A COMBINATION OF LIGHTWEIGHT ROLLING AND SAND TOPDRESSING TO DECREASE FUNGICIDE INPUTS AND ENHANCE GOLF COURSE FAIRWAY TURF QUALITY

By

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ABSTRACT

A COMBINATION OF LIGHTWEIGHT ROLLING AND SAND TOPDRESSING TO DECREASE FUNGICIDE INPUTS AND ENHANCE GOLF COURSE FAIRWAY TURF QUALITY

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Dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) is a pervasive turfgrass disease in the upper Midwest affecting turfgrass quality, decreasing golf course playability, and resulting in millions of dollars spent on frequent fungicide applications. Michigan State University scientists observed reduced dollar spot infection in putting greens that were rolled several times weekly. Others observed less incidence of disease in sand-topdressed putting greens. We hypothesized that dollar spot infection in fairways would be decreased by sand topdressing and by rolling thereby reducing the need for frequent fungicide treatments. Two research projects were devised to address the practicality of this disease management strategy. The first project objective was to examine dollar spot severity responses in an *Agrostis stolonifera* L. and *Poa annua* L. fairway to varying frequencies of lightweight rolling and to sand topdressing with no fungicide application. Sand topdressing reduced infection by 50%. Cumulative effects of rolling were investigated with the one, three, and five time weekly rolling treatments. The three and five time rolling treatment had less disease compared to the control during the period of dollar spot activity. The second project assessed the effects of different fungicide application rates combined with sand topdressing and lightweight rolling on dollar spot disease in fairway turf. All monthly fungicide application rates improved turfgrass quality and normalized difference vegetation index (NDVI) compared to the control. Moreover, as rolling frequency increased from 0 to 3x weekly on the no fungicide plots, sand topdressing improved turf quality and reduced dollar spot incidence.

To my great-grand father, Nathaniel Green, MD. Although we never met in life, thy spirit of life inspires me to great delight.

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INTRODUCTION

Turfgrass health is a critical concern for golf course managers in the upper Midwest. More money is expended trying to manage Dollar spot, caused by *Sclerotinia homoeocarpa* F.T. Bennett, than any other turf disease (Goodman and Burpee, 1991; Vargas, 2005). Consequently, having an effective and economical disease management strategy is very important to practically all associates of golf course industry.

Chlorothalonil (tetrachloroisophthalonitrile) is a pesticide that provides broad-spectrum control of numerous pathogens, but is primarily used as a fungicide on crop and non-crop sites such as nurseries, home lawns, and golf courses (National Marine Fisheries Service, 2011). Moreover, on Michigan golf courses, it is the most frequently used pesticide (Rothwell, 1997). In 1999-2000, the total domestic use exceeded 6.8 million kg active ingredient (a.i.) of chlorothalonil, with approximately 680,000 kg a.i. used on turf areas (National Marine Fisheries Service, 2011). In 2007, chlorothalonil was the most commonly used fungicide in the agricultural sector (3.6 million kg a.i.) as well as the industry/commercial/government market sector (1.8 million kg a.i.) (National Marine Fisheries Service, 2011).

A surveyed report of 49 Michigan golf course superintendents revealed that fairways averaged 1.8 applications of chlorothalonil per year while the greens received 4.4 per year (Smitley and Rothwell, 2003). Although dollar spot causes substantial turf injury and is particularly severe on fairways, fungicide use is often curtailed because of environmental, fungicide-resistance, and economic concerns with the latter related to the shear size (12-16 ha) of fairway areas on golf courses (Delvalle et al., 2011).

These combined factors, in the minds of many turf managers, lend an intractable quality to dollar spot. The causal pathogen rarely kills the grass plant; however, the symptomatic lesions that appear on the turfgrass leaf blades affects the aesthetics as well as the playability of the golf course.

If the disease is left untreated on closely mowed grasses, lesions quickly coalesce into large, obstreperous patches (Smiley et al, 1992), whereby the golf ball direction and speed of travel upon the turf surface becomes greatly impeded. Therefore, in an effort to combat the ravages of dollar spot, fungicides are often applied to maintain the playability and aesthetic appeal of the golf course.

The popularity of chlorothalonil for use to control dollar spot can be attributable to the multi-site mode of action this contact fungicides possess, which make the development of pathogen resistance less likely to occur (Golembiewski et al., 1995). Another quality that makes the use of contact fungicides popular among turf managers is their relative low cost, particularly when compared to single-site mode of action systemic fungicides that are more expensive, and often promote the development of pathogen resistance. Dollar spot resistance has been noted in several classes of systemic fungicides: benzimidazoles, dicarboximides, and demethylation inhibitors (Warren, 1974; Detweiler et al., 1983; Golembiewski et al., 1995).

Contact fungicides are often applied at preventative rates (reduced concentration) in anticipation of conditions conducive to dollar spot outbreak rather than at curative application rates (full concentration) when severe disease pressure is present (Williams et al., 1996). Nevertheless, the efficacy of contact fungicides is rather short lived (7-14 days) compared to systemic fungicides (21-28 days). Therefore, in light of EPA mandated pesticide use restrictions and environmental concerns, turf disease management strategies should include the use of cultural practices that promote plant health while being also antagonistic to the disease life cycle (Giordano et al., 2012).

LITERATURE REVIEW

Dollar Spot

Dollar spot, the most common foliar disease of turfgrass in the upper Midwest, affects turfgrass quality, decreases golf course playability, and results in millions of dollars spent on frequent fungicide applications. The causal pathogen, *Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett (Smiley et al., 1992), infects a variety of both warm and cool season grasses world wide, and interestingly, is considered the anomaly of fungal taxonomy whereas genus classification of this fungus is still ongoing (Cabone and Kohn, 1993). In 1937, British mycologist F.T. Bennett observed peculiar variability of species characters in dollar spot fungus; some produced spores and conidia, others produced spores and “micro-conidia”, while another isolate of the fungus was “non-sporing”, yet occasionally produced sterile apothecia (Bennett, 1937). Subsequently, the teliomorph stage (sexual) is still rarely observed in the field (Jackson, 1973; Baldwin and Newell, 1992). Therefore, the primary means of fungus survival and dissemination is the stroma, which are flattened, compact masses of fluffy white, sometimes olive, grey, yellow, or brown mycelium (Smiley et al., 1992).

Dollar spot disease symptoms on closely mowed (putting green or fairway) turf appear as small circular, straw-colored sunken spots that range in size from 2 to 6 cm in diameter (Vargas, 2005). Under favorable environmental conditions the spots can enlarge and coalesce, and thus decimate vast areas of turfgrass. Lesions on individually infected leaf blades first appear chlorotic, and then water-soaked, and finally, a bleached coloration. Moreover, these lesions have a distinct hour-glass-shape with tan or reddish-brown margins (Smiley et al., 1992). All grasses except *Poa annua* L. exhibit this lesion border color characteristic (Vargas, 2005). When dew persists on dollar spot infected grass blades white, fluffy mycelium may often be observed on the turf surface (Monteith and Dahl, 1932).

The dollar spot fungus survives unfavorable environmental conditions as dormant mycelia in infected plant tissue and as stromata on leaf blade surfaces. This fungus spreads mainly through movement of mycelia and infected plant tissue by equipment, humans, animals, wind, or water, and as favorable conditions arise and fungal growths reprise, mycelium can then penetrate leaf tissue, invade through stomata, or enter cut leaf ends and cause infection (Smiley et al., 1992).

Temperature and humidity are influential factors for epidemics of turfgrass plants caused by the facultative-saprophytic fungus *S. homoeocarpa.* Warm, humid conditions and a susceptible host favor the pathogen's growth. Drought-stressed plants (Couch and Bloom, 1960; Couch, 1966) with depleted nitrogen levels (Couch and Bloom, 1960; Markland et al., 1969; Liu et al., 1995; Williams et al., 1996; Landschoot and McNitt, 1997) are particularly prone to severe plant damage. Cyclic air temperatures of 15.5 to 26.8° C (Bennett, 1937; Endo, 1963) and periods of high humidity (Couch, 1962) in the turf canopy favor rapid proliferation of the aerial mycelium of dollar spot fungus.

Dollar Spot Management

The use of primary cultural practices like fertilization, irrigation, and mowing along with supplementary cultural practices of cultivation, rolling, and sand topdressing can suppress dollar spot activity. Although perhaps not as effective as conventional, chemical pest management systems, certain culture practices have proven to be acceptable disease management strategies in terms of playing conditions (Rossi and Grant, 2009).

Fertilization supplies plants with the essential elements needed for optimal growth and development. Research has shown that turf plants that received adequate to high rates of nitrogen had less dollar spot infection than unfertilized plants, or those that received low rates of nitrogen (Couch and Bloom, 1960; Markland et al., 1969; Liu et al., 1995; Williams et al., 1996; Landschoot and McNitt, 1997). Markland et al. (1969) also associated higher levels of potassium with reduced incidence of dollar spot in creeping bentgrass. Potassium, an essential element, increases plant disease resistance; it also affects the wear tolerance, rooting, and drought and temperature extreme hardiness of grasses (Reid, 1933; Bell and DeFrance, 1944; Holt and Davis, 1948; Markland and Roberts, 1967). For example, wear tolerant plants have thick, robust cell wall structures that are less prone to crushing, or tearing during mowing operations, thus lessening the chance for pathogen penetration and infection at leaf wound sites (Beard, 1973)

Infectious foliar diseases thrive in warm, humid environments. Some researchers have shown the direct relationship of temperature and duration of leaf wetness to anthracnose disease severity (Danneberger et al., 1984). However, others have steadfastly reported on the relationship of irrigation frequency and timing to brown patch (causal pathogen, *Rhizoctonia solani* Kuhn) severity in perennial ryegrass (*Lolium perenne* L.) (Settle et al., 2001), and concluded that dew removal by light and frequent, daily watering regimes reduced disease severity. Therefore, it appears that irrigation has a two-fold effect on dollar spot reduction: one being to replenish soil moisture levels to avoid drought-stress related disease epidemics (Couch and Bloom, 1960; Couch, 1966), and the other, depending on the timing, to disrupt pathogen activity on the leaf surface (Settle et al., 2001). Light and frequent irrigation refers to replenishing soil moisture levels to field capacity while the terms deep and infrequent refer to watering at onset of plant leaf wilt (Fry and Huang, 2004). Some researchers have reported that light and frequent, daily applications of water during late-afternoon, or late-evening reduced dollar spot in creeping bentgrass compared to the infrequently (at 22:00 h, twice weekly) irrigated plots (Dykema, 2014).

While dollar spot can be suppressed with fungicides, turfgrass managers commonly limit their use due to economic, environmental, and fungicide resistance concerns (Delvalle et al., 2011). However, the rising cost and imminent ban of certain chemical pesticides have caused turf managers to clamor for effective yet inexpensive means to control turf diseases. One chemical slated for ban is chlorothalonil, the most commonly used fungicide in the turf industry (McDonald et al., 2006), and currently one of 54 fungicides, insecticides, and herbicides listed in the lawsuit filed by several Northwest Pacific Environment Coalitions against the Environmental Protection Agency (EPA, 2011). The reason for the potential ban lies solely in the toxicity levels of chlorothalonil metabolites and degradation products, which adversely affect rainbow trout egg production and survival rate (Davies and White, 1985). This contact fungicide is relatively inexpensive, provides broad-spectrum control of numerous foliar diseases, and is a favorite among turf managers because it is less likely to cause pathogen resistance, which can occur in many systemic fungicide groups like the benzimidazoles (Warren et al., 1974), dicarboximides (Detweiler et al., 1983), and demethylation inhibitors (DMI)(Golembiewski et al., 1995). Therefore, if recent plans from the EPA to ban chlorothalonil come to fruition then it is up to the turf research scientists to find effective and affordable alternatives for managing *S. homoeocarpa.*

Lightweight Rolling

The use of rolling (by manually drawn/driven stone, wooden, or metal cylinders) to flatten, level, or smooth a turf surface is a cultural practice that dates back to the early 1700s (Beard et al., 2014). This practice was primarily used to correct imperfections after winter thawing and frost heaving, and by burrowing insects and mammals (Welton and Carroll, 1940), but sometime around the 1930s, rolling fell out of favor, particularly on putting greens, once the adverse effects from soil compaction were acknowledged (Beard and Beard, 2005). The reason for the early demise of rolling could be attributed to the popularization of the game during the late-1880s and into the 1930s as more golf course construction projects moved inland onto loamy-textured soils, and away from the sandy dune strewn, coastal region where the modern game of golf originated (Beard and Beard, 2005). In contrast to sand-based putting greens, rolling practices were adversely affecting the quality of loam-based putting greens with the primary result being compaction—the severe reduction of volume and continuity of the larger pores (Ball et al., 1988). On the other hand, sand-textured soils are highly resistant to compaction and shearing forces due to a phenomenon called dilatancy. Sand soil is predisposed to expand when subjected to shearing stress as particle surfaces begin sliding across another and grains commence rolling over another, porosity increases in the area of shearing (Reynolds, 1885).

The resurgence of the practice of rolling greens could be attributed to the United States Golf Association Green Section Staff article that detailed a method of sand-based putting green construction (USGA Green Section Staff, 1960). In the late 1950s, Dr. Ray Kunze and others conducted extensive research to develop specifications for the USGA putting green. They observed an increase of turf quality when soil mixtures had greater than 70% sand by volume (Kunze, 1956). The USGA's work as well as the work of Dr. Gardner (Washington State University) helped determine the ideal physical characteristics of soils for putting greens (Ferguson, 1968), and their contributions can directly be attributed to the subsequent and widespread adoption of the layered-sand USGA construction method.

The advent of the USGA putting green in the 1960s did not necessarily mark the triumphant return of rolling practices. It was the availability of the self-propelled lightweight roller (first used on grass tennis courts in Australia) in the late 1980s that contributed to the reassessment of the benefits of rolling (Hartwiger, 2001). In recent years, these rollers have been used extensively not only to increase turf smoothness and quality (Beard, 1982), but also to increase the golf ball speed and travel distance on the putting green. While studying these rolling effects on putting distance, turfgrass scientists at Michigan State University discovered a novel strategy for plant disease management. Rolling several times per week not only increased putting distance, but also, unexpectedly, reduced dollar spot incidence (Nikolai, 2001). Moreover, rolling reduced the severity of anthracnose (caused by *Colletotrichum graminicola*), particularly when conditions conducive to disease outbreak were moderate (Inguagiato et al., 2009). Consequently, researchers then began to ponder the mechanisms surrounding the effects of rolling on disease suppression. Settle et al. (2001) also reported that dew removal by mechanical wiping of foliage reduced brown patch disease (caused by *R. solani*) in perennial ryegrass. These findings are further corroborated by the conclusions of Williams et al.

(1996) and Delvalle et al. (2011) on the beneficial practice of mechanical wiping and morning mowing to control dollar spot disease in creeping bentgrass, and how displacement of leaf surface moisture contributed to disease suppression.

In recent years, the popularity of greens rolling has increased, and as a result, turf equipment manufacturers have introduced not only dedicated greens rollers, but also rollers specifically designed for fairway applications (Williams, 2012). In some instances, the level of cultural intensity for the fairway does not greatly differ from the green—whatever works for the green, will work on the fairway. Thus, the beneficial aspects associated with greens rolling will most likely be observed if rolling practices are implemented on a fairway.

