TIMING OF FUNGICIDE APPLICATIONS FOR THE MANAGEMENT OF DOLLAR SPOT

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* * * *

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ABSTRACT

Dollar spot caused by Sclerotinia homoeocarpa is one of the most important diseases of turfgrass. Previous research has shown that fungicide applications to asymptomatic turfgrass in the fall and/or spring, at times when fungicide applications are not typically made, can reduce dollar spot severity the following growing season. The purpose of this research was to: (a) validate previous findings regarding the efficacy of late fall and/or early spring fungicide applications to suppress dollar spot, and (b) to determine the relationship between air temperature and the timing of all effective fall/spring fungicide applications with the goal of developing practical recommendations for golf course superintendents. Replicated field studies were established at two locations within central Ohio from October 2006 to July 2008 to assess the impact of late fall and early spring fungicide applications to suppress dollar spot. Mean daily air temperatures were collected throughout the 2-year study. Single fall applications of the fungicides propiconazole and chlorothalonil, as a tank mix, had no impact on disease severity the following season. In contrast, multiple sequential fall applications of these same fungicides did significantly reduce dollar spot severity. Both single and sequential multiple fungicide applications in March and April resulted in significantly less dollar
spot severity the following summer during both years of the study. The effective single spring applications can be classified into two general groups based on the timing of when these applications were made: “Early Spring” applications (at The Ohio Turfgrass Research and Educational Facilities (OTF) on April 3; at both locations April 10, 17, 24; and at The Golf Club (TGC) on May 5, 2007); and “Late Spring” applications (at TGC on May 15, 29, June 5; and at OTF on June 5 and 12, 2007). Two distinct groups of effective single spray applications were also observed at OTF in “Early Spring” of 2008 on March 17, 25 April 2, 15, 22, 29 and May 6; and “Late Spring” on May 27 June 9, 17, 25, and July 1, 2008. The average air temperature range associated with these “Early Spring” effective dates in 2006-07 trial year was 41-71 °F and at TGC 44-70 °F. Growing degree-day (GDD) measurements for the effective single applications at both locations and years have a very wide range from GGD$_{33}$ 344 – 1348; GGD$_{40}$ 160 – 827; and GGD$_{50}$ 28 –340. GDD may be a useful tool at predicting the timing of “Early Spring” fungicide applications to suppress dollar spot. To ensure low dollar spot activity a golf course superintendent would make a fungicide application when the pathogen is metabolically active (41-70 °F) theoretically before the pathogen reached a level capable of inciting disease. If a fungicide is applied in the early spring once the mean daily air temperature is above 41 °F and if fungicide applications continue as recommended by the labeled date rotation until the mean daily air temperatures are above 70 °F, a significant reduction in dollar spot severity would likely occur as we observed both years of the study.
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter/Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1</td>
<td>Literature Review</td>
<td>1</td>
</tr>
<tr>
<td>Chapter 2</td>
<td>Timing of Fungicides to Manage Dollar Spot</td>
<td>19</td>
</tr>
<tr>
<td>Appendix A</td>
<td>Study plot plans plot identification</td>
<td>41</td>
</tr>
<tr>
<td>Appendix B</td>
<td>Digital imagery analysis procedure to include operation of camera, photo box and saving images: plus real time procedures on how to use APS Press Assess software</td>
<td>44</td>
</tr>
<tr>
<td>Appendix C</td>
<td>Digital imagery analysis for assessing dollar spot</td>
<td>59</td>
</tr>
<tr>
<td>Appendix D</td>
<td>Use of watchdog weather stations and sensors to monitor local weather conditions</td>
<td>68</td>
</tr>
<tr>
<td>Appendix E</td>
<td>First incident of annual bluegrass weevil, <em>Listronotus maculicollis</em>, Damage in Ohio</td>
<td>75</td>
</tr>
<tr>
<td>Appendix F</td>
<td>List of references</td>
<td>78</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 2.1 Treatments used in 2006-07 and 2007-08 field studies. ..................................30

Table 2.2 Contrasts of treatments by each location during the 2006-07 field studies. .....31

Table 2.3 Application schedule and results from the 2006-07 field studies .................32

Table 2.4 Contrasts of treatments by location during the 2007-08 field studies.............33

Table 2.5 Application schedule and results from the 2007-08 field studies. ..............34

Table 2.6 Growing degree-days calculations for 2006-2008 field studies at various bases from January 1 to June 30..................................................................................................................35

Table 2.7 Growing degree-days calculations for the “Early Spring” fungicide applications the effectively reduce dollar spot severity (2006-07 and 2007-08).............36

Table D.1 Pearson correlation coefficient, N=24 correlating single treatments 2006-2008 with regional climatic conditions with P-values.........................................................74
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1</td>
<td>Dollar spot symptoms on a golf course fairway</td>
<td>10</td>
</tr>
<tr>
<td>Figure 1.2</td>
<td>Diagnostic hourglass lesion with cinnamon banding characteristic of dollar spot showing <em>Sclerotinia homoeocarpa</em> growing from the lesion</td>
<td>11</td>
</tr>
<tr>
<td>Figure 1.3</td>
<td>Mycelium of <em>Sclerotinia homoeocarpa</em> in the field on creeping bentgrass (<em>Agrostis stolonifera</em>)</td>
<td>11</td>
</tr>
<tr>
<td>Figure 1.4</td>
<td>Aerial mycelium characteristic of <em>Sclerotinia homoeocarpa</em> when grown in culture</td>
<td>12</td>
</tr>
<tr>
<td>Figure 1.5</td>
<td>Septate hyphae of <em>Sclerotinia homoeocarpa</em></td>
<td>12</td>
</tr>
<tr>
<td>Figure 1.6</td>
<td>Growth of <em>Sclerotinia homoeocarpa</em> on potato dextrose agar (14 days post inoculation)</td>
<td>13</td>
</tr>
<tr>
<td>Figure 1.7</td>
<td>Projected pathogen activity curve for <em>Sclerotinia homoeocarpa</em> under field conditions in central Ohio</td>
<td>14</td>
</tr>
<tr>
<td>Figure 1.8</td>
<td>Dollar spot disease cycle developed as part of this thesis and based on the peer reviewed scientific literature</td>
<td>15</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>Observed high and mean daily air temperatures at The Ohio Turfgrass Foundation Research and Education Facility (OTF) and The Golf Club (TGC) relative to the 30-year mean daily air temperatures for February 1 through July 31, 2007</td>
<td>37</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Observed high and mean daily mean temperatures at The Ohio Turfgrass Foundation Research and Education Facility (OTF) relative to the 30-year mean daily air temperatures for February 1 through July 26, 2008</td>
<td>38</td>
</tr>
</tbody>
</table>
Figure A.1  Field studies layout and plot plan at the Ohio Turfgrass Foundation Research and Education Facility and The Golf Club 2006-07 ..........................................................42

Figure A.2  Field studies layout and plot plan at the Ohio Turfgrass Foundation Research and Education Facility and The Golf Club 2007-08 .........................................................43

Figure B.1  Light fixture mount in the rating box .................................................................50

Figure B.2  Generator mounting with generator attachment on the rating box ...............51

Figure B.3  Interior wire framing the “Point of Interest” in APS Assess Software Program ..............................................................................................................................51

Figure B.4  Removal of the rating box’s hitch and tires prior to taking ratings ..............52

Figure B.5  Location of the manual settings on the Nikon D 50 camera .......................53

Figure B.6  Location of the lens adjustment to set for the proper lens height .............53

Figure B.7  The use of a coffee filter to set the camera’s white balance .......................54

Figure B.8  Proper mounting of the camera on top of the rating box .........................55

Figure B.9  Location of the F-Stop +/- button on a Nikon D50 Camera .......................56

Figure B.10 Improper poker chip placement on rating surface .......................................57

Figure B.11 Correct poker chip placement on rating surface ..........................................57

Figure C.1  Simple linear regression comparing dollar spot infection centers counts to digital imaging analysis’s percent data .................................................................64

Figure C.2 A and B  Pictures from The Golf Club taken on 7/24/2008 revealing drought stress and inert matter were included in the percent measurement 65

Figure C.3 A and B  Pictures from Ohio Turfgrass Research and Education Center in on 7/15/2008 revealing dollar spot flecking and thatch were included in the percent measurement .................................................................66

Figure C.4 A and B  Pictures from Ohio Turfgrass Research and Education Center on 6/12/2008 revealing brown patch and earthworm castings were included in the percent measurement .................................................................67

Figure C.5 A and B  Pictures from Ohio Turfgrass Research and Education Center on 6/20/2008 revealing earthworm castings were included in the percent measurement 68
Figure D.1 Watchdog weather station installed at The Golf Club and The Ohio Turfgrass Research and Educational Facility .................................................................69

Figure D.2 Mean air temperature collected by the Watchdog data loggers at The Golf Club (TGC) and Ohio turfgrass Foundation research and Experimental Station (OTF) in 2006-2008. .............................................................................................70

Figure D.3 Mean soil temperature collected by the Watchdog data loggers at The Golf Club (TGC) and Ohio turfgrass Foundation research and Experimental Station (OTF) in 2006-2008. .............................................................................................71

Figure D.4 Accumulated daily precipitation amounts collected by the Watchdog data loggers at The Golf Club (TGC) and Ohio turfgrass Foundation research and Experimental Station (OTF) in 2006-2007. .................................................................72

Figure D.5 Mean daily relative humidity measurements from the Watchdog data loggers at The Golf Club (TGC) and Ohio turfgrass Foundation research and Experimental Station (OTF) in 2007-2008...............................................................................................73
CHAPTER 1
LITERATURE REVIEW

Dollar spot, caused by *Sclerotinia homoeocarpa* F.T.Bennett, is one of the most economically important diseases of turfgrass. *S. homoeocarpa* infects a wide range of turfgrass in the temperate and subtropical regions of the world (Vargas 2004). With the exception of the Pacific Northwest and Western Canada, dollar spot is the most common turfgrass disease in North America (Couch, 1995). Despite dollar spot’s economic importance, little is known about the biology, ecology, and epidemiology of this pathogen (M.J. Boehm, personal communication).

