ABSTRACT

Title of Thesis: SEASONAL DEVELOPMENT OF DOLLAR SPOT EPIDEMICS IN MARYLAND AND NITROGEN EFFECTS ON FUNGICIDE PERFORMANCE IN CREEPING BENTGRASS

Christopher Patrick Ryan, Master of Science, 2011

Thesis directed by: Professor Peter H. Dernoeden, Ph. D.
Department of Plant Science and Landscape Architecture

Dollar spot (*Sclerotinia homoeocarpa)* is a common and destructive disease of creeping bentgrass (*Agrostis stolonifera).* The frequency and severity of dollar spot epidemics has not been quantified and there are no effective predictive models. High rates of nitrogen (N) reduce dollar spot injury, but low N rates applied in summer have not been assessed for disease suppression. Field studies were conducted from 2008 to 2010 with the following objectives: a) to describe the relationship among season, environmental factors and the severity of dollar spot epidemics in six creeping bentgrass cultivars; b) to evaluate six water soluble N sources applied at a low rate (7.3 kg N ha^{-1}) in summer for their impact on dollar spot severity; and c) to assess the performance of low fungicide rates tank-mixed with N on dollar spot severity. Two epidemics were observed each year between spring and mid- autumn, with the second being most severe. A third, late autumn epidemic also was observed in each year. The first epidemic in May was effectively predicated using a degree day model having a biofix date of 1 April and a 15°C base temperature. Ammonium sulfate was most consistently effective in reducing dollar spot injury, but caused foliar injury. Tank-mixing a low chlorothalonil rate with N generally reduced fungicide efficacy.

SEASONAL DEVELOPMENT OF DOLLAR SPOT EPIDEMICS IN MARYLAND AND NITROGEN EFFECTS ON FUNGICIDE PERFORMANCE IN CREEPING BENTGRASS

By

Christopher Patrick Ryan

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Science
2011

Advisory Committee:
Professor Peter H. Dernoeden, Chair
Associate Professor Arvydas P. Grybauskas
Assistant Professor Yilmaz Balci

© Copyright by
Christopher Patrick Ryan
2011

Acknowledgements

First and foremost, I would like to thank my graduate advisor, Dr. Peter H. Dernoeden. He provided me with this great opportunity and my gratitude is immeasurable. It has been more than a privilege to work with such an influential figure in this industry. With Dr. Dernoeden's knowledge and guidance I was able to learn so much and develop into a more, well-rounded professional.

I also would like to thank my graduate committee members, Dr. Arvydas Grybauskas and Dr. Yilmaz Balci, for their help and input in this project. They may not be "turfies" but these gentlemen are two of the best in their respective fields, and it has been an honor to work with and learn from them.

Thanks to the other great professors in our turfgrass management department, notably Dr. Thomas Turner and Dr. Mark Carroll. They were always available whenever I had any questions or concerns. Another faculty member that I must thank is Dr. Bahram Momen. He did an amazing job helping me understand statistics, and I simply could not have done the analysis without him.

I also thank my friends at the University of Maryland Paint Branch Turfgrass Research Facility. It has been a great pleasure working with, and just being around, such a fine group of people. Mr. David Funk, Mr. Joe DeRico, Mr. Matt Katsureles, Mr. Raymond Pigati, and Mr. Andrew Adle were instrumental in the success of this project. They made this entire experience that much more enjoyable. Not only were they always helpful and willing, but they made this midwestern kid feel right at home from day one. Also, thanks to Dr. Jinmin Fu, who showed me the way when I first arrived in College Park.

A very special thanks to my undergraduate advisor at Purdue University, Dr. Cale Bigelow. It was Dr. B that recognized my potential and pushed me to reach that potential. Without his guidance and encouragement, I never would have set forth on this journey, and for that I am forever indebted to him.

Finally, I must thank my family and friends for their total support, especially my mother, Rhonda, to whom I owe everything.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

Full Meaning[†]	Abbreviation
Acre	A
Active ingredient	a.i.
Analysis of variance	ANOVA
Ante meridian	AM
Carbon Dioxide	CO_2
Centimeter	cm
Feet	ft
Fluid	fl
Gallon	gal
Gallon per acre	GPA
Gram	g
Hectare	ha
Hour	h
Inches	in
Infection centers	IC
Kilogram	kg
Kilopascal	kPa
Least significance difference	LSD
Liter	L
Maryland	MD
Meter	m
Milligram	mg
Millimeter	mm
Ounce	oz
Pounds per square inch	psi
Product	prod
Post meridian	PM
United States of America	USA
United States Environmental Protection Agency	USEPA
Volume to volume	v/v

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

Chapter I: Review of Literature

Biology of Sclerotinia homoeocarpa and Epidemiology of Dollar Spot in Turfgrasses

Dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) is a major disease of turfgrasses that is problematic for golf course superintendents throughout most of the United States. While many superintendents in the Mid-Atlantic region regard Pythium blight (*Pythium* spp.) as being the most destructive disease on golf courses, more money is spent on fungicides for dollar spot control than on any other disease (Vargas, 2005).