Sand Topdressing

With plentiful supplies of sand around Scottish linksland golf courses, the practice of sand patching and topdressing was regularly used as early as the 1840s (Beard et al., 2014). Patching was described as sand filling rabbit scrapes and burrows, and pre-dated broadcast topdressing. Early topdressing applications usually involved shovel-scattering either sand, or sand amended with manure, bone/blood meal, or seaweed (Beard et al., 2014) across the turf surface, and then brushing or poling to uniformly incorporate the material.

In recent years, sand topdressing has become normal practice on putting greens because it enhances turfgrass health (Skorulski et al., 2010). Since healthy plants can withstand disease pressure more readily (Couch and Bloom, 1960), these same procedures that are used on the greens would likely be successful on the fairways.

Thatch is organic material loosely composed of both living and dead, lignified-plant parts such as the leaves, stems, stolons, rhizomes, and shallow roots (Ledeboer and Skogley, 1967). Excessive accumulation of this substance has been attributed to numerous turfgrass deficiencies such as increased localized dry spot (Cornman, 1952); exacerbated disease incidence (Beard, 1973; Murray and Juska, 1977); and adversely affected water infiltration rates (Murray and Juska, 1977).

Some researchers have the belief sand topdressing can provide a favorable microclimate to facilitate thatch decomposition within the turf canopy and upper rhizosphere (Ledeboer and Skogley, 1967). On the other hand, some researchers believe that sand topdressing dilutes thatch (McCarty et al., 2005), and this dilution effect is just as important as biodegradation in dealing with excessive thatch accumulation within the turfgrass ecosystem (Couillard et al., 1997).

Therefore, sand topdressing could be an alternative for managing turf diseases in lieu of chemical pesticide applications, and offer major advantages such as the following: they reduce the necessity for fungicides, extend the efficacy of fungicides, and reduce the possibility of human exposure to them (Giordano et al., 2012). Instead of applying eight to nine fungicide treatments per season at a cost of $16,000-27,000 annually on fairways (Turf Producers International, 2011), sand topdressing alone may alleviate this annual expenditure, and possibly cut the cost per application by 25 to 50%.

SUMMARY

Research has shown that lightweight rolling and sand topdressing can be used to improve turfgrass quality and decrease disease incidence on putting greens (Nikolai et al., 2001). However, the effectiveness of these cultural practices at managing the ravages of dollar spot disease in a golf course fairway is a novel procedure, and lacks sufficient research.

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CHAPTER 1:

EFFECTS OF LIGHTWEIGHT ROLLING AND SAND TOPDRESSING ON THE SEVERITY OF DOLLAR SPOT INFECTION AND QUALITY OF TURFGRASS IN A GOLF COURSE FAIRWAY

ABSTRACT

Sclerotinia homoeocarpa F.T. Bennett (dollar spot) is the causal pathogen of dollar spot disease. If left untreated, this disease can decimate turf stands, and render golf course conditions unplayable; thus, negatively affecting revenues and resulting in millions of dollars spent on frequent fungicide applications. Scientists observed reduced dollar spot infection in putting greens that were rolled several times weekly. Others observed reduced incidence of disease in putting greens treated with sand topdressing. We hypothesized that dollar spot infection in a golf course fairway would be decreased by the combination of sand topdressing and rolling thereby reducing costly fungicide treatments. The objective was to examine turf quality and dollar spot severity responses in an *Agrostis stolonifera* L. and *Poa annua* L. fairway to lightweight rolling and sand topdressing. The study was conducted from 2011 to 2014 at the Hancock Turfgrass Research Center at MSU using a split block design with treatments consisting of biweekly sand topdressing, rolling at three frequencies (once, three times, or 5 times weekly), a control, and three replications. Infection was visually estimated. Sand topdressing significantly ($P < 0.05$) reduced infection up to 50% at the peak of the dollar spot activity in 2011, 2013, and 2014. The 3x and 5x weekly rolled treatments exhibited 50% less dollar spot injury in 2013. Some data results showed that the combination of rolling 3 and 5x weekly and sand topdressing decreased dollar spot severity more than the aforementioned treatments alone.

INTRODUCTION

Doubtless, the necessity to maintain the health, performance, and aesthetics of golf course turf has produced many innovative turf management strategies. Mowing, rolling, and coring as well as fertilizing and irrigating are a few examples of beneficial cultural practices employed by turfgrass managers around the world. One of the earliest turf culture practices was rolling of the green. It was typically used to smooth surface imperfections, and in fact, predates mechanical mowing (Beard et al., 2014). The original rollers were cylindrically shaped stone devices manually pushed, or pulled across the turf surface (Beard et al., 2014). Methods improved over time, and when new fabrication techniques came along, wooden, cast iron, and steel alloy rollers respectively replaced the heavy stone units. Horse-drawn and subsequently, engine-driven devices followed soon thereafter, and thus, rolling became routine practice on virtually every "ball" sport turf sward at the turn of the twentieth century (Beard et al., 2014).

The practice of lightweight rolling is uniquely associated with the advent of the performance-engineered sand putting green in the 1960s. The USGA Green Section Staff began sand-based putting green research in the late 1940s and early 1950s, and with the collaboration of various research institutions, a momentous contribution was made toward performance putting green specifications and methods of construction, and the eventual development of the USGA specification putting green (Ferguson, 1968). However, golf superintendents and golf course architects were not eagerly excited to adopt this construction method, and many considered the late 1960s and 1970s the "dark ages" of the golf industry with very few USGA specification putting greens being constructed in the United States. Most people believed that the economic recession and energy shortage were probable causes for the decline of new golf course construction (Moncrief, 1977). Likewise, rolling practices and particularly sand topdressing lost favor with golf course superintendents during this time era (Bengeyfield, 1962; Hall, 1978). Despite the dearth of innovation following the introduction of the USGA putting green, technological advancements in turf machinery, irrigation and drainage systems as well as material like engineered sands for topdressing could be hailed as the catalysts that eventually led to the widespread adoption of the sand-based putting green construction method during the golf course building boom of the mid 1980s to early 2000s (NGF, 2013), and subsequently brought rolling and sand topdressing (Madison, 1981) back into the turf culture regimes of the golf course superintendent.

From a modern golf turf culture perspective, lightweight rolling has been used to increase ball roll speed and distance (Nikolai et al., 2001) as well as to smooth the surface of the putting green. Whether rolling is applied daily or weekly, a device of varying force per unit area (from 0.3 to 0.7 kg cm^{-2}) and design configuration (this includes rollers on mowers) is often employed on a putting green. In the late 1990s, Michigan State University researchers discovered a novel disease management strategy while deciphering the effects of rolling and soil fertility on different root zones of a putting green. They reported that rolling at a frequency of three times weekly unexpectedly reduced dollar spot incidence, localized dry spot, moss, and broadleaf weeds in creeping bentgrass (Nikolai et al., 2001).

The research results of MSU scientists were met with cautious skepticism by golf course superintendents and researchers alike, and besides MSU's research, few other institutions were studying the effects of lightweight rolling on disease reduction. For example, over a decade elapsed before one study observed that rolling decreased the severity of anthracnose caused by *Colletotrichum cereale* (Inguagiato et al., 2009) while another reported that rolling not only increase ball roll distance, but also did not exacerbate anthracnose disease in annual bluegrass putting greens (Roberts et al., 2012). These experiments, simple in themselves, demonstrated that turfgrass edaphic environment and pathogen activity could be affected by rolling practices; however, the mechanisms surrounding the effects of rolling on disease suppression are somewhat mysterious. Many people believe leaf exudate (guttation) and dew that accumulate on the leaf surface provide sustenance for pathogens like *R. solani* and *S. homoeocarpa* (Monteith and Dahl, 1932; Williams et al., 1996). Consequently, most golf course superintendents regularly remove dew from the turf surface by any means necessary; they will swipe with a fiberglass pole, or drag a rubber hose, from rolling to irrigating, all in the quest to rid the turf area of dew (Vargas, 2005). Nevertheless, researchers have reported that displacement of leaf surface moisture has some effect on disease incidence, and dew removal by mechanical wiping of foliage and morning mowing not only reduces brown patch disease (caused by *R. solani*) in perennial ryegrass (Settle et al., 2001), but also dollar spot in creeping bentgrass (Williams et al., 1996; Delvalle et al., 2011).

Rolling, like tillage and traffic, alters soil porosity particularly the volume and continuity of the macropores (Beard, 1973; Ball et al., 1988). Depending on the texture, soils vary greatly in the degree of compactability (Beard, 1973). Since compaction increases the matric potential of soil without an increase in mass of water (Hillel, 1998), a coarse textured soil can benefit from certain compaction operations like rolling. Studies have shown that sand textured (80% sand, 10% peat, 10% soil) plots that were rolled had increased percentage water retention in comparison to the non-rolled plots (Nikolai et al., 2001). The mechanism by which rolling is suppressive to the dollar spot pathogen could be attributed the effect of proper soil moisture level on avoidance of drought-stress related disease epidemics (Couch and Bloom, 1960; Couch, 1966), or the effect of beneficial microorganisms that proliferate in the edaphic environment of a turfgrass community (Giordano et al., 2012).

The objective of the study was to evaluate the hypothesis regarding lightweight rolling and sand topdressing effects on dollar spot severity in a mixed-sward creeping bentgrass and annual bluegrass fairway. Different rolling frequency and sand topdressing treatments were used in order to garner data that would help validate this hypothesis. Our objective was to investigate the hypothesis that dollar spot severity would be decreased by rolling and by sand topdressing, thus reducing the need for frequent fungicide applications on golf course fairways.

MATERIALS AND METHODS

Field research on the effects of rolling and sand topdressing on the severity of dollar spot infection on golf course fairways was conducted from May through October in 2011, 2012, 2013, and 2014 at the Hancock Turfgrass Research Center, East Lansing, Michigan. The experimental site was a mixed-stand fairway of annual bluegrass (*Poa annua* L.) and creeping bentgrass (*Agrostis stolonifera* L. 'Penncross') seeded in 2009 on a loam-textured native soil (MSU Soil and Plant Nutrient Laboratory, East Lansing, MI)(Table 1).

The site was divided into six 542 m^2 experimental units—three blocks received a sand topdressing treatment and three blocks were not sand topdressed (native soil). Also, within this site, twenty-four 3.8 x 4.8 m plots were randomly assigned a rolling treatment—half would be on the sand topdressed blocks with the other half on native soil blocks. We maintained the site as a typical, Michigan golf course fairway; it was mowed (clippings not collected) three times weekly at 0.127 cm, and if no rain events occurred, 0.4 cm of water was applied in a single irrigation period from May to October. Fungicides were not applied to any of the treatment plots for the duration of the study; however, at the end of each growing season azoxystrobin (does not control dollar spot) was applied to discourage gray snow mold disease (*Typhula incarnata* Lasch ex Fr., (syn. *Typhula itoana* Imai). Moreover, the site was not core cultivated during the course of the study in order to minimize surface disruption and soil displacement. Herbicides and insecticides were applied seasonally as needed.

Table 1. MSU Hancock Turfgrass Research Center experimental fairway site soil test results; analysis performed at the MSU Soil and Plant Nutrient Laboratory. East Lansing, MI 2014.

pH	7.8
	cmol kg^{-1}
CEC	15
Soil Particle Analysis	%
Sand (0.05 - 2.0 mm)	50
Silt (0.002 - 0.05 mm)	24
Clay (< 0.002 mm)	26
Soil Type	Loam

In 2011, liquefied, granular fertilizer 46-0-0 (24.5 kg N ha^{-1}) was applied six times from May to September. In 2012, we changed the fertilizer formulation to a 28-0-0 (6.1 kg N ha^{-1}) applied at 10-d intervals, and this became our fertilizer regime for the duration of the study. Moreover, in 2013 and 2014, we supplemented our liquid fertilizer regime with several applications of polymer coated, slow-release fertilizer 29-0-10 (61.1 kg N ha^{-1}): one on July 20, 2013, and another on June 7, 2014. The final supplemental fertilizer application was once again a polymer coated, slow-release 29-2-9 (51.8 kg N ha^{-1}) on August 29, 2014.

The first two seasons of the study, in 2011 and 2012, we relied upon natural, *S. homoeocarpa* inoculum to produce dollar spot, but in 2013 and 2014, to encourage uniform coverage of the disease, all treatment plots were artificially inoculated using the Dykema (2014) protocol, which is an enhanced version of the Goodman and Burpee (1991) technique. After a 10-d incubation period, this concoction of silica sand, cornmeal, potato dextrose agar, and *S. homoeocarpa* 'VCG-B' (Powell and Vargas, 2001) inoculum was applied at a rate of 440 kg ha^{-1} using a Gandy drop-spreader (Model 36H13, Gandy Co, Owatonna, MN).

The plots were rolled 1, 3, and 5 times weekly using True-Surface (Turfline, Inc. Moscow, MO) vibratory-roller units (38.6 kg $unit^{-1}$) affixed to a John Deere 2500A (Deere & Co. Moline, IL) triplex-mower (590.9 kg) with a swath of 1.6 m, and a vertical force value of 0.32 kg cm^{-2}. Sand topdressing was applied biweekly from May to September using a Toro Topdresser 2500 (Toro Co., Bloomington, MN) at a rate of 11.2 m^3 ha^{-1} that provided a 3.6 cm sand layer over a four-year period (Table 2).

Table 2. Particle size distribution of topdressing sand; analysis performed at the MSU Soil and Plant Nutrient Laboratory. East Lansing, MI 2015.

Particle Size (mm)	Percentage Distribution (%)
Gravel (> 2)	0.4
Very Coarse Sand (1.0 – 2.0)	10.9
Coarse Sand (0.5 – 1.0)	25.3
Medium Sand (0.25 – 0.5)	41.6
Fine Sand (0.10 – 0.25)	19.6
Very Fine Sand (0.05 – 0.10)	0.6
Silt (0.002 – 0.05)	0.9
Clay (< 0.002)	0.7
Soil Type	Sand

The percentage plot surface area affected by dollar spot lesions was visually rated on a scale of 0 to 100% on a weekly basis when symptoms occurred. Turfgrass quality was visually assessed using methods established by the National Turfgrass Evaluation Program, Inc. (NTEP, Beltsville Agricultural Center, Beltsville, MD), whereas color, density, uniformity, texture, and biotic and abiotic stress constitute quality ratings based on a 1 (dead or poor) to 9 (best) rating scale, with 6 being acceptable.

The experimental design was split-plot randomized complete block design with three replications. Treatment factors included rolling frequencies of 1, 3, and 5 times weekly with a control, and sand topdressing (control and biweekly sand topdress applications). The experimental data was analyzed using PROC GLIMMIX procedure in SAS (version 9.3 and 9.4; SAS Institute Inc., Cary, NC, 2014). Main effects were rolling frequency (whole plot), and sand topdressing (split-plot). Analysis of variance was used to determine significant effects ($P<0.05$), and when significant differences were detected, means were separated using Fisher's and Tukey-Kramer methods (Westfall et al., 1999).

RESULTS AND DISCUSSION

Effects on Dollar Spot Severity

Significant main effects of sand topdressing and rolling frequency on percentage plot surface area affected by dollar spot (causal pathogen, *Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett) lesions were observed in our study.