**Signs and Symptoms.** The name dollar spot is derived from the circular blighted or straw colored spots, which grow approximately the size of a silver dollar on low cut turfgrass such as golf course fairways (Bennett, 1937). On low cut turfgrass, *S. homoeocarpa* infects the foliage and in severe cases, can kill the infected plant and cause a pitting of the turf to the soil (Couch, 1995; Figure 1.1). Dollar spot infection centers rarely grow to be larger than 5 cm in diameter, but under ideal conditions, may coalesce increasing the area and significance of the disease outbreak (Smiley et al., 2005). The diagnostic symptom on the leaf blade is an hourglass-shaped, straw to bleach white lesion that extends the width of the entire leaf blade (Figure 1.2). Cinnamon colored banding is
typically observed on either side of the hourglass lesion (Figure 1.3). In temperate climates, dollar spot typically occurs from late spring through autumn when temperatures range from 68-86°F. Disease progress may slow or ceases temporary during hot periods of dry weather (Smiley et al., 2005).

White cobweb-like aerial mycelium is typically observed early in the morning prior to the evaporation or removal of dew and guttation water (Jackson, 1989; Smith et al., 1989; Figures 1.2 and 1.3). Mycelium of the dollar spot fungus grows outward spreading from the infected lesions to adjacent host tissue (Figures 1.2 and 1.3). A link between lesion formation and “toxin” production by the pathogen has been hypothesized (Smiley et al., 2005). Recent work by Venu et al. (2009) has revealed that *S. homoeocarpa* produces several acids when grown on potato dextrose agar (PDA) or in potato dextrose broth (PDB) to include oxalic acid. Acid production is greatest between 68-86°F, the same temperature at which symptoms are most often observed in the field (Venu et al., 2009).

In culture, the pathogen will typically grow and completely cover a PDA Petri dish within 4 days (Figure 1.4). The pathogen produces no fruiting structures, and relatively nondescript septate hyphae (Figure 1.5). The mycelium of *S. homoeocarpa* becomes more darkly pigmented over time. The formation of dark brown to black substratal stroma on PDA is readily observed 2-3 weeks post inoculation (Figure 1.6). Observation of substratal stroma in the field is rare and has been confined to fine fescue (*Festuca* spp.; Festermacher, 1980).
THE PATHOGEN

Taxonomy. Dollar spot was first described in 1932 by Monteith and Dahl. They named the disease little brown patch and implicated a species of Rhizoctonia as the causal agent. In 1937, the British scientist, Fredric T. Bennett, examined the pathogen in detail. He collected several isolates from Great Britain, North America and Australia. He described several different forms of the pathogen including a perfect strain from the Great Britain which produced both ascospores (in apothecia) and conidia, and nonspore forming isolates from North America and Australia, respectfully (Bennett, 1937). He also noted the production of sclerotial-like structures, and based on these observations placed the fungus in the genus Sclerotinia. Because of the similarity in the appearance of the ascospores and conidia produced by the British strain, Bennett named the fungus Sclerotinia homoeocarpa (1937).

Efforts to produce fertile apothecia or microconidia of S. homoeocarpa have been unsuccessful (Fenstermacher, 1970; 1980 Orshinsky and Boland, 2009). The taxonomic classification of this pathogen remains in question. One reason for this is that the pathogen does not produce sclerotia or apothecia like the other fungi belonging to the genus Sclerotinia (Kohn, 1979). Several researchers have suggested alternative taxonomic classification of the fungus dollar spot pathogen (Kohn, 1979; Novak and Kohn, 1991; Powell and Vargas 2001; Vargas, 2004). Today, most turfgrass pathologists and fungal taxonomists place the dollar spot fungus in the family Rutstroemiacae (Linda Kohn, personal communication).
Influence of Environmental Factors on Dollar Spot. The generally accepted optimal temperature range for the growth of *S. homoeocarpa* and development of dollar spot symptoms is (68-86°F) with high relative humidity (greater than 85%), and/or prolong (12-14 hours) of leaf wetness (Couch, 1995: Smiley et al., 2005; Vargas, 2004). Disease is typically most severe on turfgrass that is under-fertilized and grown on dry soils (Couch, 1995; Endo, 1963). Most recently, work done by Venu et al. (2009) confirmed this temperature optimum for growth of *S. homoeocarpa* in culture and showed that acid production by the pathogen was also greatest during this same temperature range. An illustration of the projected pathogen activity curve for *S. homoeocarpa* under field conditions in central Ohio is was developed based on Couch and Venu’s research (Figure 1.7).

Disease forecasting models. Management strategies such as disease forecasting models, that are based on knowledge about the host - pathogen interaction and epidemiology are used in many important cropping systems. For example, TomCast is a computer generated forecasting system used to predict several important diseases including early blight, septoria leaf spot and anthracnose on tomatoes. This system provides growers the means to monitor environmental conditions and alert them when the probability for a disease outbreak is high.

Predictive models have also been developed for several turfgrass diseases including dollar spot (Leslie, 1994). Mills and Rothwell (1982) used air temperatures and relative humidity to publish the first disease forecasting model for dollar spot. In this model, a fungicide application is recommended when the maximum air temperature
reaches or exceeds 77°F and maximum relative humidity is \( \geq 90\% \) for 3 days during any 7-day period. When used to time fungicide applications, this model provided a conservative prediction of dollar spot activity resulting in the application of an excessive number of fungicides applications (Burpee and Goulty, 1986). Shortly thereafter, Hall (1984) published a second dollar spot forecasting model also developed using precipitation and mean daily air temperature. Hall’s model called for a fungicide application after 2 consecutive days of rainfall if mean daily air temperature exceeded 71.6°F, or after 3 consecutive days of rainfall when mean daily air temperatures exceeded 59°F. When validated in the field, Hall’s model proved to be a less accurate predictor of dollar spot and when used to time fungicide applications, resulted in a lack of acceptable disease suppression (Burpee and Goulty, 1986).

**Disease Cycle.** Despite the economic impact of dollar spot, relatively little is known about the ecology, biology, and epidemiology of *Sclerotinia homoeocarpa*. As part of this thesis, a new illustrated dollar spot disease cycle was developed based on the peer-reviewed scientific literature (Figure 1.8). It is generally accepted that *S. homoeocarpa* survives periods of dormancy as dormant mycelium in infected lesions (Britton et al., 1969; Couch, 1995) or as substratal stromata in decaying host tissue or thatch (Fenstermacher, 1970, 1980). When favorable weather conditions are conducive for pathogen growth, mycelia from these infected tissues and/or stroma grows and infects neighboring susceptible plant tissue. *Sclerotinia homoeocarpa* is believed to enter the host through wounds and/or stomates (Monteith & Dahl, 1932). There have been no reports of *S. homoeocarpa* infection of bentgrass roots, but root stunting and various stages of necrosis have been observed in the laboratory (Endo, 1963). Primary
dissemination of *S. homoeocarpa* is thought to be through the movement of mycelium and/or infected tissue by animals, people (golfers), and equipment (Couch, 1995).

**INTEGRATED DOLLAR SPOT MANAGEMENT**

**Genetic Host Resistance.** The susceptibility of the different turfgrass species and/or cultivars/varieties to dollar spot is well documented (National Turfgrass Evaluation Program). For example, tall fescue (*Festuca arundinacea*) and perennial ryegrass (*Lolium perenne* L.) are relatively resistant where as Kentucky bluegrass (*Poa pratensis*), annual bluegrass (*Poa annua*) and creeping bentgrass (*Agrostis stolonifera*) are relatively susceptible. Within a given species there can be variation between cultivars. For example, creeping bentgrass cultivars Declaration and L93 are relatively resistant where as cultivar Crenshaw is relatively susceptible (National Turfgrass Evaluation Program). To date, cultivars of bentgrass immune to dollar spot do not exist, but efforts to develop them are underway (Bonos et al., 2006). The use of genetically resistant cultivars for managing dollar spot is limited to either new construction or turfgrass areas undergoing renovation.

**Biological Control.** The use of biological control as a means to suppress diseases in crop systems has been a focus of a great deal of research due to environmental concerns over the use of chemical pesticides (Raudales and McSpadden Gardener, 2008). Over the past 20 years, several biological control organisms have been isolated and developed for the suppression of dollar spot to include *Pseudomonas aureofaciens*, *Enterbacter cloacae*, and *Gliocladium virens*. The bacterium *Pseudomonas aureofaciens* is a commercially available product for use in a sprayer or in the Bioject system. The reliability of the Bioject delivery system is variable however, and does not provide consistent or
commercially acceptable levels of disease control (Vargas, 2004). Other biological agents tested that contribute to the reduction of dollar spot symptom development include *Enterbacter cloacae* (Nelson and Craft, 1991), *Gliocladium virens* (Haygood and Mazur, 1990), and other fungal, microbial and bacterial agents (Walsh et al., 1999). Results from studies with these biological controls agents revealed that they were less effective than fungicides (Sigler et al., 2001).

**Cultural Practices.** Exercising sound cultural management practices can reduce dollar spot severity and such strategies are an important part of successfully managing dollar spot on golf courses. In general, dollar spot severity can be significantly reduced by improving the overall health of the turfgrass and minimizing leaf wetness (Couch, 1995). Although cultural management practices are employed to reduce dollar spot severity, fungicides are still typically required to maintain acceptable control of this disease.

The removal of dew and/or guttation water from the leaf blade has been shown to reduce dollar spot severity by limiting the duration of leaf wetness (Ellram et al., 2007; Williams et al., 1996). Means of reducing leaf wetness include polling or wiping, mowing, rolling, dragging, and syringing the turf. The removal of trees and shrubbery has also proved effective as a means to reduce leaf wetness by increasing air movement and sunlight penetration (Koh et al., 2003; Vargas, 2004).

In a greenhouse study, an increase in dollar spot severity was observed when the turf was inadequately irrigated (Couch and Bloom, 1960) suggesting that proper water management reduces dollar spot severity. Couch (1995) reports that limiting thatch at the soil interface may result in a reduction in dollar spot severity because high thatch amounts inhibits water penetration into the soil, causing excessively dry soils while at the
same time providing an environment ideal for the growth of *S. homoeocarpa*. One way to reduce thatch is through core cultivation or aerification. This method increase gas exchange and water infiltration rates within the upper 4-6 inches of the soil profile. Liu et al. (1995) recommended combining hollow core cultivation with a fungicide application to achieve maximum suppression of dollar spot. Soil pH does not appear to affect growth of *S. homoeocarpa* (Couch and Bloom, 1960).