The first noted turfgrass disease in the U.S.A. was large brown patch (*Rhizoctonia solani* Kuhn) in 1914 and small brown patch (a.k.a. dollarspot or dollar spot) was recognized later as a distinctively different disease (Monteith and Dahl, 1932). Prior to a formal description of the pathogen by Bennett (1937), the symptoms of dollar spot in creeping bentgrass (*Agrostis stolonifera* L.) were described by Monteith in a national trade magazine for golf course superintendents in 1927 and 1928. Monteith (1927, 1928) considered dollar spot a disease incited by an unknown *Rhizoctonia* spp. and referred to the disease as both dollar spot and small brown patch. Dollar spot was distinguished in the field from large brown patch (*Rhizoctonia solani* Kuhn) by its relatively small patches. According to Monteith (1927 and 1928), dollar spot was characterized by bleached brown spots in turf that seldom exceeded the size of a silver dollar. In cool-season turfgrass species, dollar spot symptoms first appear as chlorotic lesions on leaf blades that become water-soaked and then finally turn bleached white or straw-colored (Smiley et al., 2005). In some cases the entire leaf blade may become blighted. Dollar spot lesions may be hour-glass-shaped, white in color and have reddish-brown margins. Lesions also may be oblong or oval. Aerial mycelium that is cottony and white in color can be seen when dew is present on leaf tissue.

Taxonomy of the Causal Agent

As previously noted, the causal agent once was thought to be a species of *Rhizoctonia*, and the disease was referred to as "small brown patch" (Monteith, 1927 and 1928). This error likely was due to some similarities in aerial mycelium and the lack of spore production in pure culture (Bennett, 1937). The high frequency of right angle branching found on mycelium of *S. homoeocarpa* also could have been confused with a *Rhizoctonia spp.* Its current classification has been under much speculation and recently it has been proposed that the dollar spot pathogen be considered a *Rutstroemia* species (Powell and Vargas, 1999, 2001 and 2007).

F.T. Bennett formally described *S. homoeocarpa* in 1937. Bennett (1937) isolated several strains of *S. homoeocarpa* from various parts of the world including Britain, U.S.A. and Australia. In Britain, Bennett (1937) isolated what he referred to as the perfect strain. This strain was characterized by having white aerial mycelium that turned a cinnamon color after 4 to 6 weeks of growth on wheatmeal agar. This perfect strain also formed dark sclerotial structures beneath or at the edge of the reddish-brown mycelium on agar. Under certain cultural conditions this strain was shown to freely produce sporophores that would eventually become conidiophores or ascophores, or remain sterile. Bennett (1937) isolated another strain from Britain that he referred to as an ascigerous strain. This strain was characterized as having white mycelium that was more dingy in color than the perfect strain. This mycelium could have a faint bluish-green tinge, but would also turn cinnamon in color. Like the perfect strain, the ascigerous strain produces sporophores, but does not produce conidiophores or conidia. The aforementioned strain also produces ascophores and ascospores. It was noted that the ascospores of this strain were smaller than that of the perfect strain. Another difference between this strain and the perfect strain is the occurrence of microconidia. Bennett (1937) also obtained isolates from Britain, U.S.A. and Australia that he referred to as non-sporing strains. These strains produce mycelia that vary slightly in their white color. The British strain was noted to be slightly bluish, while the American strain was slightly yellowish and the Australian strain remained white. These strains produced sclerotial structures similar in color to those previously mentioned, and they also form sporophores.

According to Bennett (1937), apothecia of British strains of *S. homoeocarpa* can reach full development in spring when temperatures reach 5 to 12°C (41 to 54 °F). The maturation of ascospores occurs in apothecia at temperatures of 15 to 20°C (59 to 68 °F). At this maturation temperature (15 to 20 °C), however, the new apothecia do not develop from swollen apices of existing sporophores.

Fenstermacher (1980), however, reported that sterile apothecia are produced in nature in the U.S.A. Isolates typically produce white aerial mycelium that were described as sparsely floccose on potato dextrose agar (Fenstermacher, 1980). With age, colonies develop shades of olive, gray, brown and yellow, become appressed and blackened stromatal rinds are produced on the surface and/or are submerged in agar (Fenstermacher, 1980; Smiley et al. 2005). On leaves of cool-season turfgrasses, sclerotia (more appropriately stroma) are black, only a few cells thick and generally are found on the borders of leaf lesions. The pathogen survives as sclerotia or thin sclerotial flakes on infested tissue (Fenstermacher, 1980). Sclerotia or stroma (i.e., compacted masses of mycelium with or without host tissue) are rarely found in the mid-Atlantic region of the U.S.A. (Dernoeden, personal communication). It is believed that the fungus primarily overwinters in infected plants or infested debris (Fenstermacher, 1980; Smiley et al, 2005).