In 2011, the sand topdressing treatment significantly reduced the percentage plot surface area affected by dollar spot compared to the control (native soil) (Table 3). High frequency rolling produced the greatest reduction in dollar spot disease in comparison to the control on several dates. A sand topdressing x rolling frequency interaction was observed on one collection date in 2011, whereas the 3 and 5 x weekly rolling treatments in combination with sand topdressing significantly reduced dollar spot disease (Figure 1). This interaction supports earlier claims that sand topdressing and rolling significantly reduces turf disease severity.

Main effects of sand topdressing were not significant in 2012; however, main effects of rolling frequency were significant on two collection dates (Table 4). Contrary to the overall trend observed in 2011, dollar spot incidence was most severe on the plots that received the high frequency rolling treatments. Although dollar spot disease was not rampant and somewhat difficult to investigate in Michigan due to the persistently hot, dry weather conditions of the 2012-growing season, our observations support earlier statements that drought-stressed turf is more susceptible to the ravages of dollar spot disease as well as to the detrimental effects of high-frequency traffic on low-input bentgrass/annual bluegrass fairways (Watkins et al., 2010) (Table 5)

Table 3. Effects of sand topdressing and rolling frequency on percentage plot surface area affected by dollar spot disease [z]. East Lansing, MI 2011.

2011 Treatment		Percentage of plot surface area affected by dollar spot disease (0-100%)			
		19 Aug	22 Aug	2 Sep	10 Sep
Soil Type (S)	Sand Topdress [y]	9.5	17.1	21.4	28.8
	Native Soil [x]	22.8	27.9	37.2	43.2
Significance (P = 0.05) [w]		*	*	*	*
Rolling Frequency (R) [v]	0x/wk	16.0	21.3	34.0 a [u]	39.8
	1x/wk	16.5	22.7	31.5 ab	38.2
	3x/wk	16.2	24.0	28.3 bc	34.0
	5x/wk	15.8	22.0	23.3 c	31.8
LSD (P = 0.05)		NS	NS	5.2	NS
S x R		NS	NS	*	NS

[z] Causal pathogen, *Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett
[y] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[x] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[w] * and NS indicate significant and not significant at the 0.05 level of probability, respectively.
[v] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.
[u] Within columns, means followed by the same letter not significantly; Fisher's least significant difference at P = 0.05.

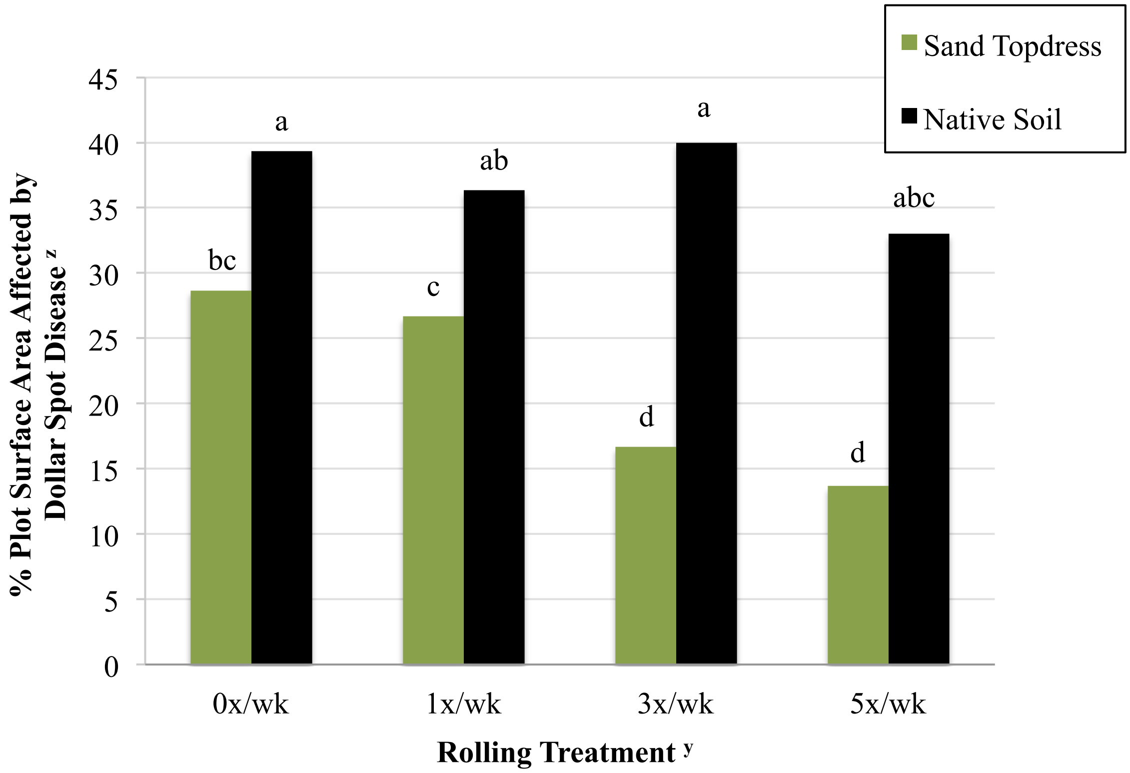

Figure 1. Effects of sand topdressing x rolling frequency on percentage plot surface area affected by dollar spot disease observed on September 2, 2011. East Lansing, MI.

[z] Causal pathogen, *Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett.

[y] Vibratory-rollers (38.6 kg unit^{-1}) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.

Sand applied biweekly, May to September, at a rate of 11.2 m^{3} ha^{-1}.

Capac loam (native) soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.

Columns with the same letter not significantly different; Tukey-Kramer Grouping at P = 0.05.

Table 4. Effects of sand topdressing and rolling frequency on percentage plot surface area affected by dollar spot disease [z]. East Lansing, MI 2012.

2012 Treatment		Percentage of plot surface area affected by dollar spot disease (0-100%)				
		6 July	28 July	10 Aug	25 Aug	3 Sep
Soil Type (S)	Sand Topdress [y]	5.8	20.6	17.1	15.9	19.1
	Native Soil [x]	2.3	16.2	17.7	13.8	22.2
Significance (P = 0.05) [w]		NS	NS	NS	NS	NS
Rolling Frequency (R) [v]	0x/wk	1.8	14.8	13.5 a [u]	10.7 a	16.7
	1x/wk	5.8	16.8	14.8 a	10.8 ab	18.0
	3x/wk	3.8	17.7	19.3 ab	16.7 bc	21.8
	5x/wk	4.8	24.2	21.8 b	21.3 c	26.0
LSD (P = 0.05)		NS	NS	5.9	5.9	NS
S x R		NS	NS	NS	NS	NS

[z] Causal pathogen, *Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett
[y] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[x] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[w] * and NS indicate significant and not significant at the 0.05 level of probability, respectively.
[v] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.
[u] Within columns, means followed by the same letter not significantly different; Fisher's least significant difference at P =0.05.

Table 5. Seasonal precipitation amounts received at the Hancock Turfgrass Research Center. East Lansing, MI; June-September 2011-2014.

Year	cm
2011	24.8
2012	11.7
2013	28.0
2014	28.8

Latitude: 42.7110 deg.
Longitude: -84.4760 deg.
Elevation: 256.64 m
Data provided by the Michigan Automated Weather Network (MAWN) and Enviro-weather Program, Michigan State University.

Main effects of sand topdressing and rolling frequency were observed on several collection dates in 2013. A significant sand topdressing x rolling frequency interaction effect was also observed at this time (Table 6).

When compared to the control, the sand-topdressing treatment notably reduced dollar spot disease incidence by 34% and 66% on August 21 and 30 respectively. Moreover, during this time period, we experienced ideal climatic conditions for an epidemic of dollar spot (Table 7). Despite this fact, the 5x weekly rolling treatment resulted in lower percentage plot surface area affected by dollar spot disease in comparison to the control and the 1 and 3x weekly rolling treatments on August 21. Furthermore, the sand topdressing x rolling frequency interaction helped us determine that as rolling frequency was increased on the sand-topdressed plots, dollar spot severity subsided when compared to the native soil plots that received the same rolling treatments (Figure 2). Once again validating previous statements that sand topdressing and rolling applications can alleviate turf disease severity.

Main effect of sand topdressing was observed in 2014; however, main effect of rolling frequency was not observed throughout the entirety of the data collection period. Only one date resulted in a significant treatment effect on dollar spot with the sand-topdressed plots less dollar spot incidence than the control (Table 8).

Effects on Turfgrass Quality

Significant main effects of sand topdressing and rolling frequency on turfgrass quality were observed in 2011. A significant sand topdressing x rolling frequency interaction effect was also observed during the data collection period (Table 9).

Table 6. Effects of sand topdressing and rolling frequency on percentage plot surface area affected by dollar spot disease [z]. East Lansing, MI 2013.

2013 Treatment		Percentage of plot surface area affected by dollar spot disease (0-100%)				
		27 June	22 July	21 Aug	30 Aug	10 Sep
Soil Type (S)	Sand Topdress [y]	5.2	23.8	11.8	4.3	2.6
	Native Soil [x]	3.9	24.2	17.8	12.7	4.7
Significance (P = 0.05) [w]		NS	NS	*	*	NS
Rolling Frequency (R) [v]	0x/wk	3.8	26.7 a [u]	20.8 a	12.2 a	4.5
	1x/wk	4.5	26.7 a	14.2 b	8.3 ab	2.8
	3x/wk	5.3	24.2 a	14.7 b	7.8 ab	3.8
	5x/wk	4.5	18.3 b	9.7 c	5.7 b	3.3
LSD (P = 0.05)		NS	4.0	3.9	4.5	NS
S x R		NS	NS	*	NS	NS

[z] Causal pathogen, *Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett

[y] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.

[x] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.

[w] * and NS indicate significant and not significant at the 0.05 level of probability, respectively.

[v] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.

[u] Within columns, means followed by the same letter not significantly different; Fisher's least significant difference at P = 0.05.

Table 7. Seasonal climatic conditions experienced at the Hancock Turfgrass Research Center. East Lansing, MI 2013.

Date	Air Temperature (C°)		Precipitation	Relative Humidity (%)	
	Max.	Min.	cm	Max.	Min.
20 Aug	28.6	14.8	---	91.5	22.9
21 Aug	29.2	17.5	---	89.7	42.8
22 Aug	26.1	17.9	0.58	90.0	56.9
23 Aug	27.0	15.0	---	88.1	21.4
24 Aug	27.4	11.5	---	92.8	33.8
25 Aug	28.8	13.7	---	91.5	47.5
26 Aug	28.6	20.0	---	86.4	57.7
27 Aug	30.2	20.9	4.34	92.5	62.1
28 Aug	27.9	19.3	3.56	92.8	58.0
29 Aug	31.3	16.4	---	94.1	42.0
30 Aug	29.5	19.1	0.33	90.7	54.0

Latitude: 42.7110 deg.
Longitude: -84.4760 deg.
Elevation: 256.64 m
Data provided by the Michigan Automated Weather Network (MAWN) and Enviro-weather Program, Michigan State University.

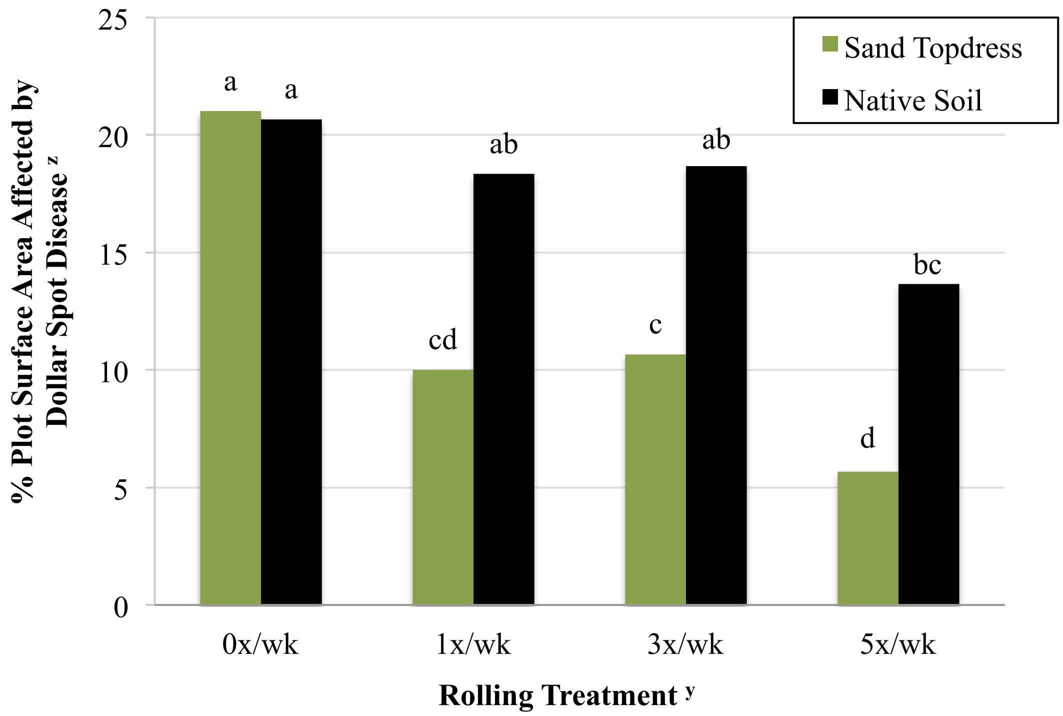

Figure 2. Effects of sand topdressing x rolling frequency on percentage plot surface area affected by dollar spot disease observed on August 21, 2013. East Lansing, MI.

^{z} Causal pathogen, *Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett.

^{y} Vibratory-rollers (38.6 kg unit^{-1}) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.

Sand applied biweekly, May to September, at a rate of 11.2 m^{3} ha^{-1}.

Capac loam (native) soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.

Columns with the same letter not significantly different; Tukey-Kramer Grouping at P = 0.05.

Table 8. Effects of sand topdressing and rolling frequency on percentage plot surface area affected by dollar spot disease [z]. East Lansing, MI 2014.

2014 Treatment		Percentage of plot surface area affected by dollar spot disease (0-100%)				
		26 June	17 July	11 Aug	25 Aug	2 Sep
Soil Type (S)	Sand Topdress [y]	4.7	14.3	5.7	5.8	7.6
	Native Soil [x]	2.5	10.3	11.1	10.8	7.7
Significance (P = 0.05) [w]		NS	NS	NS	*	NS
Rolling Frequency (R) [v]	0x/wk	3.2	13.2	10.0	9.7	8.3
	1x/wk	5.5	10.3	7.5	7.2	7.8
	3x/wk	3.0	15.8	9.7	9.3	7.8
	5x/wk	2.8	9.7	6.3	6.8	6.5
LSD (P = 0.05)		NS	NS	NS	NS	NS
S x R		NS	NS	NS	NS	NS

[z] Causal pathogen, *Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett

[y] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.

[x] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.

[w] * and NS indicate significant and not significant at the 0.05 level of probability, respectively.

[v] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.

[u] Within columns, means followed by the same letter not significantly different; Fisher's least significant difference at P = 0.05.

Table 9. Effects of sand topdressing and rolling frequency on turfgrass quality. East Lansing, MI 2011.