Proper turf fertility is often a challenge for golf course superintendents. If the putting greens are adequately fertilized, they tend to grow rapidly leading to a decrease in ball roll and increase in maintenance expenses. In contrast, maintaining inadequately fertilized turf increases ball roll, but sacrifices turfgrass health, making it more susceptible to dollar spot and resulting in a slower recovery time when disease occurs (Couch and Bloom, 1960; Walsh et al., 1999).

**Chemical Control.** To sustain the aesthetics and playability of turf, golf course superintendents rely heavily on pesticide applications (Cole et al., 1968). This is especially true on putting greens (~2.5 acres of putting green per golf course). Turfgrass managers control dollar spot and other fungal diseases by using a combination of contact and systemic fungicides. There are currently only two contact fungicides labeled for dollar spot control; Thiram and Chlorothalonil. There are numerous systemic fungicides labeled for dollar spot control such as those in the chemical families Dicarboximides, Benzimidazoles, Carboxamides, and the Sterol Inhibitors or Demethylase Inhibitors. One concern with these site specific or single mode of action fungicides is the development of resistance (Vargas, 2004). The term “resistant” generally implies the loss of disease control in the field even when the turf has been treated with an effective
fungicide. Through the intense use of fungicides, documentation regarding both cross and multiple resistance to all systemic fungicide families and dollar spot has been developed. These findings highlight the need to develop fungicide use patterns or integrated pest management approaches that limit the use of such fungicides or otherwise slow the development of resistance within populations of *Sclerotinia homoeocarpa* (Cole et al., 1968; Couch and Smith, 1991; Golembiewski 1995; Vargas et al., 1992; Vargas, 2004).

**Thesis Goal.** Previous research has shown that fungicide applications to asymptomatic turfgrass in the fall and/or spring, at times when fungicide applications are not typically made, can reduce dollar spot severity the following growing season (Niver 2007). The goal of this thesis is to: (a) validate previous findings regarding the efficacy of late fall and/or early spring fungicide applications to suppress dollar spot; and (b) to determine the relationship between air temperature and the timing of these effective fungicide applications in hopes of developing practical recommendations for deploying this dollar spot management strategy.
Figure 1.1 Dollar spot symptoms on a golf course fairway. Dollar spot symptom observed on a golf course fairway compiled of creeping bentgrass, \textit{(Agrostis stolonifera)}), and annual bluegrass, \textit{(Poa annua)}, mowed at 0.125 inches. The disease was called dollar Spot due to the silver dollar size spots it creates on low cut turf as seen above.
**Figure 1.2** Diagnostic hourglass lesion with cinnamon banding characteristic of dollar spot showing *Sclerotinia homoeocarpa* growing from the lesion. Photograph courtesy of D. S. Gardner – used with permission.

**Figure 1.3** Mycelium of *Sclerotinia homoeocarpa* in the field on creeping bentgrass (*Agrostis stolonifera*). Photograph courtesy of M.J. Boehm – used with permission.
Figure 1.4  Aerial mycelium characteristic of *Sclerotinia homoeocarpa* when grown in culture.

Figure 1.5  Septate hyphae of *Sclerotinia homoeocarpa*.
Figure 1.6 Growth of *Sclerotinia homoeocarpa* on potato dextrose agar (14 days post inoculation). Black arrows highlight the production of substratal formation.
Figure 1.7  Projected pathogen activity curve for *Sclerotinia homoeocarpa* under field conditions in central Ohio. Black line represents the 30 average daily air temperatures for Columbus, Ohio. Blue green and red shading represents temperatures at which *Sclerotinia homoeocarpa* is dormant (blue), actively growing (green), and dormant due to excessive heat (red) based on pathogen growth in the laboratory.
Dollar Spot Disease Cycle — Northern Climate
Caused by Sclerotinia homoeocarpa (F.T. Bennett)

Figure 1.8 Dollar spot disease cycle developed as part of this thesis and based on the peer reviewed scientific literature.
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Detection of demethylation inhibitor (DMI) resistance in Sclerotinia


CHAPTER 2

Timing of Fungicides to Manage Dollar Spot

Management strategies, such as disease foresting models, that are based on knowledge about the host-pathogen interaction and epidemiology are used in many important cropping systems. For example, TomCast is a computer generated forecasting system used to predict several important diseases including early blight, septoria leaf spot and anthracnose on tomatoes. This system provides growers the means to monitor environmental conditions and alert them when the probability for a disease outbreak is high.

Predictive models have also been developed for several turfgrass diseases including dollar spot (Leslie, 1994). Mills and Rothwell (1982) used air temperatures and relative humidity to publish the first disease forecasting model for dollar spot. In this model, a fungicide application is recommended when the maximum air temperature reaches or exceeds 77°F and maximum relative humidity is ≥ 90% for 3 days during any 7-day period. When used to time fungicide applications, this model provided a conservative prediction of dollar spot activity resulting in the application of an excessive number of fungicides applications (Burpee and Goulty, 1986). Shortly thereafter, Hall (1984) published a second dollar spot forecasting model also developed using
precipitation and mean daily air temperature. Hall’s model called for a fungicide application after 2 consecutive days of rainfall if mean daily air temperature exceeded 71.6°F, or after 3 consecutive days of rainfall when mean daily air temperatures exceeded 59°F. When validated in the field, Hall’s model proved to be a less accurate predictor of dollar spot and when used to time fungicide applications, resulted in a lack of acceptable disease suppression (Burpee and Goulty, 1986).

Previous research conducted by Boehm et al. (2005, 2007) on dollar spot showed that fungicide applications applied in the fall and/or spring to asymptomatic turfgrass have the potential to reduce dollar spot severity the following season; however, the impact of these applications is variable. Niver (2007) showed the impact of these preventive fungicide applications varied by site and over time. She suggested that weather conditions at or around the time of a fungicide application likely accounted for the variability observed. To show the influence of weather conditions on the efficacy of these fungicide applications, Niver (2007) focused on air temperature trends following the application of fungicides. In the case of fall applications, she hypothesized that if air temperatures following a fall fungicide application(s) (within 21 days of an application) dropped to and stayed ≤ 32°F, that these applications would have a high probability of effectively reducing dollar spot severity the following season. Conclusions from her spring treatments stated that applications “after the second mowing” would decrease dollar spot severity later that season. She went on to propose the use of growing degree-day models and phenology as a practical means for golf course superintendents to time their early spring fungicide applications but did not develop such models.
Previous research has shown that fungicide applications to asymptomatic turfgrass in the fall and/or spring, at times when fungicide applications are not typically made, can reduce dollar spot severity the following growing season (Niver 2007). The goal of this thesis is to: (a) validate previous findings regarding the efficacy of late fall and/or early spring fungicide applications to suppress dollar spot, and (b) to determine the relationship between air temperature and the timing of these effective fungicide applications in hopes of developing practical recommendations for deploying this dollar spot management strategy.

**MATERIALS AND METHODS**

**Establishment of Field Trials.** Replicated field trials were established at The Ohio State University, Ohio Turfgrass Foundation Research & Education Facility (OTF), and The Golf Club, New Albany (TGC), between October 2006 and July 2008 to assess the impact of fall and early spring fungicide applications on dollar spot severity. Test plots were established on fairway turf mowed at a height of 0.5 inches. The OTF plots were established on preexisting stands of creeping bentgrass/annual bluegrass (*Agrostis stolonifera var. palustris/Poa annua*) with an estimated composition of 70:30, respectively. The TGC plots were established on an existing creeping bentgrass/annual bluegrass/rough bluegrass (*Poa trivialis*), with an estimated composition of 50:40:10. Randomized complete block designs (RCBD) were used in all trials. Individual plots measured 3 x 5 feet (15 ft$^2$) with a 0.5 ft buffer separating all plots (Appendix A).

Sequential single and multiple applications of the fungicides propiconazole (1.0 oz/1000ft$^2$ of Banner Maxx; Syngenta Crop Protection, Greensboro, NC) and chlorothalonil (3.2 oz / 1000ft$^2$ of Daconil Ultrex; Syngenta Crop Protection, Greensboro,
NC) as a combination treatment (tank mix) were used in all the studies. Applications were made with a hand-held, CO2-powered boom sprayer using 6503 TeeJet nozzles at a pressure of 40 psi, (water equivalent to 2.0 gal water/1000 sq ft or 88 gal / acre) for all treatments. Treatments were applied weekly to asymptomatic turfgrass. The 2006-07 trial incorporated 28 treatments replicated 4 times, with 8 check plots. The 2007-2008 trial incorporated 33 treatments replicated 6, times with 12 check plots (Table 2.1). Most treatments consisted of a single application in the fall or spring. The multiple treatments were sprayed every 21 days. Appendix A provides detailed plot maps for these studies. Both field sites have a history of natural and uniform dollar spot severity so natural inoculations were used.

Disease severity was rated by counting the number of dollar spot infection centers (DSIC) per plot. Weekly ratings were made starting at the onset of disease symptoms (June 5, 2007 and June 6, 2008) and continued for 2 weeks after the final fungicide application. For each treatment, areas under disease progress curves (AUDPC) were calculated from June 6 -July 18, 2007 and June 5 - July 15, 2008 using the following equation

\[ \text{AUDPC} = \sum_{j=1}^{nj-1} \left( \frac{y_j + y_{j+1}}{2} \right) (t_{j+1} - t_j) \]

where \( j \) is the order index for the times, \( n_j \) is the number of times , \( y \) is the dollar spot infection center (DSIC) count, and \( t \) is time (Madden et al. 2007). Linear contrasts were developed to compare treatment combinations with each other. Differences between treatments were determined using analysis of variance (ANOVA) using the GLIMMIX
procedure from the software program SAS (SAS Institute Inc, Carey, NC). Mean separation values were determined using the least significant difference (P=0.05).

