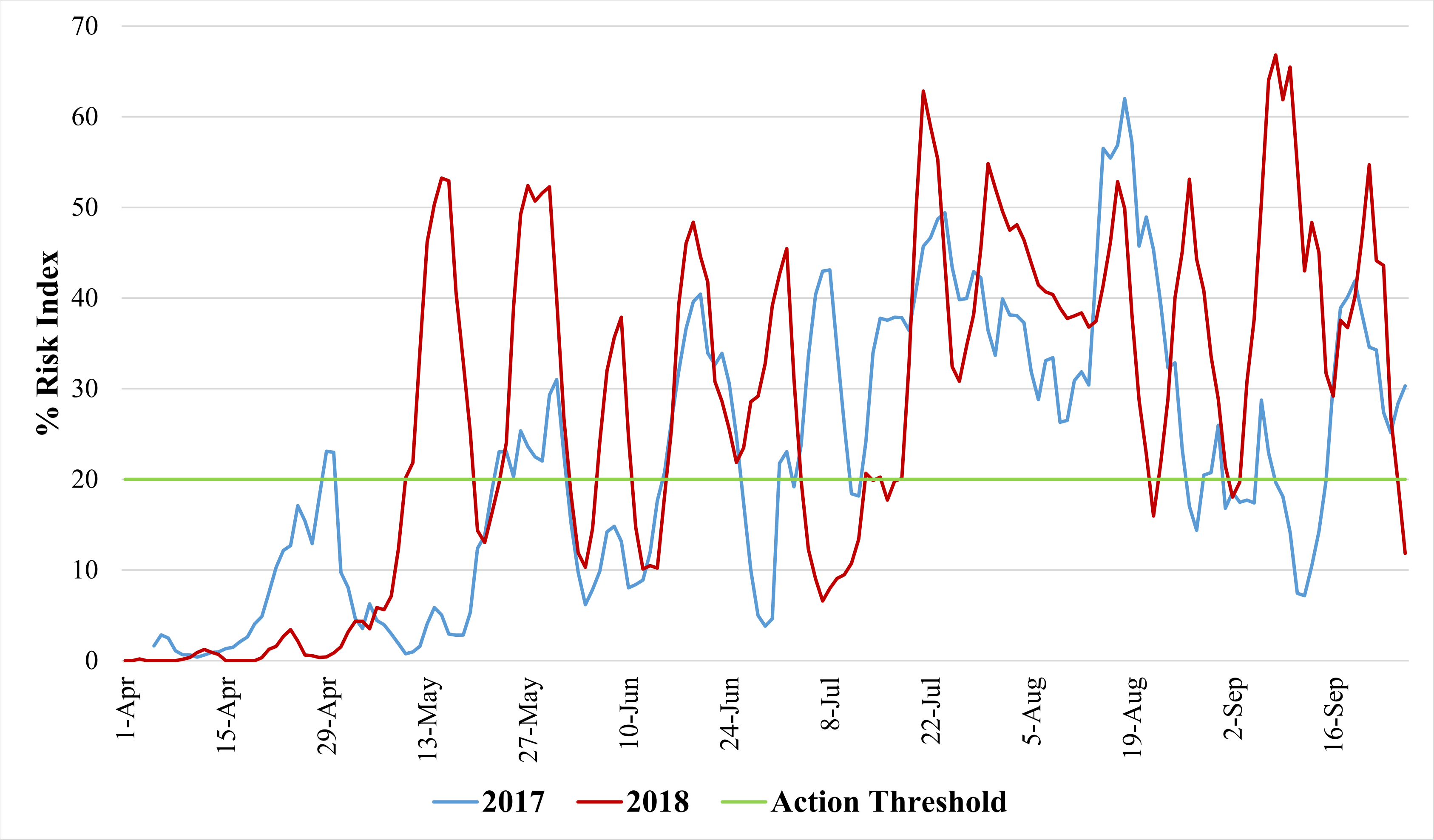
Date	(r)^y	Significance
2017		
19 July	0.80	***
17 August	0.31	NS
2018		
9 July	0.44	*
7 September	0.54	**

[z] Area under disease progress curve, generated using the trapezoidal method (Madden et al. 2007). Values generated from dollar spot incidence on rating date immediately before and after sample date.

[y] Correlation for disease ratings and tissue nitrogen generated from main plot + all sub-plot treatments and main plot treatments, respectively.

$^{*, **, ***, NS}$ refer to the 0.05, 0.01, 0.001 significance level, and non-significant respectively.

Figure 2. Dollar Spot Probability Chart for College Park, MD According to the Smith-Kerns Index, 2017-2018.



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