2011 Treatment		Turfgrass Quality (1-9) [z]			
		19 Aug	22 Aug	2 Sep	10 Sep
Soil Type (S)	Sand Topdress [y]	7.1	6.4	7.0	6.8
	Native Soil [x]	5.0	4.8	4.7	4.3
Significance (P = 0.05) [w]		*	*	*	*
Rolling Frequency (R) [v]	0x/wk	6.2	5.8	5.3 a [u]	5.0
	1x/wk	6.0	5.5	5.2 a	5.3
	3x/wk	5.8	5.3	6.2 ab	5.5
	5x/wk	6.2	5.7	6.7 b	6.2
LSD (P = 0.05)		NS	NS	1.1	NS
S x R		NS	NS	NS	*

[z] Quality based on a 1 (dead or poor) to 9 (best) rating scale with 6 being acceptable.
[y] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[x] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[w] * and NS indicate significant and not significant at the 0.05 level of probability, respectively.
[v] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.
[u] Within columns, means followed by the same letter not significantly different; Fisher's least significant difference at P = 0.05.

The sand topdressing treatment produced a notable increase in turfgrass quality when compared to the control, native soil plots. Significant differences among rolling treatments were only observed on September 2, 2011. The 5x weekly rolling treatment had a significant effect on turfgrass quality when compared to the 1x weekly rolling treatment and control. A sand topdressing x rolling frequency interaction, observed on September 10, revealed that as rolling frequency was increased on the sand topdressed plots, turfgrass quality was likewise increased when compared to the native soil plots that received the same rolling treatments (Figure 3).

Main effects of sand topdressing were not significant in 2012; however, main effects of rolling frequency were significant on one collection date. Turfgrass quality was adversely affected on the plots that received the higher frequency, 3 and 5x weekly rolling treatments (Table 10). The persistently hot, dry weather conditions of the 2012-growing season, nevertheless, affected turfgrass quality results despite our efforts to supply adequate irrigation amounts to the research site. Moreover, our observations support earlier statements that drought-stressed turf is more susceptible to a plethora of turf diseases that in effect cause a marked decrease of turfgrass quality.

Main effects of sand topdressing and rolling frequency on turfgrass quality were observed in 2013 (Table 11). Sand topdressed plots had higher turfgrass quality indices when compared to the control. Additionally, plots that received the 3 and 5x weekly rolling treatments had higher turfgrass quality ratings in comparison to the control on two data collection periods in August. Surprisingly, on August 30 and September 10, the plots that received the 1x weekly rolling treatment had higher turf quality ratings when compared to the control.

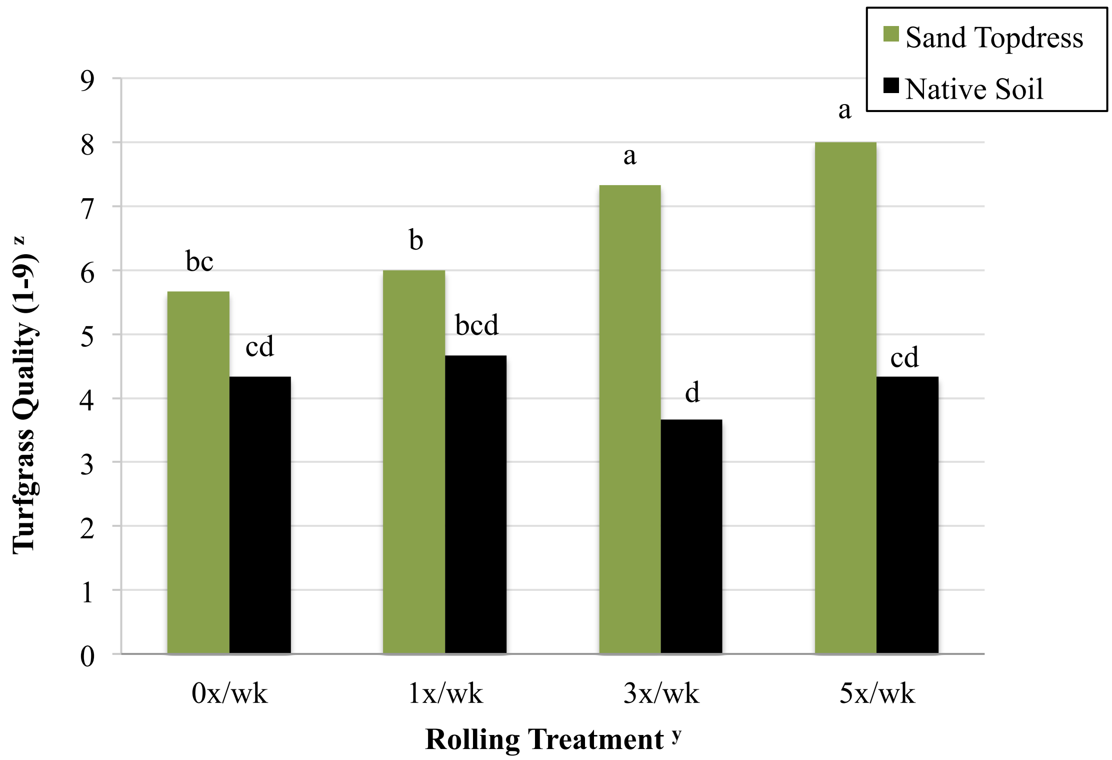

Figure 3. Effects of sand topdressing x rolling frequency on turfgrass quality observed on Sep. 10, 2011. East Lansing, MI.

[z] Quality based on a 1 (dead or poor) to 9 (best) scale with 6 being acceptable.

[y] Vibratory-rollers (38.6 kg unit^{-1}) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.

Sand applied biweekly, May to September, at a rate of 11.2 m^{3} ha^{-1}.

Capac loam (native) soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.

Columns with the same letter not significantly different; Tukey-Kramer Grouping at P = 0.05.

Table 10. Effects of sand topdressing and rolling frequency on turfgrass quality. East Lansing, MI 2012.

2012 Treatment		Turfgrass Quality (1-9) [z]			
		24 June	13 July	10 Aug	16 Sep
Soil Type (S)	Sand Topdress [y]	7.2	6.6	5.5	5.8
	Native Soil [x]	6.3	5.5	4.9	5.1
Significance (P = 0.05) [w]		NS	NS	NS	NS
Rolling Frequency (R) [v]	0x/wk	6.7	5.5	5.7 a [u]	5.5
	1x/wk	6.7	6.0	6.0 a	5.7
	3x/wk	7.0	6.3	4.7 b	5.0
	5x/wk	6.7	6.3	4.5 b	5.5
LSD (P = 0.05)		NS	NS	0.9	NS
S x R		NS	NS	NS	NS

[z] Quality based on a 1 (dead or poor) to 9 (best) rating scale with 6 being acceptable.
[y] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[x] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[w] * and NS indicate significant and not significant at the 0.05 level of probability, respectively.
[v] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.
[u] Within columns, means followed by the same letter not significantly different; Fisher's least significant difference at P = 0.05.

Table 11. Effects of sand topdressing and rolling frequency on turfgrass quality. East Lansing, MI 2013.

2013 Treatment		Turfgrass Quality (1-9) [z]			
		24 June	17 Aug	30 Aug	10 Sep
Soil Type (S)	Sand Topdress [y]	5.4	5.2	6.7	6.3
	Native Soil [x]	5.7	4.4	4.2	5.7
Significance (P = 0.05) [w]		NS	NS	*	NS
Rolling Frequency (R) [v]	0x/wk	5.8	4.0 a	4.5 a [u]	5.3 a
	1x/wk	5.7	4.8 ab	5.7 b	6.3 bc
	3x/wk	5.2	5.0 b	5.5 b	5.8 ab
	5x/wk	5.5	5.5 b	6.0 b	6.5 c
LSD (P = 0.05)		NS	0.8	0.97	0.5
S x R		NS	NS	NS	NS

[z] Quality based on a 1 (dead or poor) to 9 (best) rating scale with 6 being acceptable.
[y] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[x] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[w] * and NS indicate significant and not significant at the 0.05 level of probability, respectively.
[v] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.
[u] Within columns, means followed by the same letter not significantly different; Fisher's least significant difference at P = 0.05.

Significant main effects of sand topdressing and rolling frequency on turfgrass quality were observed in 2014 (Table 12). Two dates, August 11 and 25, resulted in significant treatment effects on turfgrass quality with the sand topdressed plots having had better quality ratings than the control, native soil plots. Only one data collection date resulted in significant rolling frequency treatment effects on turfgrass quality; the 5x weekly rolling treatment produced the highest quality rating when compared to the 3x weekly rolling treatment and control.

Table 12. Effects of sand topdressing and rolling frequency on turfgrass quality. East Lansing, MI 2014.

2014 Treatment		Turfgrass Quality (1-9) [z]			
		28 July	11 Aug	25 Aug	9 Sep
Soil Type (S)	Sand Topdress [y]	6.9	5.9	6.0	5.9
	Native Soil [x]	6.0	4.1	4.8	5.9
Significance (P = 0.05) [w]		NS	*	*	NS
Rolling Frequency (R) [v]	0x/wk	6.2 a	4.7	5.2	5.8
	1x/wk	6.7 ab	5.2	5.5	6.0
	3x/wk	5.8 a	4.7	5.2	5.8
	5x/wk	7.2 b	5.5	5.7	6.0
LSD (P = 0.05)		0.9	NS	NS	NS
S x R		NS	NS	NS	NS

[z] Quality based on a 1 (dead or poor) to 9 (best) rating scale with 6 being acceptable.
[y] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[x] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[w] * and NS indicate significant and not significant at the 0.05 level of probability, respectively.
[v] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.
[u] Within columns, means followed by the same letter not significantly different; Fisher's least significant difference at P = 0.05.

CONCLUSIONS

In most instances, the sand topdressing treatment decreased dollar spot severity and increased turfgrass quality. Similar to our observation, Skorulski et al. (2010) noticed that the severity of infection was reduced by sand topdressing. Their results also indicated that sand topdressing increased fairway turfgrass quality, color, and density. Hempfling et al. (2015) observed decreased anthracnose (*Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman) (Crouch et al., 2006) on an annual bluegrass (*Poa annua* L.) fairway that was sand topdressed in spring and summer. Some researchers have speculated that the shape of sand and the topdressing incorporation method exacerbate turf disease severity response, but Inguagiato et al. (2013) found that neither the sand shape, nor the method of incorporation enhanced anthracnose severity. Moreover, they noticed that routine sand topdressing reduced disease severity on annual bluegrass putting greens. In another study, Inguagiato et al. (2012) found that comparatively low sand rates applied at short intervals substantially reduced anthracnose disease severity. Perhaps seasonal accumulations of sand topdressing not only dilutes thatch, "a layer of intermingled living and dead stems and roots above the soil surface" (Beard, 1973), but also dilutes the fungal stroma of dollar spot by and which is the primary means of pathogen survival and dissemination (Vargas, 2005).

Our research efforts determined that rolling frequency treatments significantly affected disease incidence on fairway turf; however, the 5x weekly rolling treatment appeared to be the most efficacious, and in most instances, had the lowest percentage plot surface area affected by dollar spot when compared to the control and the 1 and 3x weekly rolling treatments. These results support the findings of Nikolai et al. (2001) that rolling at least three times per week not only increased green speeds, but also, unexpectedly, reduced dollar spot incidence in creeping bentgrass. Giordano et al. (2012) found that rolling 5x weekly, whether in the early morning, or in the afternoon, and either once or twice daily, significantly reduced dollar spot severity when compared to the control. Rolling has also been found to decrease the severity of anthracnose caused by *Colletotrichum cereale* (Inguagiato et al., 2009)

Nevertheless, no research, excepting our study, has attempted to address lightweight rolling effects on fairway turf, particularly the mechanism involved in dollar spot suppression. The major differences between a fairway turf and a putting green turf is the height of cut, and more or less, the intensity of cultural practices that affect the amount of thatch present in the respective areas. In most circumstances a putting green, in comparison to a fairway having the same composition of turfgrasses, will have less thatch. Therefore, rolling intensity and the mechanical forces involved in rolling might have to be greater in order to induce an effect on the edaphic environment of fairway turfgrass. This may explain why the highest rolling frequency was the most effective treatment for suppressing dollar spot disease in our study.

Some people believe leaf guttation and dew provide sustenance for pathogens (Monteith and Dahl, 1932; Williams et al., 1996), and while it has been shown that displacement of leaf surface moisture has some effect on disease incidence (Williams et al., 1996; Settle et al., 2001; Delvalle et al., 2011) others have challenged this theory and provided evidence to suggest that daily lightweight rolling may induce some kind of "biological or physiological mechanism" whereby reductions of dollar spot are evident and substantial (Giordano et al., 2012). Since rolling affects soil porosity (Beard, 1973; Ball et al., 1988) and increases the matric potential of soil without an increase in mass of water (Hillel, 1998), sand-based rootzone mediums can benefit from certain compaction operations like rolling (Nikolai et al., 2001; Giordano et al., 2012). The mechanism by which rolling is suppressive to the dollar spot pathogen could be attributed the effect of proper soil moisture level on avoidance of drought-stress related disease epidemics (Couch and Bloom, 1960; Couch, 1966). These findings are in agreement with the research of Nikolai et al. (2001) and Giordano et al. (2012), in that they observed greater differences between the rolled and non-rolled plots in regard to water holding capacity, disease severity and turfgrass quality. In that manner, “rolling consistently resulted in lower disease severity as well as superior turfgrass quality ratings” (Giordano et al., 2012).

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CHAPTER 2:

EFFECTS OF LIGHTWEIGHT ROLLING AND SAND TOPDRESSING ON THE EFFICACY OF FUNGICIDE APPLICATION RATES FOR THE REDUCTION OF DOLLAR SPOT DISEASE IN A GOLF COURSE FAIRWAY

ABSTRACT

Dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett), the most common turfgrass disease in the upper Midwest, affects turfgrass quality, decreases golf course playability, and results in millions of dollars spent on frequent fungicide applications. We hypothesized that a combination of lightweight rolling and sand topdressing would increase fungicide efficacy to reduce dollar spot disease in a golf course fairway. Our objective was to examine dollar spot severity responses on an *Agrostis stolonifera* L. and *Poa annua* L. fairway to combinations of lightweight rolling, sand topdressing, and different fungicide application rates. The study was conducted in 2013 and 2014 at the Hancock Turfgrass Research Center, Michigan State University using a strip-split-plot design, and treatments consisted of boscalid fungicide at 0.14, 0.14 + 0.14, 0.28, 0.28 + 0.28, 0.56, and 0.56 + 0.56 kg ha^{-1} $month^{-1}$, rolling 3x weekly, sand topdressing, and controls. Infection was visually estimated. All monthly fungicide applications improved normalized difference vegetation index (NDVI) and turf quality responses compared to the control. Moreover, rolling on the no fungicide plots and sand topdressing improved turf quality and reduced dollar spot incidence.

INTRODUCTION

Dollar spot is a foliar disease of turfgrass that causes significant injury if left untreated. The causal pathogen, *Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett (Smiley et al., 1992), infects a wide range of warm- and cool-season grasses throughout the United States (Vargas, 2005); however, severe disease epidemics can occur in turfgrasses of the upper Midwest as a result of environmental conditions and turfgrass cultural regimes that favor disease outbreak.