Daily average air temperature for each location was collected using regional weather data from Port Columbus for TGC, and OSU’s Don Scott Airport for OTF (http://weatherunderground.com). Effective fungicide applications are identified as “Early Spring” (at OTF on April 3; at both locations April 10, 17, 24; and at TGC on May 5); and “Late Spring” (at TGC on May 15, 29, June 5; and at OTF on June 5 and 12). The average air temperatures associated with these “Early Spring” effective application dates at OTF 41-71 °F and at TGC 44-70 °F (Figure 2.1). Although the dates of application are different than those observed for 2006-2007, two distinct groups of effective single spray applications were also observed in early spring of 2008 on March 17, 25 April 2, 15, 22, 29 and May 6; and Late Spring on May 27 June 9, 17, 25, and July 1 (Table 2.3, 2.5). The average air temperatures associated with the 2007-2008 “Early Spring” effective dates at OTF 46-70 °F (Figure 2.2). Growing degree-days (base 33, 40, 50, and 68°F) were calculated from January 1 through June 1 for 2007 and 2008 data, and for the 30-year historical average to characterize trends. Growing degree-days (base 33, 40, 50, and 68) starting on January 1 of 2007 and 2008 were calculated for all effective single spring fungicide application treatments. These base temperatures were selected because they are documented as important growing thresholds for cool season turfgrass, for *S. homoeocarpa* growth, on the observation of dollar spot symptoms (Bennett, 1937; Couch, 1995; Smith et al., 1989; Vargas, 2004; Venu et al., 2009). Base 33 was selected because this is the lower threshold for *S. homoeocarpa* growth *in vitro* (Bennett, 1937; Venu et al., 2009). Base 40 was selected because this is when creeping bentgrass and
annual bluegrass breaks winter dormancy and begins to grow in the spring. Base 50 was
selected because this is the standard base temperature relative to other published studies.
Base 68 was chosen because this is the lower temperature threshold at which symptoms
of dollar spot often appear in the field (Couch, 1995).

RESULTS

In 2006-07, significant differences were observed between the single fall and
single spring applications at each location and between single spring applications and the
nontreated controls (Table 2.3). Differences were not observed with the single fall
applications and the nontreated controls (Table 2.3). At The Golf Club, dollar spot
disease severity was lower than at OTF both years. In 2007-2008, disease pressure at
TGC was so low that it was not possible to yield statistical data. Contrasts to compare
the various treatment types by category, such as spring vs. fall applications or single vs.
multiple applications, were developed and are shown in tables 2.2 and 2.3.

In 2006-07, only two single fall treatment (Oct 24, and Oct 31 at the TGC)
resulted in a statistically (P=0.05) significant reduction in dollar spot symptom
development the following season (Table 2.4). In contrast, several of the single spring
applications significantly (P=0.05) reduced dollar spot severity in June 2007 (Table 2.4).
The effective single spring applications can be classified into two general groups based
on when the applications were made: “Early Spring” (at OTF on April 3; at both
locations April 10, 17, 24; and at TGC on May 5); and “Late Spring” (at TGC on May
15, 29, June 5; and at OTF on June 5 and 12). Although the dates of application are
different than those observed for the spring 2007, two distinct groups of effective single
spray applications were also observed in “Early Spring” of 2008 on March 17, 25 April 2,
15, 22, 29 and May 6; and “Late Spring” on May 27 June 9, 17, 25, and July 1, 2008 (Table 2.3, 2.5).

In 2006-07, differences were observed between all multiple application treatments to the nontreated control, between multiple applications to all single applications, and between multiple fall application treatments to multiple spray applications treatments (Table 2.2). In general, multiple application treatments resulted in significantly (P=0.05) less dollar spot symptoms as compared to the nontreated control (Table 2.2). Multiple spring applications resulted in significantly (P=0.05) less dollar spot symptoms when compared to the nontreated control and the single fall application treatments (Table 2.4). With the exception of the positive fungicide control treatment, no significant (P=0.05) differences are observed between any of the effective single spring applications treatments to any of the multiple spring application treatments suggesting, the single spring applications are as effective as the multiple spring application treatments (Table 2.4). Similar results for the multiple application treatments were observed for the OTF location in 2007-08 (Tables 2.3 and 2.5). The average air temperatures associated with these “Early Spring” effective dates in 2006-2007 trial year at OTF was 41-71 °F and at TGC 44-70 °F (Figure 2.1). The average air temperatures associated with the 2007-2008 “Early Spring” effective dates at OTF was 46-70 °F (Figure 2.2).

Table 2.6 shows the growing degree-days (base 33, 40, 50, and 68) counts from January 1 through June 1 for the 30-year average, spring 2007, and spring 2008. When comparing the 30-year growing degree-days to the trial years, both 2007 and 2008 were warmer than the 30-year averages. The 2007 trial year was warmer than 2008 trial year.
Over all, OTF was consistently warmer than TGC in both years of the study (Table 2.6; Figure 2.2 and 2.3).

Growing degree-day calculations (base 33, 40, and 50) starting with January 1 and ending at the time of spraying, for the effective single spring 2006-07 and 2007-08 treatments, are shown in Table 2.7. The growing degree-days for the effective single applications at both locations during both years had a very wide range, from 344 – 1348 for GGD33, 160 – 827 for GGD40, and 28 –340 for GGD50 (Table 2.7).

**DISCUSSION**

The findings from this study were consistent with previous findings validating early fungicide applications have the potential to suppress dollar spot activity. Findings indicate that early single spring applications have the ability to reduce dollar spot severity the following summer (Table 2.3 and 2.5). One hypothesis for this effect is, as the spring air temperatures increase, the pathogen’s activity also increases. When a fungicide is present, the pathogen’s metabolic activity will be adversely affected thus reducing dollar spot symptoms later that growing season. If one could properly deploy this early season fungicide single application, they could reduce *S. homoeocarpa* activity, thereby minimizing dollar spot severity later in the season and overall pesticide usage.

Although previous studies showed that fall fungicide applications can reduce dollar spot severity for the following season, being able to predict when to make such applications is difficult because it depends on predicting future weather trends. Venu et al.’s *in vitro* study suggests that fungal growth occurs in absence of symptom development on the host (Venu et al 2009). In this instance, if a fungicide application is made in the fall when air temperatures are above 40°F, it is likely that the pathogen is
actively growing undetected (Figure 2.2 and 2.3). If the fungicide is applied in the early spring when the air temperature is between 40-70°F, then it is likely that the pathogen is metabolically active and growing and that a fungicide application made at this time would temporally inhibit pathogen growth. If the fungicide is applied later in the spring ("Late Spring) when the air temperatures are above 70°F, the pathogen is likely to be very active and may have already reached a level capable of inciting disease.

The “Late Spring” single fungicide applications were not at as effective as the “Early Spring” applications (Table 2.3 and 2.5). It is hypothesized with the preventative applications the pathogen already established itself at population thresholds required to cause disease, thus disease suppression was not be achieved.

Early-to-mid single summer applications proved to effectively control dollar spot symptoms. This result is not unexpected given how the fungicides used in this study are labeled to give 21-days of effective for dollar spot control post application.

Multiple spring applications proved to be effective against suppressing dollar spot symptom development the following summer (Table 2.3 and 2.5). This was expected because the single and multiple treatments were applied at the same time (Table 2.3 and 2.5). For example, in the spring of 2007 at OTF, all multiple application treatments were started on April 3. On this date, an effective single “Early Spring” fungicide application treatment was applied. Because this single application has had an effect at reducing dollar spot symptoms, it is no surprise that the multiple application treatment applied on this same date also was effective at reducing dollar spot.

Based on the results of this research, the air temperature at or surrounding the time of application appears to influence the efficacy of the treatment imposed. Figures
2.1 and 2.2 show that all effective “Early Spring” fungicide applications at both locations were made when air temperatures were between 40°F and 70°F. These results are similar to those of Venu et al. (2009) which they showed that *S. homoeocarpa* growth occurred at temperatures below that which dollar spot symptoms are typically observed in the field (68-86°F). The “Early Spring” applications were applied within the same temperature window that Hall used in his model to start preventative fungicide applications for controlling dollar spot.

Table 2.6 shows the growing degree-days (base 33, 40, 50, and 68) for the 30 year daily mean air temperatures for January 1- June 1 as well as for these same periods in 2007 and 2008. When compared to the 30-year growing degree days, it is clear that both 2007 and 2008 trials were warmer than the 30 year averages (Table 2.6).

Growing degree-days (base 33, 40, and 50) for the mean regional air temperatures for January 1- June 1 for all statistically significantly (P=0.05) single spray applications treatments in the 2006-07 and 2007-08 trials are shown in Table 2.7. The growing degree-day counts for the effective single applications at both locations during both years have a very wide range. In the spring of 2007 the calendar date of April 3rd was chosen based on Niver’s results. Perhaps the initial spring application date was not early enough for effective dollar spot control and for that reason, the 2007-08 field trials were scheduled to continuously be applied starting in the fall of 2007 through early summer 2008. Applications in 2007-08 were skipped only when snow cover made it impossible for fungicides to be applied (late February through mid March).

In conclusion, both single and multiple applications made in late March to early April in both years of the study resulted in significantly less dollar spot later in the
season. Single fall fungicide applications had no impact on disease severity whereas some multiple fall application treatments did significantly reduce dollar spot severity the following July. Overall, no significant differences were observed between the effectiveness of single vs. multiple spring applications. Growing degree-day measurements for the effective single applications at both locations during both years had a very wide range indicating that there is likely a rather wide “window of opportunity” to make effective “Early Spring” fungicide applications.

Given this research, controlling dollar spot requires sound integrated pest management practices in combination with fungicide applications. To ensure low dollar spot activity, a golf course superintendent would need to apply a fungicide when the pathogen is metabolically active. This research suggests that a fungicide application (or a series of applications) begun in the early spring when mean daily air temperatures reaches 40°F and continuing until mean daily air temperatures reach or exceeds 70°F will likely result in effective control of dollar spot later in the growing season. Future research aimed at determining the minimum number of fungicide applications required to realize disease reductions and the cost savings of associated with this approach, are needed.
Table 2.1 Treatments in 2006-07 and 2007-08 field studies.