As previously noted, the dollar spot fungus produces stroma, which are sclerotia-like and this is the primary reason why taxonomists now exclude *S. homoeocarpa* from the genus *Sclerotinia* (Smiley et al., 2005). Jackson (1974) and Fenstermacher (1980) were among the first to suggest that the dollar spot fungus was a species of *Rustroemia*. More recently, Powell and Vargas (1999 and 2007) proposed that the causal agent of dollar spot in the U.S.A. to be a species of *Rustroemia*. A study by Powell and Vargas (2007) compared isolates from North America with those from Australia, The Netherlands and Britain, to include cultures used in the original description of *S. homoeocarpa* by Bennett. Using ITS1 and ITS2 sequencing they reported that the original cultures of *S. homoeocarpa* used by Bennett resembled *Rutstroemia cuniculi* (Boudier) and *R. henningsianum* (Plöttn) more than it did the isolates from North America. Powell and Vargas (2007) proposed that isolates from North America, Australia and The Netherlands be identified by the epithet *Rutstroemia floccosum.*

Growth of the Causal Agent

Bennett (1937) examined the influence of temperature on rate of *S. homoeocarpa* growth. This study was conducted in Petri dishes using mycelium from the margins of a young colony grown on wheatmeal agar. Growth rates were calculated as the average daily increase in colony diameter. Using both American and British strains of *S. homoeocarpa*, it was determined that the optimum temperature for growth of the British strains was 20 to 25°C (68 to 77°F) and about 30°C (86°F) for the American strains. The maximum temperature for growth for all strains was 35 to 36° C (95 to 97°F); growth was inhibited within a few hours at 37° C (99°F).

Several factors contribute to *S. homoeocarpa* infection. Before infection can occur, the temperature around the leaf tissue must reach temperatures of 12 to 16°C (55 and 60°F) and infections can continue at temperatures as high as 32°C (90°F) (Bennett, 1937; Endo, 1963). Low nitrogen fertility, extended periods of leaf wetness, low soil moisture, and low mowing heights favor infection (Endo, 1966).

Endo (1963) studied the influence of temperature on the rate of *S. homoeocarpa* growth and on the rate of disease spread on inoculated creeping bentgrass. Using 'Seaside' creeping bentgrass grown in deep glass dishes filled with sterilized quartz sand, plants were inoculated with *S. homoeocarpa* mycelium taken from the margin of an actively growing colony grown on potato-dextrose agar. Mycelium was placed in the center of each plate containing four-day-old bentgrass seedlings. Once inoculated, plants were incubated at 4.5, 10.0, 15.5, 21.0, 26.8, and 32.0°C (40, 50, 60, 70, 80 and 90°F). The influence of temperature on the linear spread of the pathogen was measured by recording the increase in diameter of the infected areas from the original point of inoculation. No plants that were incubated at 4.5 and 10.0°C (40 and 50°F), or at temperatures above 32.0°C (90 °F) showed any symptoms. Mycelium, however, had extended completely over the surface of the quartz sand in one week at all temperatures between 10 and 32°C (50 and 90 °F). Foliar blight developed slowly and only at 15.5 to 26.8°C (60 and 80 °F). Sclerotia were observed on some seeds at temperatures between 10.0 and 26.8°C (50 and 80°F), but not at 4.5 or 32°C (40 or 90 °F). In short, mycelia grew at all temperatures, but foliar infection only occurred from 15.5 to 26.8 °C (60 to 80 °F). Upon completion of the experiment, plant roots were examined. It was found after five weeks of infection that the fungus had not directly invaded roots at any temperature. It was observed, however, that at 21.0°C (70 °F) and 26.8°C (80 °F), roots were necrotic and severely stunted. It was at these temperatures that *S. homoeocarpa* produced mycotoxins that possibly caused damage to turfgrass roots (Endo, 1963, Malca and Endo, 1965). At 15.5°C (60 °F) some roots showed slight stunting and browning, while at 4.5, 10.0, and 32.0°C (40, 50, and 90°F) there was no disease development (Endo, 1963)..