Millions of dollars are spent in efforts to manage dollar spot on golf courses (Vargas, 2005), and turf managers can choose from a variety of fungicides that suppress dollar spot disease symptoms; however, they generally limit applications of these chemicals due to economic, environmental, and fungicide resistance concerns (Delvalle et al., 2011). Additionally, with the rising cost and looming ban of certain chemical pesticides, turf managers are seeking alternative yet inexpensive means of controlling turf diseases. The ever popular, and the most effective fungicide in the turf industry, chlorothalonil (McDonald et al., 2006), is one of a variety of fungicides, insecticides, and herbicides listed in the lawsuit filed by several Northwest Pacific Environment Coalitions against the Environmental Protection Agency (EPA, 2011). The pending lawsuit could result in the ultimate demise of chlorothalonil from the disease management regimes of not only turf managers, but also farmers and horticulturalists alike. Studies have found that chlorothalonil transport by rainfall/runoff can be substantial (King and Balogh, 2013). Upon application, chlorothalonil persists in the ecosystem and concentrations in discharge water have been observed to adversely affect egg production and survival rate of certain fish (Davies and White, 1985), hence the potential ban and loss of this product from the market. The U.S. Environmental Protection Agency (EPA, 1999) estimated that upwards of 680,000 kilograms of chlorothalonil were applied in both recreational and golf course turf in 1999 to 2000. Chlorothalonil is inexpensive, provides broad-spectrum control of numerous foliar diseases, and is less likely to cause pathogen resistance, which can occur in many site-specific, systemic fungicide groups (Warren et al., 1974; Detweiler et al., 1983; Golembiewski et al., 1995). Therefore, if the EPA bans chlorothalonil then an effective and affordable alternative must be sought for the control of dollar spot disease in turfgrass.

A recent study examining the effects of golf course fairway mowing frequency and dew removal on fungicide efficacy for dollar spot control showed that as mowing frequency was increased from 2 to 6 days weekly disease severity was abated across all fungicide treatments (Delvalle et al., 2011). Moreover, Delvalle et al. (2011) have documented associations between turf cultural practices and the efficacy of certain fungicides. They found that daily (7 days week^{-1}) dew removal increased the number of days needed to reach a disease threshold value when compared to fungicide treatments (chlorothalonil, 8.2 kg a.i. ha^{-1}; propiconazole, 0.7 kg a.i. ha^{-1}; and iprodione, 2.1 kg a.i. ha^{-1}) in which dew was not removed. In this study, a Toro ReelMaster 5400-D fairway mower (The Toro Company. Bloomington, MN) was not only used for the mowing treatments, but also used for the dew removal treatments by driving the mower across the plots with the cutting units lowered and disengaged. Depending on the model designation, this particular fairway mower may weigh between 1,136 and 1,186 kg with each cutting unit (5 units mower^{-1}) weighing between 50 to 69 kg. Essentially, a force per unit area was being exerted upon the turfgrass and underlying rootzone, and therefore, being subjected to a lightweight rolling regime since all reel cutting units are equipped with rollers. Therefore, the mechanisms of disease suppression in turfgrass certainly involves something more than the removal or dispersal of surface dew and guttation fluid as elucidated by Williams et al. (1996). They observed significant reduction of dollar spot after morning mowing and poling (mower unit disengaged and lowered) treatments on a putting green and a fairway turf compared to the afternoon mowing treatments. Conversely, Giordano et al. (2012) observed no difference between afternoon (after dew and guttation fluid dispersed) and morning rolling treatments in terms of dollar spot severity with both treatments resulting in significant dollar spot reductions compared to the control. A variety of research projects have shown that rolling could be used to decrease disease in turfgrass. Nikolai et al. (2001) and Giordano et al. (2013) concluded that rolling several times weekly increased turf quality and reduced dollar spot severity compared to non-rolled plots. Thus, rolling could be used to not only reduce the need for frequent fungicide applications, but also to increase the efficacy of conservative fungicide application rates.

Very little research has been conducted to evaluate the effects of sand topdressing on fungicide efficacy. Datnoff et al. (2005) investigated the role of silicon in suppressing foliar diseases in warm-season grasses, and found that rootzone mixtures amended with calcium silicate slag ($CaSiO_3$) enhanced the resistance of both St. Augustinegrass (*Stenotaphrum secundatum* L.) and bermudagrass (*Cynodon dactylon* L.) to foliar diseases. They also concluded that silicon could enhance fungicide usage at lower application rates. Although silicon is the second most abundant element in the crust and soils of the earth (Savant et al., 1997), plant-available silicon is in short supply. Even quartz sand (SiO_2) is lacking in plant-available silicon (Datnoff et al., 2005). Therefore, other suppression mechanisms must be at work in regard to a sand topdressing effect on disease occurrence in turf. Roberts and Murphy (2014) observed that sand topdressing applications on annual bluegrass putting greens reduced anthracnose (*Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman, 2006), and a combination of sand topdressing and foot traffic (main plots received 327 foot steps m^{-2} daily; the walkers wore spiked-golf shoes, and had an average weight of 65 kg) resulted in the "least anthracnose and best overall turf quality over the course of their study". They also noted that despite greater soil bulk density indices, the plots that received foot traffic and sand topdressing treatments not only had higher turf quality, but also had lower disease occurrence compared to non-trafficked plots. This is in support of the observation of Giordano et al. (2012) whereby "reduced dollar spot from lightweight rolling was associated with increased volumetric water content because drought stress has been observed to increase disease susceptibility in turf".

Rolling and sand topdressing could have significant economic and environmental benefits if the effects of these practices on fungicide efficacy could be substantiated in this study as well as future research studies.

Our objective was to examine the hypothesis regarding the effects of combinations of lightweight rolling, sand topdressing, and monthly fungicide application rates on dollar spot severity and turf quality responses on an *Agrostis stolonifera* L. and *Poa annua* L. fairway. Different rolling frequency, sand topdressing, and fungicide application rate treatments were used in order to garner data that would help us validate this hypothesis. Therefore, our objective was to investigate the hypothesis that dollar spot severity would decrease and turf quality would increase by rolling and by sand topdressing, thereby enhancing fungicide usage at lower applications rates.

MATERIALS AND METHODS

Field research was conducted from May through October in 2013 and 2014 at the Hancock Turfgrass Research Center, East Lansing, Michigan. The study evaluated the effects of combinations of soil type (sand topdressed and native soil), rolling frequency (0 and 3x weekly), and monthly fungicide application rates (0.14, 0.14 + 0.14, 0.28, 0.28 + 0.28, 0.56, and 0.56 + 0.56 kg ha^{-1}) on dollar spot reduction in a golf course fairway. Our experimental site was a very large (3,252 m^2), mixed-stand fairway of annual bluegrass (*Poa annua* L.) and creeping bentgrass (*Agrostis stolonifera* L. 'Penncross') seeded in 2009. The soil on this site was a loam-textured native soil.

This site was composed of six 542 m^2 experimental units; three blocks were sand topdressed while the remainders of the blocks were not sand topdressed (native soil). Also, within this site, ninety-six 1.2 x 1.8 m plots (16 plots per experimental block) were randomly assigned a fungicide treatment—the levels of fungicide were stripped across both levels of rolling within each level of soil type. Fairways were mowed (clippings not collected) three times weekly at 0.127 cm, and if no rain events occurred, 0.4 cm of water was applied in a single irrigation period from May to October. Moreover, herbicides and insecticides were applied seasonally as needed. Additionally, in attempts to minimize surface disruption and soil displacement, this site was never core cultivated for the duration of the study.

In order to discourage gray snow mold disease (*Typhula incarnata* Lasch ex Fr., (syn. *Typhula itoana* Imai), azoxystrobin fungicide was applied at the end of each growing season. We chose this strobilurin fungicide, a quinol oxidation inhibitor (QoI) with the chemical name of methyl (E)-2-{2-[6-(2-cyanophenoxy) pyrimidin-4yloxy] phenyl} 3-methoxyacrylate, because QoI fungicides are not particularly effective at controlling asexual reproducing fungi like dollar spot (Godwin et al., 2002; Vincelli, 2002). Spore germination and zoospore motility are stages of fungal development that are particularly sensitive to QoI fungicides (Godwin et al., 2002). The dollar spot pathogen is predominately an asexual reproducer, surviving by disseminating mycelia around and upon the host plant (Smiley et al., 1992), and rarely producing spores in the field (Jackson, 1973; Baldwin and Newell, 1992).

The fertilizer regime consisted of a 28-0-0 (6.1 kg N ha^{-1}) applied at 10-d intervals; however, in 2013 and 2014, we supplemented our liquid fertilizer regime with several applications of polymer-coated, slow-release fertilizer 29-0-10 (61.1 kg N ha^{-1}): one on July 20, 2013, and another on June 7, 2014. A final supplemental fertilizer application was once again a polymer-coated, slow-release 29-2-9 (51.8 kg N ha^{-1}) on August 29, 2014.

In 2013 and 2014, to attain even coverage of dollar spot disease, all treatment plots were artificially inoculated using the Dykema (2014) protocol, which is a modification of the Goodman and Burpee (1991) technique. The concoction of silica sand, cornmeal, potato dextrose agar, and *S. homoeocarpa* ‘VCG-B’ (Powell and Vargas, 2001) inoculum was applied at a rate of 440 kg ha^{-1} using a Gandy drop-spreader (Model 36H13, Gandy Co, Owatonna, MN).

For this study, we selected boscalid fungicide because of the moderate resistance risk, and the excellent control of dollar spot disease in turfgrass. This systemic fungicide has the chemical name of 3-pyridinecarboxamide, 2-chloro-N- (4’chloro[1,1 ‘biphenyl]-2-yl, and is within the chemical group carboxamide/anilide. Fungicide treatments were initiated once dollar spot disease was active, and administered using a CO_2-powered backpack-boom-sprayer (R & D Sprayer, Bell Spray, Inc., Opelousas. LA) at 15 and 30-d intervals. The plots were rolled 3 times weekly using True-Surface (Turfline, Inc. Moscow, MO) vibratory-roller units (38.6 kg unit^{-1}) attached to a John Deere 2500A (Deere & Co. Moline, IL) triplex-mower (590.9 kg) with a swath of 1.6 m, and a vertical force value of 0.32 kg cm^{-2}. Also, sand topdressing was applied biweekly from May to September using a Toro Topdresser 2500 (Toro Co., Bloomington, MN) at a rate of 11.2 m^3 ha^{-1}, and over a four-year period of seasonal applications provided a 3.6 cm sand layer.

The percentage plot surface area affected by dollar spot lesions was visually rated on a scale of 0 to 100% on a weekly basis when symptoms occurred and the disease cycle was active. Turfgrass quality was visually assessed using methods established by the National Turfgrass Evaluation Program, Inc. (NTEP, Beltsville Agricultural Center,
Beltsville, MD), whereas color, density, uniformity, texture, and biotic and abiotic stress constitute quality ratings based on a 1 (dead or poor) to 9 (best) rating scale, with 6 being acceptable. Chlorophyll content is a good indicator of plant health (Kruse et al., 2006); therefore, we used a normalized difference vegetation index meter (NDVI-TCM 500, Spectrum Technologies, Inc. Aurora, IL) to quantitatively evaluate turfgrass quality response. This instrument calculates an index value range from 0.000 to 1.000 with higher values indicative of healthier plants.

The experimental design was strip-split-plot design with three replications. Treatment factors included monthly boscalid fungicide application rates of 0.14, 0.14 + 0.14, 0.28, 0.28 + 0.28, 0.56, and 0.56 + 0.56 kg ha^{-1}; rolling 3x weekly, sand topdressing, and controls. The experimental data was analyzed using PROC GLIMMIX procedure in SAS (version 9.3 and 9.4; SAS Institute Inc., Cary, NC, 2014). Main effects were different monthly fungicide application rates (whole plot), rolling (strip-plot) and sand topdressing (split-plot). Analysis of variance was used to determine significant effects ($P<0.05$), and when significant differences were detected, means were separated using Fisher's and Tukey-Kramer methods (Westfall et al., 1999).

RESULTS AND DISCUSSION

Effects on Dollar Spot Severity

Main effects of fungicide application rate on percentage plot surface area affected by dollar spot (causal pathogen, *Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett) lesions were significant; however, no differences between sand topdressing and rolling frequency were observed in 2013.

When differences among fungicide application rate levels (0.14, 0.14 + 0.14, 0.28, 0.28 + 0.28, 0.56, and 0.56 + 0.56 kg ha^{-1} $month^{-1}$) were observed, all treatments significantly reduced dollar spot disease compared to the control only on July 22 (Table 13). Nevertheless, the 0.14 kg $ha^{-1}month^{-1}$ application rate was as efficacious as the full, label recommended application rates of 0.56 and 0.56 + 0.56 kg ha^{-1} $month^{-1}$.

In 2014, monthly fungicide application rate produced a main effect on percentage plot surface area affected by dollar spot lesions, while no other main effects or interactions were significant. All fungicide application rates yielded the greatest reduction of dollar spot disease compared to the control (Table 14). On August 25, the 0.28 + 0.28 kg $ha^{-1}month^{-1}$ application rate controlled dollar spot severity just as effectively as the 0.56 + 0.56 kg ha^{-1} $month^{-1}$ application rate. Moreover, the 0.14 + 0.14 kg ha^{-1} $month^{-1}$ application rate was just as efficacious as the full, label recommended application rate of 0.56 kg ha^{-1} $month^{-1}$.

Effects on Normalized Difference Vegetation Index (NDVI)

Significant main effects of monthly fungicide application rate and rolling frequency on normalized difference vegetation index (NDVI) were observed in 2013, while sand topdressing and interaction effects were not significant. All fungicide application rates produced greater NDVI values when compared to the control (Table 15). Surprisingly, no differences were noticed between the lowest monthly application rate (14 kg ha^{-1}) and the full, label recommended application rate (0.56

kg ha^{-1}) on NDVI, and as the number of application increased over the season, little to no difference was noted among the treatment levels. Rolling frequency produced differences in NDVI on one collection date in 2013, whereas rolling increased NDVI response compared to the control.

Table 13. Effects of sand topdressing, rolling frequency, and boscalid fungicide application rate on percentage plot surface area affected by dollar spot disease (*Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett). East Lansing, MI 2013.

2013 Treatment		Percentage of plot surface area affected by dollar spot disease (0-100%)				
		22 July	6 Aug	17 Aug	21 Aug	10 Sep
Soil Type (S)	Sand Topdress [z]	7.9	4.3	4.0	3.6	1.2
	Native Soil [y]	4.2	4.5	5.2	3.6	1.4
LSD (P = 0.05) [x]		NS	NS	NS	NS	NS
Rolling Frequency (R)	0x/wk	7.0	5.1	5.1	3.9	1.1
	3x/wk [w]	5.2	3.7	4.1	3.3	1.5
LSD (P = 0.05)		NS	NS	NS	NS	NS
Monthly Fungicide Application Rate: kg ha^{-1} (F)	Control	18.7 a [v]	28.5	25.8	20.2	6.6
	0.14	5.0 b	1.7	3.0	2.7	0.9
	0.14 + 0.14	2.1 b	0.2	1.9	1.2	0.3
	0.28	3.1 b	0.3	1.3	0.8	0.8
	0.28 + 0.28	4.8 b	0.0	0.0	0.3	0.0
	0.56	2.8 b	0.0	0.0	0.0	0.3
	0.56 + 0.56	6.0 b	0.0	0.2	0.2	0.0
LSD (P = 0.05)		7.1	NS	NS	NS	NS
S x R		NS	NS	NS	NS	NS
S x F		NS	NS	NS	NS	NS
R x F		NS	NS	NS	NS	NS
S x R x F		NS	NS	NS	NS	NS

[z] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[y] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[x] * and NS indicate significant and not significant at the 0.05 level of probability, respectively
[w] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg) vertical force value of 0.32 kg cm^{-2}.
[v] Within columns, means followed by the same letter not significantly different with Fisher's least significant difference at P = 0.05.