<table>
<thead>
<tr>
<th>TMT(^a)</th>
<th>Application Date</th>
<th>TMT</th>
<th>Application Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Non-treated control</td>
<td>1</td>
<td>Non-treated control</td>
</tr>
<tr>
<td>2</td>
<td>Oct 24, 2006 (^b)</td>
<td>2</td>
<td>Oct 18, 2008</td>
</tr>
<tr>
<td>3</td>
<td>Oct 31, 2006</td>
<td>3</td>
<td>Nov 8, 2008</td>
</tr>
<tr>
<td>5</td>
<td>Nov 14, 2006</td>
<td>5</td>
<td>Dec 28, 2007</td>
</tr>
<tr>
<td>6</td>
<td>Nov 21, 2006</td>
<td>6</td>
<td>Jan 7, 2008</td>
</tr>
<tr>
<td>7</td>
<td>Nov 28, 2006</td>
<td>7</td>
<td>Jan 31, 2008</td>
</tr>
<tr>
<td>8</td>
<td>Dec 5, 2006</td>
<td>8</td>
<td>Oct 18 + Nov 8, 2007</td>
</tr>
<tr>
<td>9</td>
<td>Dec 12, 2006</td>
<td>9</td>
<td>Oct 18 + Nov 8 + Nov 28, 2007</td>
</tr>
<tr>
<td>13</td>
<td>Apr 17, 2007</td>
<td>13</td>
<td>Mar 17, 2008</td>
</tr>
<tr>
<td>15</td>
<td>May 1, 2007</td>
<td>15</td>
<td>Apr 1, 2008</td>
</tr>
<tr>
<td>16</td>
<td>May 8, 2007</td>
<td>16</td>
<td>Apr 8, 2008</td>
</tr>
<tr>
<td>17</td>
<td>May 15, 2007</td>
<td>17</td>
<td>Apr 15, 2008</td>
</tr>
<tr>
<td>19</td>
<td>May 29, 2007</td>
<td>19</td>
<td>Apr 29, 2008</td>
</tr>
<tr>
<td>20</td>
<td>June 5, 2007</td>
<td>20</td>
<td>May 6, 2008</td>
</tr>
<tr>
<td>21</td>
<td>June 12, 2007</td>
<td>21</td>
<td>May 13, 2008</td>
</tr>
<tr>
<td>22</td>
<td>Non-treated control</td>
<td>22</td>
<td>May 20, 2008</td>
</tr>
<tr>
<td>23</td>
<td>June 26, 2007</td>
<td>23</td>
<td>May 27, 2008</td>
</tr>
<tr>
<td>24</td>
<td>Oct 24 + Nov 14, 2006 (^c)</td>
<td>24</td>
<td>June 3, 2008</td>
</tr>
<tr>
<td>29</td>
<td>Apr 3 + Apr 24 + May 15 + June 5 + June 26, 2007</td>
<td>29</td>
<td>Mar 17 + Apr 1 + Apr 22, 2008</td>
</tr>
<tr>
<td>30</td>
<td>Mar 17 + Apr 1 + Apr 22 + May 13, 2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Mar 17 + Apr 1 + Apr 22 + May 13 + June 3, 2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Mar 17 + Apr 1 + Apr 22 + May 13 + June 3 + June 25, 2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>July 1, 2008</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Treatment identification number.
\(^b\) Plots were sprayed with a combination of chlorothalonil (3.2oz./1000ft\(^2\)) plus propiconazole (1oz./1000ft\(^2\)).
\(^c\) Treatments with multiple dates represent multiple fungicide applications.
Table 2.2 Contrasts of treatments by each location during the 2006-07 field studies.

<table>
<thead>
<tr>
<th>Contrasts c</th>
<th>Location OTF a</th>
<th>Location TGC b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall vs. spring, 1 spray</td>
<td>&lt;0.0001</td>
<td>0.0107</td>
</tr>
<tr>
<td>Linear with time, fall</td>
<td>0.9813</td>
<td>0.0814</td>
</tr>
<tr>
<td>Linear with time, spring</td>
<td>0.0792</td>
<td>0.0071</td>
</tr>
<tr>
<td>Check (1,22) vs. 1 spray</td>
<td>0.0575</td>
<td>0.0234</td>
</tr>
<tr>
<td>Check (1,22) vs. 1 fall spray</td>
<td>0.4505</td>
<td>0.1824</td>
</tr>
<tr>
<td>Check (1,22) vs. 1 spring spray</td>
<td>0.0002</td>
<td>0.005</td>
</tr>
<tr>
<td>Multiple vs. 1 spray</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Multiple vs. 1 fall spray</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Multiple vs. 1 spring spray</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Multiple vs. check (1,22)</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Multiple: fall(2) vs. spring(2)</td>
<td>0.0284</td>
<td>0.1175</td>
</tr>
<tr>
<td>Multiple: fall(3) vs. spring(3)</td>
<td>0.0189</td>
<td>0.4325</td>
</tr>
<tr>
<td>Multiple: fall vs. spring (2or3)</td>
<td>0.0016</td>
<td>0.0975</td>
</tr>
<tr>
<td>Linear, number of sprays (1-5)</td>
<td>&lt;0.0001</td>
<td>0.0019</td>
</tr>
<tr>
<td>Linear number of sprays (0-5)</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

a Location The Ohio State Turfgrass Research and Education facility.
b Location The Golf Club.
c Contrasts of each treatment type to each treatment type.
Table 2.3 Application schedule and results from the 2006-07 field studies.

<table>
<thead>
<tr>
<th>TMT</th>
<th>Application Date</th>
<th>OTF (AUDPC)</th>
<th>TGC (AUDPC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nontreated control</td>
<td>1828</td>
<td>929</td>
</tr>
<tr>
<td>2</td>
<td>Oct 24, 2006&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1703</td>
<td>454*</td>
</tr>
<tr>
<td>3</td>
<td>Oct 31, 2006</td>
<td>1862</td>
<td>519</td>
</tr>
<tr>
<td>4</td>
<td>Nov 7, 2006</td>
<td>2146</td>
<td>858</td>
</tr>
<tr>
<td>5</td>
<td>Nov 14, 2006</td>
<td>3051</td>
<td>602</td>
</tr>
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<td>Nov 21, 2006</td>
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<td>7</td>
<td>Nov 29, 2006</td>
<td>2026</td>
<td>710</td>
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<td>8</td>
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<td>1939</td>
<td>1022</td>
</tr>
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<td>9</td>
<td>Dec 12, 2006</td>
<td>1854</td>
<td>945</td>
</tr>
<tr>
<td>10</td>
<td>Dec 19, 2006</td>
<td>2019</td>
<td>621</td>
</tr>
<tr>
<td>11</td>
<td>Apr 3, 2007</td>
<td>652*</td>
<td>577</td>
</tr>
<tr>
<td>12</td>
<td>Apr 10, 2007</td>
<td>714*</td>
<td>362*</td>
</tr>
<tr>
<td>13</td>
<td>Apr 17, 2007</td>
<td>359*</td>
<td>469*</td>
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<tr>
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<td>Apr 24, 2007</td>
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<td>17</td>
<td>May 15, 2007</td>
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<td>458*</td>
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<tr>
<td>18</td>
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<td>918</td>
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<td>19</td>
<td>May 29, 2007</td>
<td>935</td>
<td>421*</td>
</tr>
<tr>
<td>20</td>
<td>June 5, 2007</td>
<td>683*</td>
<td>481</td>
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<td>21</td>
<td>June 12, 2007</td>
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<td>927*</td>
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<td>June 26, 2007</td>
<td>1356</td>
<td>895</td>
</tr>
<tr>
<td>23</td>
<td>Oct 24 + Nov 14, 2006&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1094*</td>
<td>527</td>
</tr>
<tr>
<td>25</td>
<td>Apr 3 + Apr 24, 2007</td>
<td>337*</td>
<td>261*</td>
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<td>26</td>
<td>Oct 24 + Nov 14 + Dec 5, 2006</td>
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<td>466*</td>
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<td>Apr 3 + Apr 24 + May 15, 2007</td>
<td>161*</td>
<td>334*</td>
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<td>Apr 3 + Apr 24 + May 15 + June 5, 2007</td>
<td>43*</td>
<td>216*</td>
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<td>29</td>
<td>Apr 3 + Apr 24 + May 15 + June 5 + June 26, 2007</td>
<td>16*</td>
<td>64*</td>
</tr>
<tr>
<td></td>
<td>LSD&lt;sup&gt;f&lt;/sup&gt; (P&lt;0.05)</td>
<td>920</td>
<td>436</td>
</tr>
</tbody>
</table>

<sup>a</sup> Co-application of fungicides propiconazole (1.0 oz/M) and chlorothalonil (3.25 oz/M) as a combination treatment were applied on asymptomatic turfgrass fairways.

<sup>b</sup> Multiple dates represents multiple fungicide applications on specified date.

<sup>c</sup> Area under disease progress curves (AUDPC) were calculated for each treatment. Disease severity was quantified using the Dollar Spot Infection Center (DSIC) counts.

<sup>d</sup> The Ohio State Turfgrass Foundation Research and Experimental Station (OTF).

<sup>e</sup> The Golf Club (TGC). Area under disease progress curves (AUDPC) were calculated for each treatment using both rating systems.

<sup>f</sup> Statistic analysis ANOVA (analysis of variance) was used to calculate the least significant difference (LSD) among treatments.

* Significant difference from nontreated control.
Table 2.4 Contrasts of treatments by location during the 2007-08 field studies.

<table>
<thead>
<tr>
<th>Contrasts a</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OTE b</td>
</tr>
<tr>
<td>Fall vs. spring, 1 spray</td>
<td>&lt;0.0001 d</td>
</tr>
<tr>
<td>Linear with time, fall</td>
<td>0.0478</td>
</tr>
<tr>
<td>Linear with time, spring</td>
<td>0.0011</td>
</tr>
<tr>
<td>Check (1,34) vs. 1 spray</td>
<td>0.0002</td>
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<tr>
<td>Check (1,34) vs. 1 fall spray</td>
<td>0.6159</td>
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<tr>
<td>Check (1,34) vs. 1 spring spray</td>
<td>&lt;0.0001</td>
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<tr>
<td>Multiple vs. 1 spray</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Multiple vs. 1 fall spray</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Multiple vs. 1 spring spray</td>
<td>0.0572</td>
</tr>
<tr>
<td>Multiple vs. check (1,34)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Multiple: fall(6) vs. spring(6)</td>
<td>0.0054</td>
</tr>
<tr>
<td>Multiple: fall(3) vs. spring(3)</td>
<td>0.3004</td>
</tr>
<tr>
<td>Multiple: fall vs. spring (2 or 3 spray)</td>
<td>0.0181</td>
</tr>
<tr>
<td>Linear, number of sprays (1-6)</td>
<td>0.1906</td>
</tr>
<tr>
<td>Linear number of sprays (0-6)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

a Contrasts of treatment type to other treatment type.  
b Location The Ohio State Turfgrass Research and Education facility.  
c Location The Golf Club. Low disease pressure at this location yielded no results.  
d P-value of contrasts significant to the P=0.05.
Table 2.5 Application schedule and results from the 2007-08 field studies.