Table 14. Effects of sand topdressing, rolling frequency, and boscalid fungicide application rate on percentage plot surface area affected by dollar spot disease (*Rutstroemia floccossum* syn. *Sclerotinia homoeocarpa* F.T. Bennett). East Lansing, MI 2014.

2014 Treatment		Percentage of plot surface area affected by dollar spot disease (0-100%)				
		28 July	4 Aug	11 Aug	18 Aug	25 Aug
Soil Type (S)	Sand Topdress [z]	1.4	1.2	1.6	3.7	5.3
	Native Soil [y]	1.1	0.9	1.6	3.0	5.2
LSD (P = 0.05) [x]		NS	NS	NS	NS	NS
Rolling Frequency (R)	0x/wk	1.5	1.2	1.9	3.7	5.6
	3x/wk [w]	0.9	0.9	1.4	3.0	4.9
LSD (P = 0.05)		NS	NS	NS	NS	NS
Monthly Fungicide Application Rate: kg ha^{-1} (F)	Control	4.9	7.2	8.8	13.4	16.1 a [v]
	0.14	2.4	0.0	2.2	7.0	10.2 b
	0.14 + 0.14	0.0	0.0	0.0	0.0	1.9 d
	0.28	1.3	0.0	0.3	2.4	6.3 c
	0.28 + 0.28	0.0	0.0	0.0	0.0	0.0 e
	0.56	0.0	0.0	0.0	0.5	2.3 d
	0.56 + 0.56	0.0	0.0	0.0	0.0	0.0 e
LSD (P = 0.05)		NS	NS	NS	NS	1.7
S x R		NS	NS	NS	NS	NS
S x F		NS	NS	NS	NS	NS
R x F		NS	NS	NS	NS	NS
S x R x F		NS	NS	NS	NS	NS

[z] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[y] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[x] * and NS indicate significant and not significant at the 0.05 level of probability, respectively
[w] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg) vertical force value of 0.32 kg cm^{-2}.
[v] Within columns, means followed by the same letter not significantly different with Fisher's least significant difference at P = 0.05.

Table 15. Effects of sand topdressing, rolling frequency, and boscalid fungicide application rate on normalized difference vegetation index (NDVI range from 0.000 to 1.000 with higher values indicative of healthier plants). East Lansing, MI 2013.

2013 Treatment		NDVI (0.000 to 1.000)				
		22 July	6 Aug	17 Aug	21 Aug	10 Sep
Soil Type (S)	Sand Topdress [z]	0.713	0.725	0.742	0.755	0.777
	Native Soil [y]	0.716	0.724	0.754	0.765	0.788
LSD (P = 0.05) [x]		NS	NS	NS	NS	NS
Rolling Frequency (R)	0x/wk	0.711	0.726	0.751	0.767	0.784
	3x/wk [w]	0.717	0.723	0.745	0.753	0.781
LSD (P = 0.05)		NS	NS	NS	*	NS
Monthly Fungicide Application Rate: kg ha^{-1} (F)	Control	0.654 a [v]	0.668 a	0.689 a	0.722 a	0.754 a
	0.14	0.712 b	0.724 b	0.752 b	0.759 b	0.783 b
	0.14 + 0.14	0.724 bc	0.736 bc	0.759 bc	0.768 b	0.789 b
	0.28	0.725 bc	0.731 bc	0.751 b	0.764 b	0.783 b
	0.28 + 0.28	0.728 c	0.733 bc	0.753 b	0.774 b	0.789 b
	0.56	0.724 bc	0.738 bc	0.762 bc	0.768 b	0.791 b
	0.56 + 0.56	0.731 c	0.744 c	0.772 c	0.760 b	0.790 b
LSD (P = 0.05)		0.015	0.016	0.018	0.019	0.014
S x R		NS	NS	NS	NS	NS
S x F		NS	NS	NS	NS	NS
R x F		NS	NS	NS	NS	NS
S x R x F		NS	NS	NS	NS	NS

[z] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[y] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[x] * and NS indicate significant and not significant at the 0.05 level of probability, respectively
[w] Vibratory-rollers (38.6 kg unit^{-1}) on a triplex-mower (590.9 kg) vertical force value of 0.32 kg cm^{-2}.
[v] Within columns, means followed by the same letter not significantly different with Fisher's least significant difference at P = 0.05.

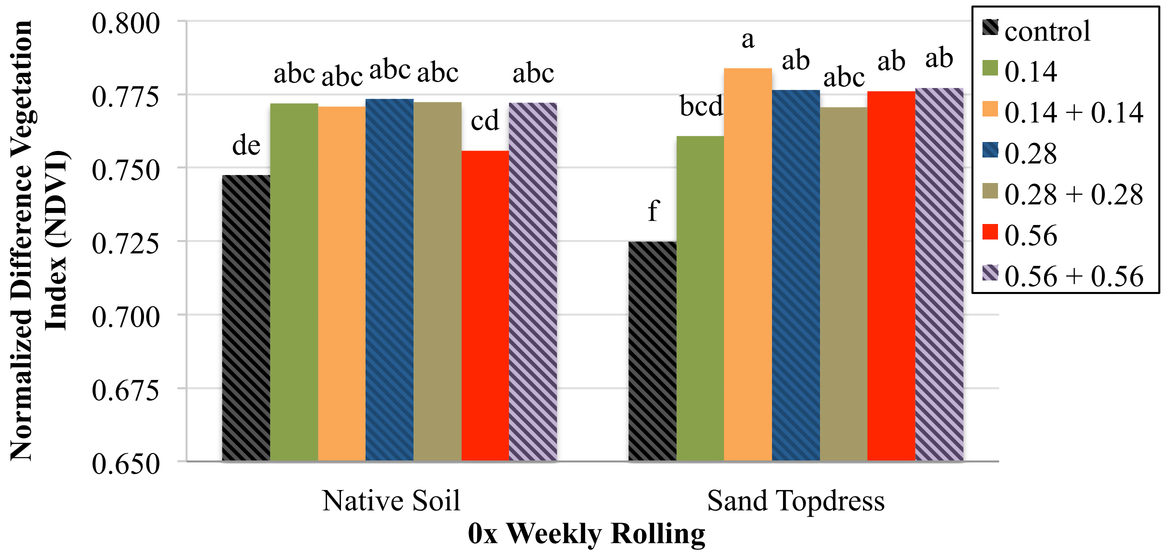
In 2014, main effects of fungicide application rate and rolling frequency on NDVI were significant, while main effects of sand topdressing were not significant. However, we did observe significant interactions involving both rolling frequency x fungicide application rate, and sand topdressing x rolling frequency x fungicide application rate at this time. Similar to 2013 data results, all fungicide treatment levels effectively suppressed dollar spot disease and resulted in higher NDVI values when compared to the no fungicide, control treatment (Table 16). The August 25 data results suggest that bimonthly applications of the lowest fungicide rate (14 + 14 kg ha^{-1}) will suppress dollar spot and increase turf health just as effectively as bimonthly applications of the full, label recommended rate (0.56 + 0.56 kg ha^{-1}). Contrary to 2013 data results, the 3x weekly rolling treatment yielded the greatest NDVI response compared to the no roll, control. These results are in agreement with Nikolai et al. (2001) in that the effect of lightweight rolling is cumulative in nature—the benefits of rolling are a function of multi-season applications.

A significant sand topdressing x rolling frequency x fungicide application rate occurred with variable and illogical means values. The interaction effects of soil type and fungicide application rate did not differ as a function of rolling frequency; however, the effect of rolling greatly influenced control plot NDVI response as a function of the sand topdressing treatment (Figure 4). Furthermore, a significant rolling frequency x fungicide application rate interaction occurred on one occasion with variable and illogical means values; however, the data results for the no fungicide, control plots support the claims of Nikolai et al. (2001) that rolling at least 3x weekly increases the turf quality and decreases the severity of dollar spot in putting greens (Figure 5).

Table 16. Effects of sand topdressing, rolling frequency, and boscalid fungicide application rate on normalized difference vegetation index (NDVI range from 0.000 to 1.000 with higher values indicative of healthier plants). East Lansing, MI 2014.

2014 Treatment		NDVI (0.000 to 1.000)				
		28 July	4 Aug	11 Aug	18 Aug	25 Aug
Soil Type (S)	Sand Topdress [z]	0.782	0.749	0.770	0.744	0.742
	Native Soil [y]	0.780	0.759	0.768	0.755	0.751
LSD ($P = 0.05$) [x]		NS	NS	NS	NS	NS
Rolling Frequency (R)	0x/wk	0.777	0.752	0.767	0.748	0.748
	3x/wk [w]	0.784	0.756	0.771	0.751	0.745
LSD ($P = 0.05$)		*	NS	NS	NS	NS
Monthly Fungicide Application Rate: kg ha^{-1} (F)	Control	0.782	0.737 a [v]	0.738 a	0.701 a	0.704 a
	0.14	0.785	0.752 b	0.772 b	0.740 b	0.722 b
	0.14 + 0.14	0.778	0.755 b	0.776 b	0.769 d	0.769 d
	0.28	0.783	0.759 b	0.775 b	0.754 bc	0.741 c
	0.28 + 0.28	0.779	0.762 b	0.774 b	0.763 cd	0.767 d
	0.56	0.779	0.760 b	0.771 b	0.759 cd	0.752 c
	0.56 + 0.56	0.779	0.752 b	0.777 b	0.760 cd	0.771 d
LSD ($P = 0.05$)		NS	0.012	0.010	0.016	0.014
S x R		NS	NS	NS	NS	NS
S x F		NS	NS	NS	NS	NS
R x F		NS	NS	NS	*	NS
S x R x F		NS	NS	*	NS	NS

[z] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[y] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[x] * and NS indicate significant and not significant at the 0.05 level of probability, respectively
[w] Vibratory-rollers (38.6 kg unit^{-1}) on a triplex-mower (590.9 kg) vertical force value of 0.32 kg cm^{-2}.
[v] Within columns, means followed by the same letter not significantly different with Fisher's least significant difference at $P = 0.05$.



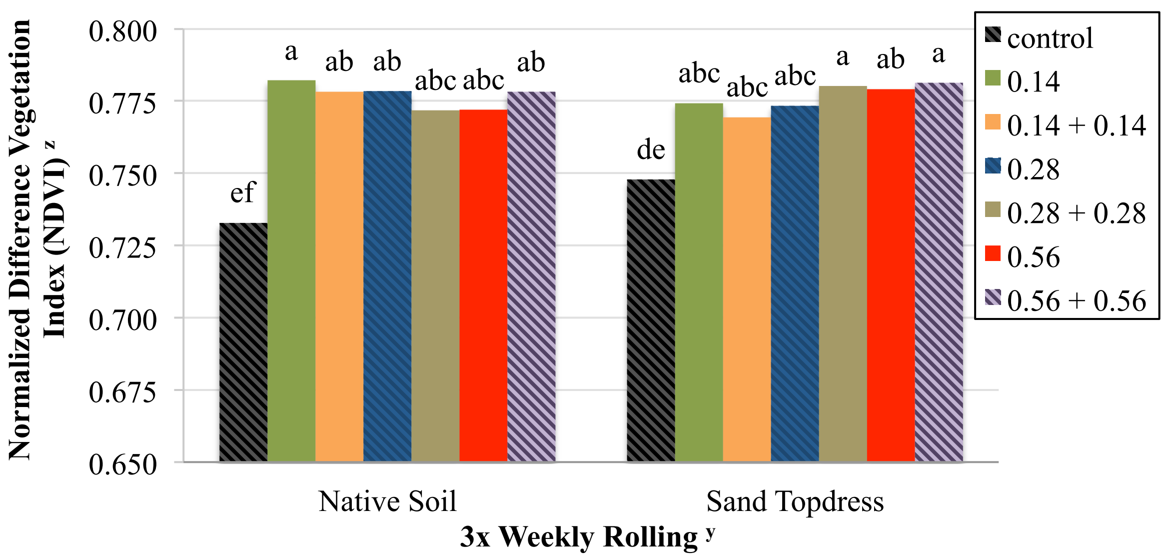


Figure 4. Effects of sand topdressing x rolling frequency x fungicide application rate on NDVI, August 11, 2014. East Lansing, MI.
^{z} NDVI range from 0.000 to 1.000 with higher values indicative of healthier plants.
^{y} Vibratory-rollers (38.6 kg unit^{-1}) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.
Total monthly boscalid fungicide application rates in kg^{-1} ha^{-1}.
Sand applied biweekly, May to September, at a rate of 11.2 m^{3} ha^{-1}.
Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
Columns with the same letter not significantly different; Tukey-Kramer Grouping at P = 0.05.

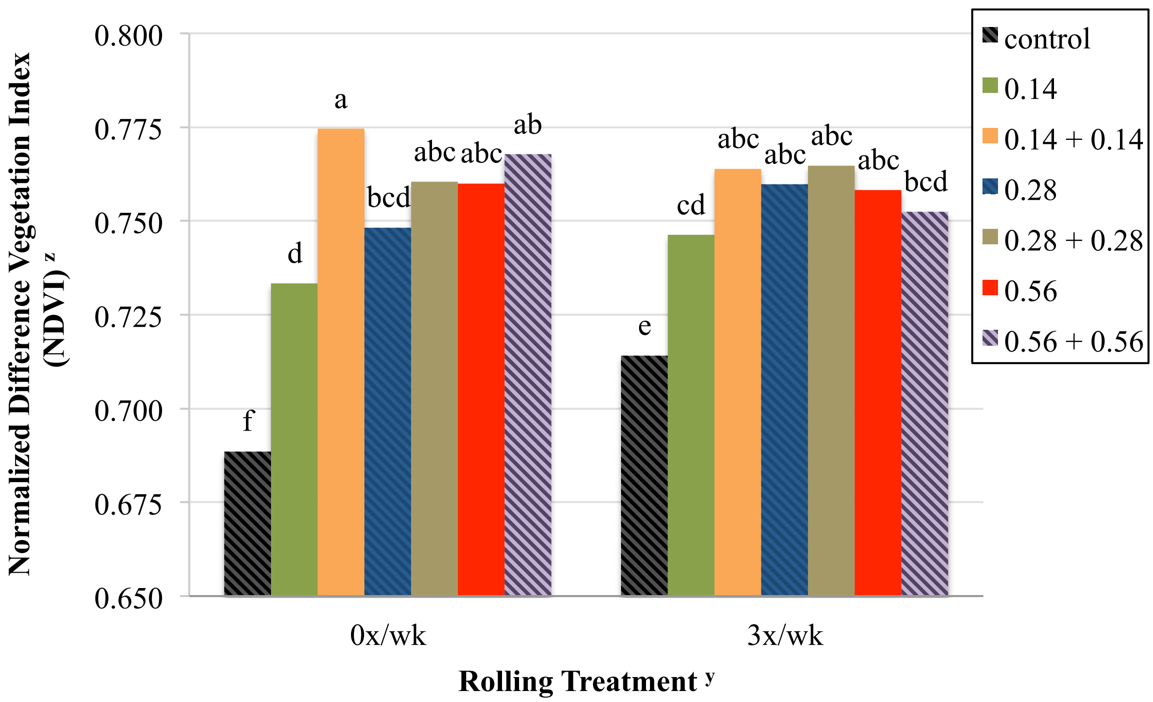


Figure 5. Effects of rolling frequency x fungicide application rate on NDVI, August 18, 2014. East Lansing, MI.

z NDVI range from 0.000 to 1.000 with higher values indicative of healthier plants.

y Vibratory-rollers (38.6 kg unit^{-1}) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.