<table>
<thead>
<tr>
<th>TMT</th>
<th>Application Date</th>
<th>AUDPC&lt;sup&gt;c&lt;/sup&gt;</th>
<th>OTF&lt;sup&gt;d&lt;/sup&gt;</th>
<th>TGC&lt;sup&gt;e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nontreated control</td>
<td>987</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Oct 18, 2007&lt;sup&gt;a&lt;/sup&gt;</td>
<td>963</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Nov 8, 2007</td>
<td>952</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Nov 28, 2007</td>
<td>1208</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Dec 28, 2007</td>
<td>1159</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Jan 7, 2008</td>
<td>641</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Jan 31, 2008</td>
<td>592*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Oct 18 + Nov 8, 2007&lt;sup&gt;b&lt;/sup&gt;</td>
<td>815</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Oct 18+Nov 8+Nov 28, 2007</td>
<td>543*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Oct 18 + Nov 8 + Nov 28 + Dec 28, 2007</td>
<td>606</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Oct 18 + Nov 8 + Nov 28 + Dec 28, 2007 + Jan 7, 2008</td>
<td>413*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Oct 18 + Nov 8 +Nov 28 +Dec 28, 2007+Jan 7, Jan 31, 2008</td>
<td>545*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mar 17, 2008</td>
<td>382*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Mar 25, 2008</td>
<td>469*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Apr 1, 2008</td>
<td>502*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Apr 8, 2008</td>
<td>640</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Apr 15, 2008</td>
<td>480*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Apr 22, 2008</td>
<td>451*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Apr 29, 2008</td>
<td>477*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>May 6, 2008</td>
<td>562*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>May 13, 2008</td>
<td>964</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>May 20, 2008</td>
<td>936</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>May 27, 2008</td>
<td>484*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Jun 3, 2008</td>
<td>624</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Jun 10, 2008</td>
<td>406*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Jun 17, 2008</td>
<td>111*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Jun 25, 2008</td>
<td>138*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Mar 17 + Apr 1, 2008</td>
<td>204*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Mar 17 + Apr 1 +Apr 22, 2008</td>
<td>276*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Mar 17 +Apr 1 +Apr 22 +May 13, 2008</td>
<td>359*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Mar 17 +Apr 1 +Apr 22 +May 13,+Jun 3, 2008</td>
<td>229*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Mar 17 +Apr 1 +Apr 22 +May 13 +Jun 3 +Jun 25, 2008</td>
<td>236*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Jul 1, 2008</td>
<td>50*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LSD<sup>f</sup> (P=0.05) 384 N/S

<sup>a</sup>Co-application of fungicides propiconazole (1.0 oz/M) and chlorothalonil (3.25 oz/M) as a combination treatment were applied on asymptomatic turfgrass fairways. Each treatment was replicated 6 times.

<sup>b</sup>Multiple dates represents multiple fungicide applications on specified date.

<sup>c</sup>Area under disease progress curves (AUDPC) were calculated for each treatment. Disease severity was quantified using the Dollar Spot Infection Center (DSIC) counts.

<sup>d</sup>The Ohio State Turfgrass Foundation Research and Experimental Station (OTF).

<sup>e</sup>The Golf Club (TGC).

<sup>f</sup>Statistic analysis ANOVA (analysis of variance) was used to calculate the least significant difference (LSD) among treatments.

* Significant difference from nontreated control
Table 2.6 Growing degree-days calculations for 2006-2008 field studies at various bases from January 1 to June 30.

<table>
<thead>
<tr>
<th>Time</th>
<th>Growing Degree Dayᵃ</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base 33</td>
<td>Base 40</td>
<td>Base 50</td>
<td>Base 68</td>
</tr>
<tr>
<td>30 year averageᵇ</td>
<td>2926</td>
<td>2073</td>
<td>1098</td>
<td>97</td>
</tr>
<tr>
<td>SP07 OTFᶜ</td>
<td>4603</td>
<td>3672</td>
<td>2510</td>
<td>897</td>
</tr>
<tr>
<td>SP07 TGCᵈ</td>
<td>3461</td>
<td>2602</td>
<td>2072</td>
<td>264</td>
</tr>
<tr>
<td>(SP07 OTF) – (30 year average)</td>
<td>1677</td>
<td>1599</td>
<td>1412</td>
<td>800</td>
</tr>
<tr>
<td>(SP07 TGC) – (30 year average)</td>
<td>535</td>
<td>529</td>
<td>974</td>
<td>167</td>
</tr>
<tr>
<td>SP08 OTF</td>
<td>4224</td>
<td>3273</td>
<td>2090</td>
<td>576</td>
</tr>
<tr>
<td>SP08 TGC</td>
<td>3237</td>
<td>2333</td>
<td>1296</td>
<td>200</td>
</tr>
<tr>
<td>(SP08 OTF) – (30 year average)</td>
<td>1298</td>
<td>1200</td>
<td>992</td>
<td>497</td>
</tr>
<tr>
<td>(SP08 TGC) – (30 year average)</td>
<td>311</td>
<td>260</td>
<td>198</td>
<td>103</td>
</tr>
<tr>
<td>(SP07 OTF) – (SP08 OTF)</td>
<td>379</td>
<td>399</td>
<td>420</td>
<td>321</td>
</tr>
<tr>
<td>(SP07 TGC) – (SP08 TGC)</td>
<td>224</td>
<td>269</td>
<td>776</td>
<td>64</td>
</tr>
</tbody>
</table>

ᵃ Growing degree days (base 33, 40, 50, and 68) were calculated from January 1 through June 1 for the 30 year historical daily mean air temperature of this same period for 2007 and 2008, as a means to characterize local weather trends.
ᵇ 30 year average from Port Columbus in central Ohio.
ᶜ The Ohio Turfgrass Foundation Research and Education Center (OTF) growing degree days were calculated from The Ohio State University’s airport.
ᵈ The Golf Club (TGC)’s growing degree days were calculated from Port Columbus.
Table 2.7 Growing degree-days calculations for the “Early Spring” fungicide applications that effectively reduce dollar spot severity (2006-07 and 2007-08).

<table>
<thead>
<tr>
<th>Application Date</th>
<th>GDD(^a) (Base 33)</th>
<th>GDD(^ ) (Base 40)</th>
<th>GDD(^ ) (Base 50)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ohio Turfgrass Foundation (OTF)(^b)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/3/2007</td>
<td>746</td>
<td>470</td>
<td>178</td>
</tr>
<tr>
<td>4/10/2007</td>
<td>766</td>
<td>474</td>
<td>178</td>
</tr>
<tr>
<td>4/17/2007</td>
<td>852</td>
<td>511</td>
<td>178</td>
</tr>
<tr>
<td>4/24/2007</td>
<td>1033</td>
<td>643</td>
<td>218</td>
</tr>
<tr>
<td><strong>The Golf Club (TGC)(^c)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/10/2007</td>
<td>766</td>
<td>474</td>
<td>200</td>
</tr>
<tr>
<td>4/17/2007</td>
<td>852</td>
<td>511</td>
<td>201</td>
</tr>
<tr>
<td>4/24/2007</td>
<td>1033</td>
<td>643</td>
<td>261</td>
</tr>
<tr>
<td>5/1/2007</td>
<td>1234</td>
<td>795</td>
<td>340</td>
</tr>
<tr>
<td><strong>Ohio Turfgrass Foundation (OTF)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/17/2008</td>
<td>344</td>
<td>160</td>
<td>28</td>
</tr>
<tr>
<td>3/25/2008</td>
<td>401</td>
<td>175</td>
<td>28</td>
</tr>
<tr>
<td>4/2/2008</td>
<td>508</td>
<td>227</td>
<td>31</td>
</tr>
<tr>
<td>4/15/2008</td>
<td>766</td>
<td>394</td>
<td>110</td>
</tr>
<tr>
<td>4/22/2008</td>
<td>957</td>
<td>536</td>
<td>128</td>
</tr>
<tr>
<td>4/29/2008</td>
<td>1146</td>
<td>676</td>
<td>193</td>
</tr>
<tr>
<td>5/6/2008</td>
<td>1348</td>
<td>827</td>
<td>340</td>
</tr>
</tbody>
</table>

\(^a\) Growing degree days (base 33, 40, and 50) starting on January 1 of 2007 and 08 (weather underground) were also calculated for all effective single spring fungicide application treatments.

\(^b\) The Ohio Turfgrass Foundation Research and Education Center (OTF)’s growing degree days were calculated from The Ohio State University’s airport.

\(^c\) The Golf Club (TGC)’s growing degree days were calculated from Port Columbus.
Figure 2.1 Observed high and mean daily air temperatures at The Ohio Turfgrass Foundation Research and Education Facility (OTF) and The Golf Club (TGC) relative to the 30-year mean daily air temperatures for February 1 through July 31, 2007. Arrows represent dates for which fungicide application were made that were effectively reduce dollar spot during summer 2007. Blue green and red shading represents temperatures at which *Sclerotinia homoeocarpa* is dormant (blue), actively growing (green), and dormant due to excessive heat (red) based on pathogen growth in the laboratory. The yellow box highlights the air temperatures at which effective fungicide application were made.
Figure 2.2  Observed high and mean daily air temperatures at The Ohio Turfgrass Foundation Research and Education Facility (OTF) relative to the 30-year mean daily air temperatures for February 1 through July 26, 2008.  Arrows represent dates for which fungicide application were made that were effectively reduce dollar spot during summer 2007. Blue green and red shading represents temperatures at which Sclerotinia homoeocarpa is dormant (blue), actively growing (green), and dormant due to excessive heat (red) based on pathogen growth in the laboratory.  The yellow box highlights the air temperatures at which effective fungicide application were made.
REFERENCES


APPENDIX A

STUDY PLOT PLANS
Figure A.1  Field studies layout and plot plan at the Ohio Turfgrass Foundation Research and Education Facility and The Golf Club 2006-07. Each block represents a test plot. Within the plot the left number represents the plot identification number and the right number represents the treatment number ([113 19] = plot # 113 and treatment # 19).
Figure A.2  Field studies layout and plot plan at the Ohio Turfgrass Foundation Research and Education Facility and The Golf Club 2007-08. Each block represents a test plot. Within the plot the left number represents the plot identification number and the right number represents the treatment number ([187 15]= plot # 187 and treatment # 15).
APPENDIX B

DIGITAL IMAGERY ANALYSIS PROCEDURES TO INCLUDE, OPERATION OF CAMERA, PHOTO BOX AND SAVING OF IMAGES: PLUS REAL TIME PROCEDURES ON HOW TO USE APS PRESS ASSESS SOFTWARE
**Construction**

A three by five foot box was constructed using 1/8\textsuperscript{th} inch galvanized sheet metal, 1/4 inch angle iron for the frame, a two wheel dally as a back axel with a metal frame attached to the backside of the dolly. A Honda ei1000 generator was mounted to the rating box to supply power to the two duel outdoor lamp fixtures equipped with four 30-Watt incandescent light bulbs to illuminate the interior of the box. Additional hardware needed included 14 gauge wire, a light switch and outlet combination fixture, switch box, wire nuts self drilling screws four eye bolts with 8 nuts, 4 lock tight washers and wire, and foam matting.