Total monthly boscalid fungicide application rates in kg^{-1} ha^{-1}.

Columns with the same letter not significantly different; Tukey-Kramer Grouping at P = 0.05.

Effects on Turfgrass Quality

Significant main effects of rolling frequency and fungicide application rate on turfgrass quality were observed in 2013, along with a significant rolling frequency x fungicide application rate interaction effect. Turfgrass quality was visually assessed and based on a 1 (poor or dead) to 9 (best) rating scale with 6 being acceptable.

On two collection dates, the 3x weekly rolling treatment significantly improved fairway turfgrass quality when compared to the plots that were not rolled albeit the control plots still yielded acceptable quality ratings (Table 17). On the other hand, all rating dates resulted in a significant effect on quality for all fungicide application rate treatments when compared to the control. The lowest application rate (14 kg ha^{-1} $month^{-1}$) resulted in acceptable (6) turfgrass quality ratings particularly as the number of fungicide application increased over the growing season in 2013.

A rolling frequency x fungicide application rate interaction effect was observed on August 6, 2013 (Figure 6). The data results suggest that the rolling treatment not only increased the efficacy of the 14 kg ha^{-1} $month^{-1}$ fungicide application rate, but also the 28 kg ha^{-1} $month^{-1}$ rate. This effect on turf quality and fungicide efficacy was not observed in other boscalid application rate treatments.

Main effects of rolling frequency and fungicide application rate on turfgrass quality were observed in 2014. A significant sand topdressing x fungicide application rate interaction was also observed. Moreover, on two data dates, a sand topdressing x rolling frequency x fungicide application rate interaction occurred.

Even though the non-rolled control plots maintained acceptable turf quality, the 3x weekly rolling treatment enhanced fairway turfgrass quality on two occasions (Table 18). Consistent with tendency and following the overall trend, all rating dates resulted in a significant effect on quality for all fungicide application rate treatments when compared to the control.

Table 17. Effects of sand topdressing, rolling frequency, and boscalid fungicide application on turfgrass quality; visually assessed on a 1 (dead or poor) to 9 (best) rating scale with 6 being acceptable. East Lansing, MI 2013.

2013 Treatment		Turfgrass Quality (1-9)				
		22 July	6 Aug	17 Aug	21 Aug	10 Sep
Soil Type (S)	Sand Topdress [z]	6.5	7.5	7.7	7.7	8.2
	Native Soil [y]	7.1	7.5	7.6	7.8	8.2
LSD (P = 0.05) [x]		NS	NS	NS	NS	NS
Rolling Frequency (R)	0x/wk	6.5	7.3	7.5	7.6	8.3
	3x/wk [w]	7.1	7.7	7.8	7.9	8.1
LSD (P = 0.05)		*	NS	*	NS	NS
Monthly Fungicide Application Rate: kg ha^{-1} (F)	Control	3.0 a [v]	3.4 a	3.5 a	4.1 a	5.3 a
	0.14	5.4 b	7.2 b	7.3 b	7.2 b	8.2 b
	0.14 + 0.14	6.9 c	8.1 c	7.7 b	8.1 c	8.7 bc
	0.28	7.4 cd	8.0 c	8.3 c	8.3 cd	8.5 bc
	0.28 + 0.28	7.8 d	8.6 d	8.8 cd	8.7 de	8.9 bc
	0.56	8.6 e	8.4 cd	8.8 cd	9.0 e	8.8 bc
	0.56 + 0.56	8.6 e	8.7 d	8.9 d	8.7 e	9.0 c
LSD (P = 0.05)		0.5	0.47	0.5	0.5	0.7
S x R		NS	NS	NS	NS	NS
S x F		NS	NS	NS	NS	NS
R x F		NS	*	NS	NS	NS
S x R x F		NS	NS	NS	NS	NS

[z] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[y] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[x] * and NS indicate significant and not significant at the 0.05 level of probability, respectively
[w] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg) vertical force value of 0.32 kg cm^{-2}.
[v] Within columns, means followed by the same letter not significantly different with Fisher's least significant difference at P = 0.05.

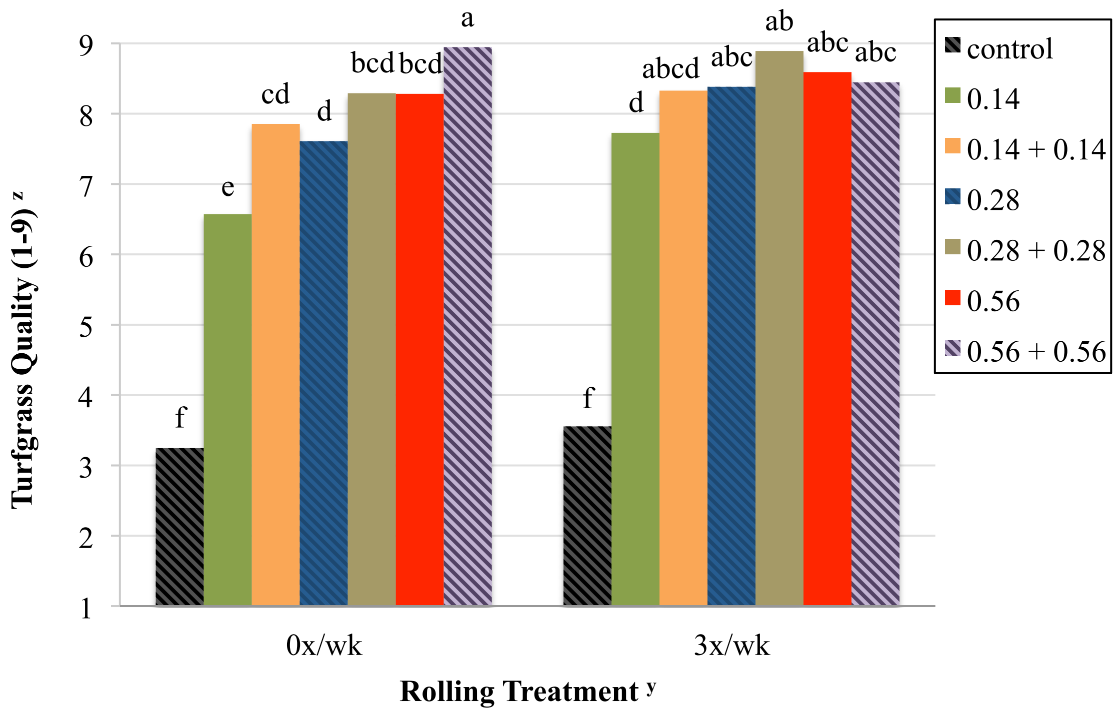


Figure 6. Effects of rolling frequency x fungicide application rate on turfgrass quality, August 6, 2013. East Lansing, MI.

[z] Visually assessed on a 1 (poor or dead) to 9 (best) rating scale with 6 being acceptable.

[y] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.

Total monthly boscalid fungicide application rates in kg^{-1} ha^{-1}.

Columns with the same letter not significantly different; Tukey-Kramer Grouping at P = 0.05.

Table 18. Effects of sand topdressing, rolling frequency, and boscalid fungicide application rate on turfgrass quality; visually assessed on a 1 (dead or poor) to 9 (best) rating scale with 6 being acceptable. East Lansing, MI 2014.

2014 Treatment		Turfgrass Quality (1-9)				
		28 July	4 Aug	11 Aug	18 Aug	25 Aug
Soil Type (S)	Sand Topdress [z]	7.5	7.8	7.9	7.0	6.6
	Native Soil [y]	7.6	7.8	7.8	7.0	6.7
LSD (P = 0.05) [x]		NS	NS	NS	NS	NS
Rolling Frequency (R)	0x/wk	7.1	7.8	7.6	6.9	6.6
	3x/wk [w]	7.6	7.8	8.1	7.1	6.7
LSD (P = 0.05)		*	NS	*	NS	NS
Monthly Fungicide Application Rate: kg ha^{-1} (F)	Control	5.7 a [v]	4.7 a	4.6 a	4.1 a	3.8 a
	0.14	6.5 b	8.2 b	7.2 b	5.0 b	4.6 b
	0.14 + 0.14	8.5 d	8.3 b	8.6 c	8.4 de	7.7 d
	0.28	7.3 c	8.3 b	8.3 c	6.4 c	5.8 c
	0.28 + 0.28	8.3 d	8.2 b	8.6 c	8.6 e	8.8 e
	0.56	8.0 cd	8.3 b	8.6 c	7.9 d	7.1 d
	0.56 + 0.56	8.6 d	8.6 b	8.9 c	8.6 e	8.9 e
LSD (P = 0.05)		0.7	0.4	0.5	0.5	0.6
S x R		NS	NS	NS	NS	NS
S x F		NS	*	NS	NS	NS
R x F		NS	NS	NS	NS	NS
S x R x F		*	NS	*	NS	NS

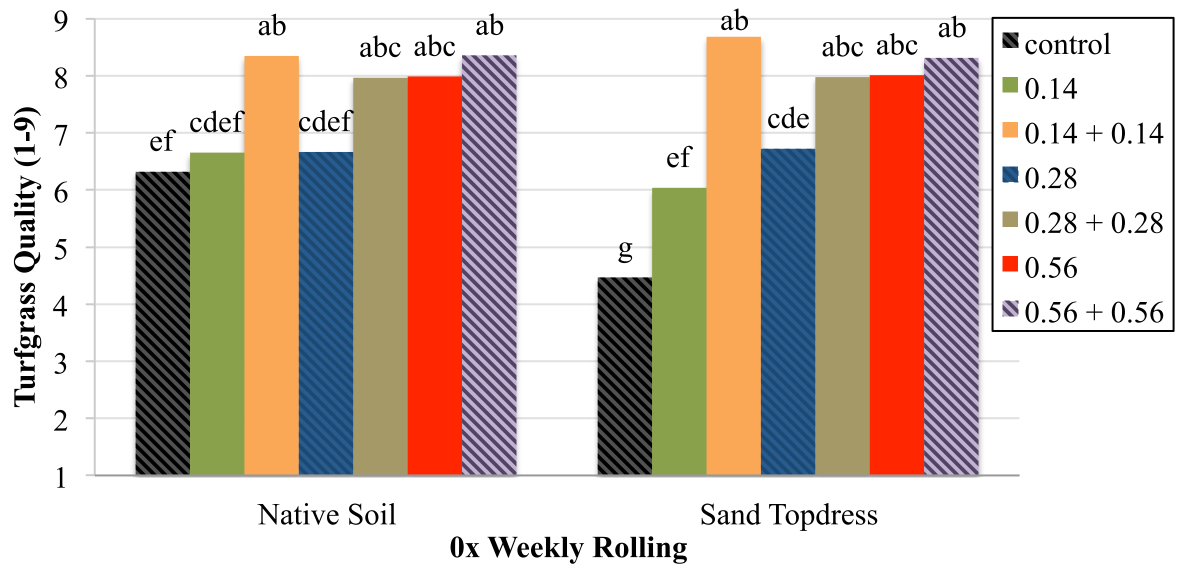
[z] Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.
[y] Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.
[x] * and NS indicate significant and not significant at the 0.05 level of probability, respectively
[w] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg) vertical force value of 0.32 kg cm^{-2}.
[v] Within columns, means followed by the same letter not significantly different with Fisher's least significant difference at P = 0.05.

Contrary to our 2013 quality results, the 14 kg ha^{-1} $month^{-1}$ rate did not improve turfgrass quality in 2014, and quality decreased as these boscalid applications accumulated over the season. Nevertheless, the double-quarter rate application treatment (14 + 14 kg ha^{-1} $month^{-1}$) was just as efficacious as the full, label recommended application rate of 0.56 kg ha^{-1} $month^{-1}$. This suggests that conservative (less than the label recommendation) fungicide rates applied over the course of a growing season will improve fairway turfgrass quality even when environmental conditions are favorable for dollar spot disease outbreak (Table 19). A significant sand topdressing x rolling frequency x fungicide application rate interaction occurred on July 28 with variable and inconsistent mean values; however, the efficacy of lightweight rolling to improve turf quality and suppress disease in turfgrass is brought to light once again. The effect of rolling greatly influenced control plot quality response as a function of the sand topdressing treatment (Figure 7). The significant sand topdressing x fungicide application rate interaction demonstrated that the sand topdressing treatment had no influence on fungicide efficacy (Figure 8). However, on August 11, a significant sand topdressing x rolling frequency x fungicide application rate interaction demonstrated that the effect of rolling not only influenced control plot quality response, but also the conservative fungicide application rate (14 kg ha^{-1} $month^{-1}$) as a function of the sand topdressing treatment (Figure 9).

Table 19. Seasonal climatic conditions experienced at the Hancock Turfgrass Research Center. East Lansing, MI 2014.

Date	Air Temperature (C°)		Precipitation	Relative Humidity (%)	
	Max.	Min.	cm	Max.	Min.
15 Aug	23.2	6.7	---	89.1	34.0
16 Aug	26.1	9.9	0.25	89.0	52.0
17 Aug	25.1	17.7	4.06	93.3	62.0
18 Aug	25.9	15.0	---	90.0	53.2
19 Aug	26.2	16.6	18.54	93.3	58.5
20 Aug	26.1	16.5	0.25	94.5	55.8
21 Aug	26.3	15.2	0.51	94.5	61.9
22 Aug	27.0	20.4	---	98.9	68.7
23 Aug	27.4	18.1	---	91.5	51.6
24 Aug	26.6	17.4	---	93.9	58.5
25 Aug	30.3	17.8	---	94.5	59.0

Latitude: 42.7110 deg.
Longitude: -84.4760 deg.
Elevation: 256.64 m
Data provided by the Michigan Automated Weather Network (MAWN) and Enviro-weather Program, Michigan State University.