**Operation**

The first step in operation is to make sure that all of the equipment is working properly. This preliminary step is vital to keep consistency from photo to photo, location-to-location, and each rating time.

First, fill the generator’s gas tank with gasoline and check the oil to assess quality and appropriate level. Change the oil at the end of every season or every 50 hours of operation. Add the appropriate fluids as necessary prior to operation. Start the generator by turning the cutoff switch to the on position then pull the ripcord. If operation does not check clear, notify the Program Coordinator for assistance. Turn on the lights by plug in the cord directly to the generator. This will allow power to be distributed to the power outlet and switch located on the box’s exterior. Install the four 30 watt lights into the light fixture and then flip the switch on the box to the on position. Plug in the light cord attached to the box to the generator and supply power to the box. This will supply power
to the light fixtures and thus illuminating the lights inside the box. Raise the box up slightly without tipping it over to observe if the lights on the inside are illuminated. Replace the burned out bulbs prior to starting the rating using the bulbs mentioned in the introduction portion of this appendix. Finally, take off the front hitch and the six-inch turf tires for there sole purpose is for transporting the box to the rating site.

The camera power supply if vital when acquiring images so much so that when the box was construct I installed a power outlet to serve as a power source in the case that the battery become uncharged during operation. Check to make sure both camera batteries are completely charged and the memory card is cleared of all photos.

It is very vital for the camera and lens to be in working condition and the right settings are implemented to ensure high quality photo. Set the camera’s white balance by turning the camera on and pressing the menu button on the backside of the camera next to the LCD screen. Once in this menu, scroll down the features using the navigation arrows on the right side of the LCD until you come to the menu that looks like a camera. After arriving to this menu highlight the white balance feature and press the right arrow on the navigation button. Scroll through the list until you highlight the PRE setting, which stands for preset feature. In this menu, you have a choice to use a previous photo or measure it manually. Measure the white balance every time prior to rating. One way to do this is by obtaining a new clean coffee filter and tightly place the coffee filter over the exterior of the lens, completely engulfing the lens with the filter. Be sure that there are no wrinkles in the paper and that there is a smooth taught surface around the lens. It is very important that the paper is tightly around the lens without any wrinkles because if not, the camera will notice the darken lines form the wrinkles and consequently the
incorrect white balance will be acquired giving an inaccurate percent rating when the DIA software is used. Next, place the camera and with the coffee filter securely surrounding the lens onto the camera mount located on the top of the rating box. There is only one way the camera securely fits on the mount, with the lens fitting into the hole. That is with the bottom of the camera, which is where the battery, the tripod mount, and model and serial numbers can be located, is facing towards the left side of the box. The left side is the side where all of wiring, electrical socket and switch are located. Make sure the box is illuminated and then select the measure feature on the camera and take the photo. This will measure and set the correct white balance for all the rating at this location. Now that everything is all, set take the coffee filter off the camera and place the camera securely back onto the mount.

The F-Stop setting on the camera needs to be set at 7.1 and the aperture speed is at 30, or three tenses of a second. The F-Stop can be adjusted by pressing down on the +/- button located behind the button used to take the photo. While holding down on the +/- button scroll or right accordingly using the scrolling dial located behind the +/- button. To observe which F-Stop you are on look at the display located on the upper right hand side of the camera or by looking in the view finder. Observe the “F” which stands for F stop and scroll accordingly until the F stop is at 7.1. Make sure that the four corners of the box are on the four coroners of your 3 feet by 5 feet plots then take the picture. Observe your first picture to ensure the picture is completely taking the interior 8 feet square. This is done my reviewing the photo in on the LCD viewer and observing the wire frame on the picture. If the wire frame is in the picture, no adjustments are needed. If the wire frame is not in the picture, the camera is not set in the mount correctly, and
attention is needed to correct this issue. Now that the box is set up, place the appropriately numbered poker chip on its corresponding plot to identify the plot ID. It is important that the chip is in the picture, but not interfering with the rating 8 feet square. That is why I place the chip in the middle of the five foot side about four inches away from the side of the plot. Note a picture speaks a thousand words. When rating using photos everything will show up in the picture. That is why it is important have the plots properly maintained and remove all debris from the surface of the rating plots. Ways of doing this is to mow the plots first while gathering the clippings and then blow the plots off to remove all inert matter.

Once the plots are cleaned you are ready to start rating. Maneuver the box to the first plot that you will be rating. Next rotate through the plots taking a picture of each plot in order. At the completion of data collecting turn everything off and put all equipment away in its appropriate locations.

**Photo Analysis**

After the photos are acquired download them to the computer and have them analyzed using APS Press’s Assess to achieve an accurate percent disease area. First download the pictures from the memory card to the computer. Next label each picture with the location, date, and plot identification so you are certain which photo belongs to which plot at which location and when the photo was taken. After this is saved to the computer delete the photos on the memory card and place the memory card back into the camera so it is ready for the next rating. Then upload the Assess and follow the procedure mapped out in the PowerPoint presentation labels John Koenig and Assess.
MAINTENANCE

Camera

- Clean lens with a micro-fiber cloth.
- Check life of batteries.
- Install and install memory card.
- Once a year turn camera into the manufacture to have the motherboard inspected.

Generator

- Change oil every season or 50 running hours
- Check air filter for imparities every season. Replace if needed.
- Check sparkplug every season for problems like cracking or rusting. Replace as needed.

Box

- Check weekly air pressure in the tires to ensure proper inflation. Pump up as needed. The correct PSI is located on the side wheel well of each tire. 25 and 35 PSI.
- Make sure the lights are in working order. Replace as needed with 30 or 40-Watt Incandescent pigtail bulbs. Calumet 40w Spiral Fluorescent Lamp Calumet #OL2000.
Figure B.1 Light fixture mount in the rating box.

- Inspect the electric wires for blemishes. If frayed wrap the exposed wires with electrical tape immediately and inform the program coordinator for inspection.

**PREPARATION**

**Camera**

- Fully charge the camera battery and backup battery.
- Clean the lens using a lens cloth.
- Clear all contents from memory card and insert into the camera.

**Generator**

- Check the oil
  - If needed change
  - If gold, but not completely filled, add the specified oil mentioned in the owners manual
  - If gold and clear of metal shavings then proceed to the next step
- Fill the gas tank with unleaded gasoline
- Inspect air filter. Replace as needed.
- Inspect ripcord for wear.

- Tie the generator to the rear of the box by attaching a tie down to the upper mount of the red dolly and the axel of the red dolly.

**Figure B.2** Generator mounting with generator attachment on the rating box.

**Box**

- Inspect interior wire frame to ensure the wires or twine are pulled tight.

**Figure B.3** Interior wire framing the “Point of Interest” in APS Assess Software Program.

- Inspect the box for holes and cracks. Fill and cover up as needed with tape.

**Plots**

- Mow plots in one direction the morning prior to rating.

- Clear the plots of all inert matter.
- Paint plot corner makers 24 hours prior to the rating day.

**NOTE:** If any problem exists, notify the Program Coordinator immediately for additional assistance.

**Rating Application Procedure**

Step 1: Perform all proper preparation referenced on pg 62.

Step 2: Install the four 30 watt lights into the light fixture and make sure the switch is in the off position.

Step 3: Start the generator by turning the cutoff switch to the on position then pull the ripcord.

Step 4: Power up the lights by plugging in the outlet cord attached to the box to the generator. Turn the light switch to the on position.

Step 5: Raise the box up slightly to observe the lights are functioning properly.

Step 6: If needed replace all damaged or burnt out bulbs.

Step 7: Remove the front hitch and the six-inch turf tires prior to rating.

**Figure B.4** Removal of the rating box’s hitch and tires prior to taking ratings.
Camera Setup

Step 1: Install fully charged battery and empty memory card.

Step 2: Set camera and lens to manual (M) mode.

Figure B.5 Location of the manual settings on the Nikon D 50 camera.

-Focus the lens manually to four feet and by using electrical tape fasten the adjusting dial to the body of the lens to ensure continuity among the pictures.

Figure B.6 Location of the lens adjustment to set for the proper lens height.
Step 3: Set proper white balance every rating date. **NOTE** setting of the white balance needs to be done in a timely manner or the camera will default to the opening menu.

-Place a new clean coffee filter tightly over the exterior of the lens, completely covering the lens without wrinkles.

![Figure B.7](image.png) The use of a coffee filter to set the camera’s white balance.

- Turn the camera on and press the menu button on the backside of the camera next to the LCD screen.

- Scroll down the features using the navigation arrows on the right side of the LCD until you come to the menu that looks like a camera.

- Highlight the white balance feature and press the right arrow on the navigation button.

- Scroll through the list until you highlight the **PRE** setting or preset feature.

  - In this menu, you have a choice to use a previous photo or measure it manually. Choose measure manually.

- Mount the camera with the coffee filter securely surrounding the lens into the camera mount located on the top of the rating box.
Figure B.8 Proper mounting of the camera on top of the rating box.

- Light up the box
- Take a photograph.
- Remove the camera from the mount and disregard the coffee filter.
- Replace the camera back in the mount.

NOTE: Refer to the owner’s manual for additional assistance.

Step 4: Set F-Stop to 7.1.

- The F-Stop can be adjusted by pressing down on the +/- button located behind the button used to take the photo. While holding down on the +/- button scroll left or right accordingly using the scrolling dial located behind the +/- button.