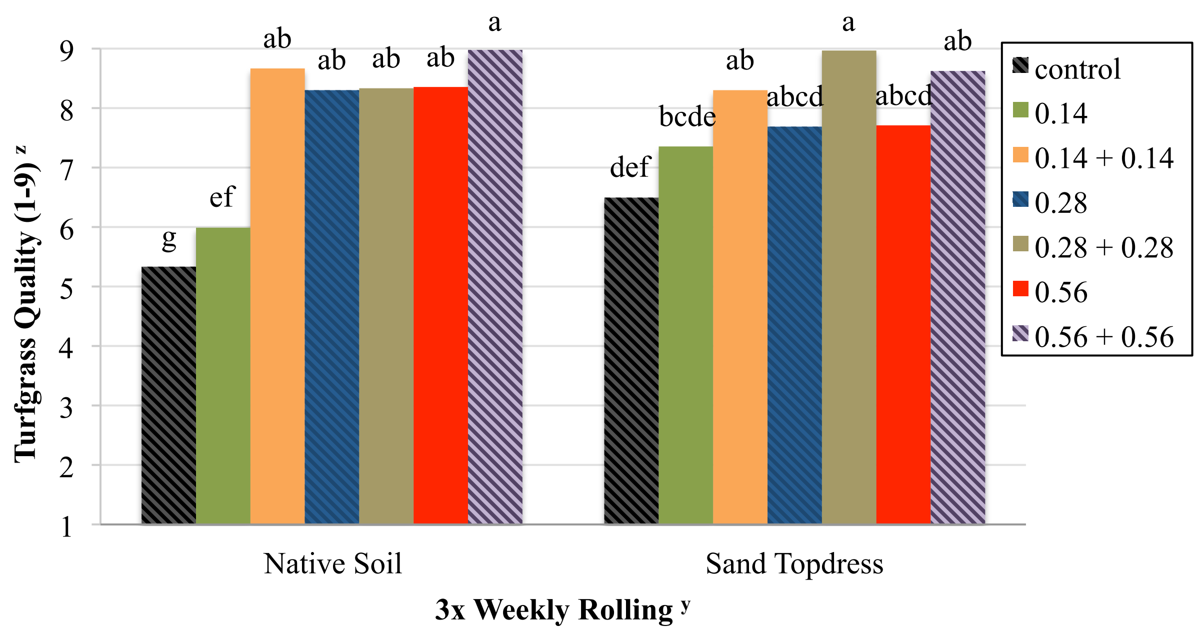


Figure 7. Effects of sand topdressing x rolling frequency x fungicide application rate on turfgrass quality, July 28, 2014. East Lansing, MI.

[z] Visually assessed based on a 1 (poor or dead) to 9 (best) rating scale with 6 being acceptable.

[y] Vibratory-rollers (38.6 kg unit^{-1}) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.

Total monthly boscalid fungicide application rates. in kg^{-1} ha^{-1}.

Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.

Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.

Columns with the same letter not significantly different; Tukey-Kramer Grouping at P = 0.05.

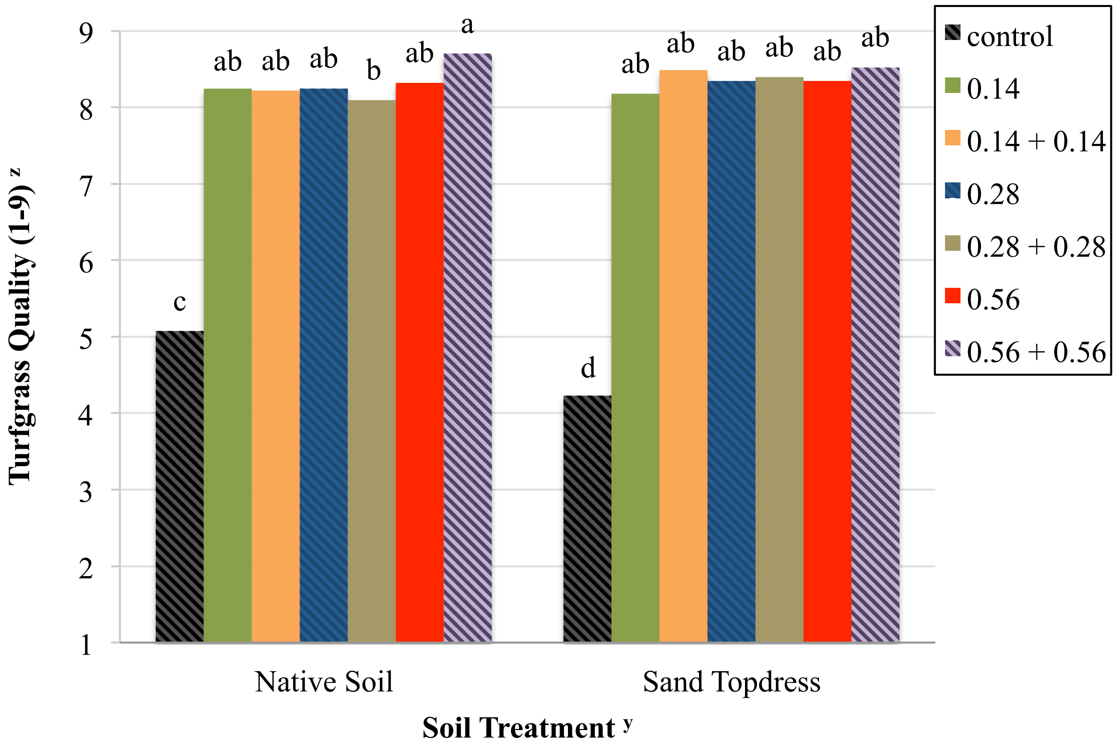


Figure 8. Effects of sand topdressing x fungicide application rate on turfgrass quality, August 4, 2014. East Lansing, MI.

[z] Visually assessed on a 1 (poor or dead) to 9 (best) rating scale with 6 being acceptable.

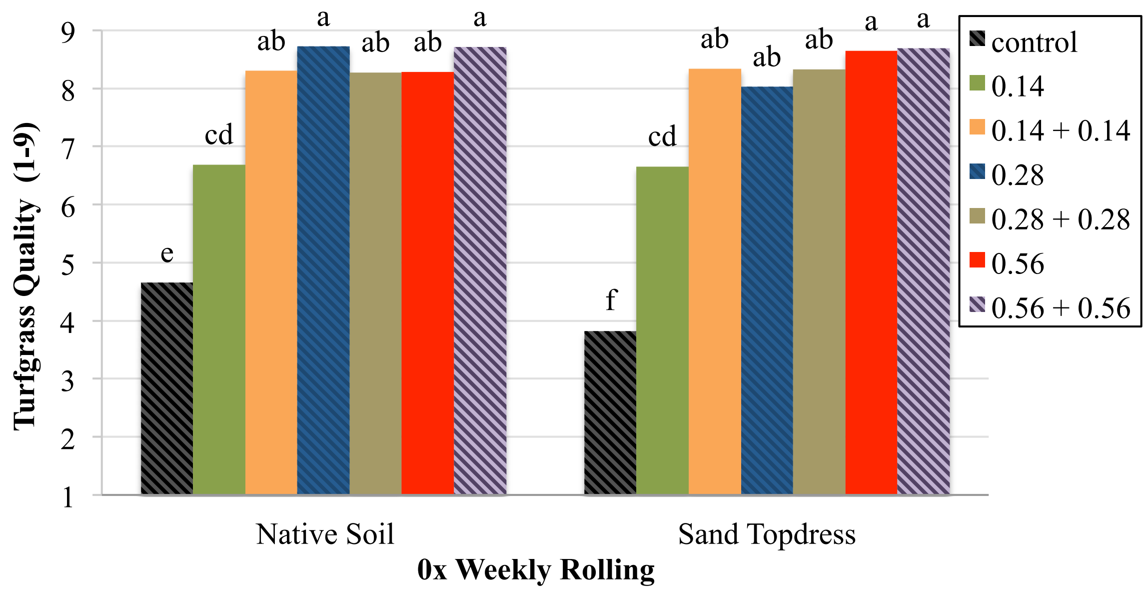
[y] Vibratory-rollers (38.6 kg unit^{-1}) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.

Total monthly boscalid fungicide application rates in kg^{-1} ha^{-1}.

Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.

Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.

Columns with the same letter not significantly different; Tukey-Kramer Grouping at P = 0.05.



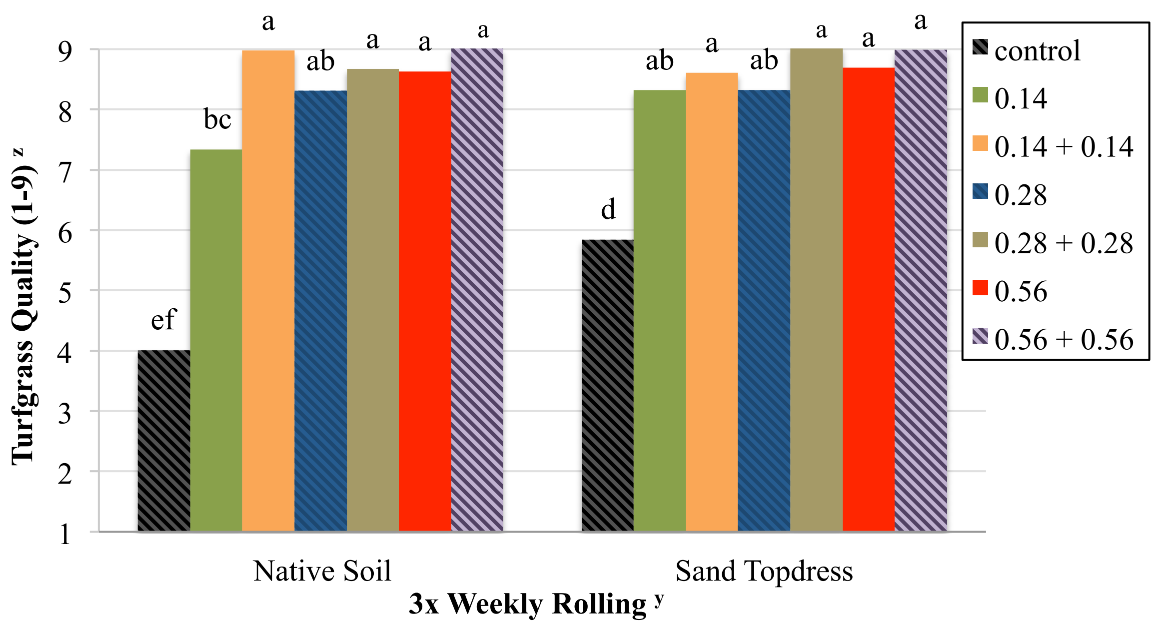


Figure 9. Effects of sand topdressing x rolling frequency x fungicide application rate on turfgrass quality, August 11, 2014. East Lansing, MI.

[z] Visually assessed based on a 1 (poor or dead) to 9 (best) rating scale with 6 being acceptable.

[y] Vibratory-rollers (38.6 kg $unit^{-1}$) on a triplex-mower (590.9 kg); vertical force value of 0.32 kg cm^{-2}.

Total monthly boscalid fungicide application rates in kg^{-1} ha^{-1}.

Sand applied biweekly, May to September, at a rate of 11.2 m^3 ha^{-1}.

Capac loam soil particle analysis of 50% sand, 24% silt and 26% clay with a 7.8 pH index.

Columns with the same letter not significantly different; Tukey-Kramer Grouping at P = 0.05.

CONCLUSIONS

In both years of the study, all boscalid fungicide application rate treatments effectively suppressed dollar spot disease when compared to the control only on two dates. Moreover, when scrutinizing disease severity, sand topdressing and rolling frequency treatments applied alone or in combination did not have synergistic effect on fungicide efficacy. This observation could be attributed to the overall effectiveness of boscalid fungicide to suppress dollar spot disease in turfgrass because the percentage plot surface area affected by dollar spot disease never exceeded 11% among all application rate treatment levels for the duration of the study. Therefore, any observable interactive treatment effects on dollar spot response were inconsequential and statistically insignificant. Contrary to these findings, Delvalle et al. (2011) observed that daily (7 days week^{-1}) dew removal by lightweight rolling increased the number of days needed to reach a disease threshold value when compared to fungicide treatments (chlorothalonil, 8.2 kg a.i. ha^{-1}; propiconazole, 0.7 kg a.i. ha^{-1}; and iprodione, 2.1 kg a.i. ha^{-1}) in which dew was not removed. In our study, the rolling treatment was only administered 3x weekly, and perhaps, the frequency was too little to reach similar results.

Nevertheless, when evaluating the effects of combinations of sand topdressing, rolling frequency, and fungicide application rates on quantitative assessments of turfgrass health, we can draw some conclusions in regard to the synergistic effects of these treatments on fungicide efficacy. Because chlorophyll content is a good indicator of plant health (Schuerger et al., 2003; Kruse et al., 2006; Baghzouz et al., 2007), we used a normalized difference vegetation index meter (NDVI-TCM 500, Spectrum Technologies, Inc. Aurora, IL) to quantitatively evaluate turfgrass quality response. With that being said, substantial increases in NDVI response were observed among all fungicide application rates when compared to the control, and surprisingly, no differences were noticed between the lowest monthly application rate (14 kg ha^{-1}) and the full, label recommended application rate (0.56 kg ha^{-1}) on NDVI in 2013. These results suggest that conservative applications rates, with definite economic benefits, applied over the course of a growing season will improve fairway turfgrass health even when environmental conditions favor dollar spot disease outbreak.

We only observed one collection date in 2013 where rolling effect was significant, but the 3x weekly rolling treatment yielded the lowest NDVI response compared to the no roll, control. However, in 2014, the 3x weekly rolling treatment yielded the greatest NDVI response compared to the no roll, control. Results are consistent with Nikolai et al. (2001) and Giordano et al. (2012) on the long-term benefits of lightweight rolling.

Sand topdressing and rolling treatments applied to a fairway turf stand produced inconsequential effects on fungicide efficacy and NDVI responses, with the exception of the control plot. Consequently, the effect of rolling greatly influenced control plot NDVI response as a function of the sand topdressing treatment. Similar to these findings, Skorulski et al. (2010) and Inguagiato et al. (2012) noticed that sand topdressing not only reduced the severity of pathogen infection, but also increased fairway turfgrass quality, color, and density. Moreover, the benefits of lightweight rolling can no longer be denied in due respect of the research of Nikolai et al. (2001), Inguagiato et al. (2009), and Giordano et al. (2012) as they have determined that rolling not only decreased dollar spot severity, but also other turf diseases such as anthracnose (*Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman, 2006).

In most instances, visual assessments of turfgrass quality were positively correlated with NDVI responses. Normalized difference vegetation index has been used extensively to reference turfgrass stress (Trenholm et al., 1999), and "to assess a plethora of growth responses, including plant water stress" (Baghzouz et al., 2007). Therefore, we felt that NDVI provided a more accurate assessment of turfgrass quality than visual quality assessments.

The 3x weekly rolling treatment improved turfgrass quality when compared to the no roll, control on several collection dates in 2013 and 2014. Once again in agreement with the findings of

Nikolai et al. (2001), Inguagiato et al. (2009), and Giordano et al. (2012) as they also observed improved turfgrass quality on plots that were rolled over time. On the other hand, the effects of cumulative rolling applications suggest that rolling can be used to increase fungicide efficacy in comparison to the control. Similar to these findings, Delvalle et al. (2012) observed reduced disease incidence and improved turfgrass quality as a result of daily (7 days week^{-1}) dew removal, and hence an increase in the number of days needed to reach a disease threshold value when compared to fungicide treatments (chlorothalonil, 8.2 kg a.i. ha^{-1}; propiconazole, 0.7 kg a.i. ha^{-1}; and iprodione, 2.1 kg a.i. ha^{-1}) in which dew was not removed by a lightweight rolling regime. Additionally, the effects of combinations of cumulative sand topdressing and rolling applications suggest that topdressing and rolling can be used to improve turfgrass quality in comparison to the control. Roberts and Murphy (2014) observed that sand topdressing applications reduced anthracnose (*Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman, 2006) in annual bluegrass putting green plots. They also noticed that the effects of combinations of sand topdressing and foot traffic reduced disease incidence and improved turf quality despite greater soil bulk density indices. Similar to the aforementioned research findings, Giordano et al. (2012) also noticed fewer dollar spot lesions in sand topdressed turfgrass plots that were rolled 5x weekly, and thus associated this effect as a function of an increase of volumetric water content since drought stress has been observed to increase disease susceptibility in turf.

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