One can observe which F-Stop you are on look at the display located on the upper right hand side of the camera or by looking in the viewfinder. Observe the “F” which stands for F-Stop and scroll accordingly until the F-Stop is at 7.1.
Figure B.9 Location of the F-Stop +/- button on a Nikon D50 Camera.

NOTE: For additional assistance, refer to the owner’s manual.

Step 5: Set aperture speed to three tense of a second or 3o setting.

NOTE: For additional assistance, refer to the owner’s manual.

Step 6: Check to ensure the proper seating of the camera on the mount.

Proper camera seating is squared to the box so that the interior wire frame can be completely observed.

NOTE: For additional assistance, refer to the owner’s manual.

**Acquiring Data**

Step 1: Clean off the plots and mow in one direction.

Step 2: Place the appropriately plot identification poker chip in the upper middle of the plot. This is on the five-foot side about four inches away from the side of the plot.

-Note: The poker chip should not be observed in the rating area designated by the wired frame.
Figure B.10 Improper poker chip placement on rating surface.

Figure B.11 Correct poker chip placement on rating surface.

NOTE: Use the same assessment order throughout the entire study.

Step 3: Maneuver the box to the first plot that you will be rating.

Step 4: Check to ensure once more all images are delegated.

Step 5: Take the picture of the first plot.

Step 6: Move box to next plot and take its picture.

Step 7: Repeat steps 6 and 7 until all digital images are acquired.

Clean up
Step 1: Remove the box from the plots.

Step 2: Turn off the lights.

Step 3: Remove the camera from the mount, turn it off, and place in its case.

Step 4: Turn off the generator.

Step 5: Install the front hitch and the six-inch turf tires.

Step 6: Store the equipment back in to its proper storage location designated by the program coordinator.

Step 7: Download the pictures.

Step 8: Name all the pictures with the rating date, location, and plot identification number.

Step 9: Upload the pictures into Assess for data analysis.

Step 10: Save and backup the files
APPENDIX C

THE USE OF DIGITAL IMAGERY ANALYSIS TO ASSESS DOLLAR SPOT
The industry standard to visually rate disease severity on turfgrass is often filled with human bias and variability between evaluators (Host 1984). This variability is difficult to remove and account for (Host 1984). To address this problem, researchers have sought to answer the question of whether a more precise mechanical method for rating turfgrass disease can be adopted. Some of these methods would include radiometry (Nutter 1993) or spectrophotometry (Bell et al., 2002), both requiring very specialized equipment. The high cost of this equipment limits their use. In time, improvements to these technologically advanced rating methods and new equipment are becoming widely available to turfgrass researchers at a lower cost (Horvath, 2005). One method uses digital images and a computer program to process a rating of the test plot. The software is programmed to differentiate between stressed and healthy tissue via the color spectrum (Horvath, 2005; Karcher, 2003; Richardson, 2001). In 2007, replicated field studies were established at two locations in central Ohio to determine if using DIA is an adequate method for assessing dollar spot severity.

**MATERIALS AND METHODS**
A self-contained, independently illuminated, metal box was constructed to acquire digital images of dollar spot infested turf plots. A Nikon D-50 camera with the Nikon AF NIKKOR 20mm lens was chosen to acquire a digital image of each plot. Each image was saved as JPEG file. The standard operation procedures for both the camera and rating box are observed in Appendix C. Rating starting on 18 April 2008 and continued weekly through 6 August 2008. The plots were mowed to 0.50 inches three times a week. The morning of each rating date, the plots were mowed to produce a consistent turf height. Grass clippings were collected and removed from the testing area on each
mowing date. Prior to rating, the plots were blown off to remove water, leaf debris, thatch, and any other inert material littering the testing area. APS Press’s Assess 2.0 software was used to analyze the digital pictures. Percent area diseased was collected and recorded for each rating date. The procedures, settings, and thresholds for Assess can be found in Appendix C. Regression analysis comparing DSIC to DIA from the 4,750 data points was used to calculate an $R^2$ value using Microsoft Office Excel.

**RESULTS AND DISCUSSION**

Using regression analysis, a weak correlation value ($R^2 = 0.5427$; Figure 1) between the count DSIC and percent disease was generated by the DIA system. These findings are similar to previous results (Horvath 2005). In this study the high variability between the two methods (Figure 1) can be contributed to the sensitivity of each system. The human eye is able to differentiate between outside turfgrass stresses that are of similar in color to those of actual dollar spot infection centers, but became increasingly variable as disease pressure increased. DIA system is unable to differentiate between turf disorders and included them in the plot rating (Figure 2, 3, and 4). DIA was able to acquire a more reliable rating when disease pressure was at its peak, given the size and coalescing of DSIC. In conclusion, the use of the self-contained rating box gives way for data collection independent to human bias, but proved to be ineffective given the software’s inability to differentiate between dollar spot infected tissue and host tissue that is damaged from other turf pests.
Figure C.1 Simple linear regression comparing dollar spot infection centers counts to digital imaging analysis’s percent data. Multiple small dollar spot infection centers (DSIC) and white balance issues can explain the variability with high DISC with low percent diseased area with the camera. High thatch amounts drought expression, and other inert matter such as earthworm castings can explained by the variability with high percent-infected area and low DSIC count data.
Figure C.2 A and B  Pictures from The Golf Club taken on 7/24/2008 revealing drought stress and inert matter were included in the percent measurement. (A) Raw picture from The Golf Club on 7/24/2008 with 7 dollar spot infection centers with senescing tissue from the rough bluegrass, bentgrass drought stress and little inert matter; and (B) screen snapshot of APS press Assess software delivering a percent rating of 47.26%.
Figure C.3 A and B  Pictures from Ohio Turfgrass Research and Education Center in on 7/15/2008 revealing dollar spot flecking and thatch were included in the percent measurement.  (A) Raw picture taken from Ohio Turfgrass Research and Education Center in Columbus Ohio on 7/15/2008 showing 34 dollar spot infection centers (flecking) and the presents of high thatch and (B) Screen snapshot of APS press Assess software delivering a percent rating of 25.81%
Figure C.4 A and B  Pictures from Ohio Turfgrass Research and Education Center on 6/12/2008 revealing brown patch and earthworm castings were included in the percent measurement. (A) Raw picture taken from Ohio Turfgrass Research and Education Center in Columbus, Ohio on 6/12/2008 showing 2 dollar spot infection centers and the presents of brown patch, thatch, and earthworm castings and (B) Screen snapshot of APS press Assess software delivering a percent rating of 7.01%.
Figure C.5 A and B  Pictures from Ohio Turfgrass Research and Education Center on 6/20/2008 revealing earthworm castings were included in the percent measurement. (A) Raw picture taken from Ohio Turfgrass Research and Education Center in Columbus, Ohio on 6/20/2008 showing 0 dollar spot infection centers and the presents of earthworm castings and (B) Screen snapshot of APS press Assess software delivering a percent rating of 2.83%. 
REFERENCES


APPENDIX D

USE OF WATCHDOG WEATHER STATIONS AND SENSORS TO MONITOR LOCAL WEATHER CONDITIONS
Figure D.1  Watchdog weather station installed at The Golf Club and The Ohio Turfgrass Research and Educational Facility.
Figure D.2 Mean air temperature collected by the Watchdog data loggers at The Golf Club (TGC) and Ohio turfgrass Foundation research and Experimental Station (OTF) in 2006-2008.
Figure D.3 Mean soil temperature collected by the Watchdog data loggers at The Golf Club (TGC) and Ohio turfgrass Foundation research and Experimental Station (OTF) in 2006-2008.
Figure D.4 Accumulated daily precipitation amounts collected by the Watchdog data loggers at The Golf Club (TGC) and Ohio turfgrass Foundation research and Experimental Station (OTF) in 2006-2007.
Figure D.5 Mean daily relative humidity measurements from the Watchdog data loggers at The Golf Club (TGC) and Ohio turfgrass Foundation research and Experimental Station (OTF) in 2007-2008.
Table D.1 Pearson correlation coefficient, N=24 correlating single treatments 2006-2008 with regional climatic conditions with P-values.

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APPENDIX E

FIRST REPORT OF ANNUAL BLUEGRASS WEEVIL, LISTRONOTUS MACULICOLLIS, DAMAGE IN OHIO.
Annual bluegrass weevil, *Listronotus maculicollis* (Kirby) (1), larvae, pupae and adults were recovered and identified in a sample received by the C. Wayne Ellett Plant and Pest Diagnostic Clinic (CWEPPDC) at The Ohio State University on 19 June 2007. Damage to the approaches and collars of four golf course putting greens was detected by the superintendent of Stonewater Golf Club, Highland Heights, OH (a suburb of Cleveland) during the week of 11 June 2007. The superintendent suspected damage from the larvae of the black turfgrass ataenius, *Ataenius spretulus* (1). Insecticide applications applied to suppress black turfgrass ataenius did not provide adequate levels of control. A sample was sent to the CWEPPDC for analysis where it was determined that the symptoms were not caused by a pathogen. Adult annual bluegrass weevils were observed in the samples. Mature larvae, pupae, callow adults and adults of *L. maculicollis* were subsequently identified at the golf course during a site visit on 20 June 2007.

The annual bluegrass weevil has previously been mentioned as causing damage in the northeastern portion of North America (2), but this is the first confirmed cast of turf damage in Ohio. The weevil has been confirmed from New Hampshire, Vermont, Massachusetts, Delaware, New York, Pennsylvania, West Virginia and Connecticut.

Adults are 3.5 to 4.0 mm long and a dark brown-black color, but they appear to be mottled gray to tan due to a covering of yellowish-brown mixed with spots of grayish-white scales (1). Eggs are deposited on the leaf sheaths of annual bluegrass and/or creeping bentgrass and hatch in 4-9 days. Larvae are creamy white in color, legless, and crescent shaped body 1 to 4.5 mm in length with a light brown head capsule that will darken with age. When mature they will grow to be about 4.5 mm in length. *L.
*maculicollis* adults overwinter in leaf litter of wood lots adjacent to managed turf areas. In early spring these adults walk and fly from these areas to search for *Poa annua* where they feed and complete two to three generations per year (1). Voucher specimens are deposited at the C. A. Triplehorn Insect Collection on The Ohio State University’s Columbus campus.


APPENDIX F

LIST OF REFERENCES