Bennett (1937) examined the influence of hydrogen ion concentration on the rate of growth of *S. homoeocarpa* at a pH range of 4.0 to 8.0 at 13 °C (55 °F). It was found that both ascospores and conidia of British strains germinated in water and in artificial media throughout the range of pH 4.0 to 8.0. Rate and vigor of germination in the pH range of 5.0 to 7.0 were equal. At the extreme ranges of pH 4.0 and 8.0, however, both spore germination and hyphal development were delayed. The amount of aerial mycelium, however, was greater at a lower pH than at a higher pH. Bennett (1937) concluded that acid conditions were more favorable for growth of *S. homoeocarpa* than alkaline because some strains of the fungus showed very little growth at pH 8.0. However, neither acidity nor alkalinity within the pH range of 4.0 to 7.0 had any significant influence on mycelial growth.

Couch and Bloom (1960) evaluated the effect of nutrition and soil pH on dollar spot in Kentucky bluegrass (*Poa pratensis* L.). This study was conducted using a continuous-flow drip-culture system, with silica sand as a growth medium. In this study it was concluded that disease severity decreased significantly under low nitrogen (N) and normal potassium and phosphorus fertility, or when overall levels of these nutrients were low. Couch and Bloom (1960) also studied plants grown under high and low N fertility at soil pH's of 4.0, 5.6, 7.0, and 9.0. Soil pH was adjusted using NaOH or HCl as needed. It was found that the soil pH levels evaluated did not alter disease severity.

Couch and Bloom (1960) also studied the influence of soil moisture on dollar spot severity. Kentucky bluegrass was grown in moistened silt loam and maintained in a greenhouse. Once roots of the bluegrass seedlings had filled the soil, pots were separated into treatments of different levels of soil moisture. The treatments were field capacity (FC), ¾ FC, ½ FC, ¼ FC, and permanent wilting point (PWP). Plants were allowed to take up water until the soil moisture reached the predetermined level based on weight for two weeks. Once this level was reached, the pots then were irrigated back to field capacity. After that two week period, plants were inoculated once the predetermined moisture level was reached and containers were covered with plastic bags. The containers were incubated for five days, after which time the bags were removed. Disease was assessed one week later. Plants maintained at field capacity exhibited far less disease injury than plants maintained at any other moisture level.

Between 2002 and 2004, McDonald et al. (2006) examined the effect of deep and infrequent morning versus light and frequent night irrigation on dollar spot incidence and severity. Field plots of 'Crenshaw' creeping bentgrass were irrigated either deep and infrequently (4 to 6 cm deep) in the morning, or light and frequently (5.0 mm deep) at night. Plots irrigated deep and infrequently were watered at 0600 hrs (6 AM) when plants began to show symptoms of drought stress. Plots irrigated light and frequently were watered at 2100 hrs (9 PM) daily, except during periods of rain. The wilting point of the silt loam soil was determined to be 0.22 cm^3cm^{-3}. When soil moisture levels fell below 0.23 cm^3cm^{-3} during the late summer of 2002 and 2004, dollar spot became more severe in infrequently irrigated plots. Dollar spot severity was negatively correlated with soil moisture levels on two dates in late August 2002. In 2003, it was noted that temperatures were unusually cool and there had been frequent rainfall. It was in this year that there was no significant relationship between dollar spot severity and irrigation frequency treatments. In 2004 tarps were used to cover plots and thus control the influence of rain. It was not until 24 August 2004, however, that the effect of irrigation treatment was significant. On 24 and 30 August 2004, dollar spot severity was again negatively correlated with soil moisture levels. In late summer, when disease pressure was the highest, the fungicide chlorothalonil provided better dollar spot control in frequently irrigated plots versus infrequently irrigated plots. This was attributed to less severe disease pressure in plots subjected to daily, light and frequent irrigation.

Infections and Models

Sclerotinia homoeocarpa overwinters as dormant mycelium in the crowns and tissues of infected plants and in infested, necrotic tissue (Fenstermacher, 1980; Smiley, et al. 2005). As temperatures rise in the spring and approach 15°C (60 °F), mycelial growth resumes, but disease development reaches its peak at temperatures between 21 to 27°C (70 to 80°F), when the nighttime atmospheric humidity is 85 percent or higher (Endo, 1963). As previously noted, American strains of *S. homoeocarpa* do not produce spores (Baldwin and Newell, 1992). Instead, the pathogen is spread by the movement of infested grass clippings, foot traffic, mowers and other maintenance equipment. Leaves become infected by mycelium growing into cut leaf tips and stomates, and by direct penetration of intact leaf surfaces (Monteith and Dahl, 1932; Endo, 1966).

Hall (1984) developed a dollar spot prediction model based on temperature and precipitation in Ontario, Canada. Hall (1984) referred to dollar spot as occurring in a series of steps in one annual epidemic. He defined a step as a point where a decline in the epidemic rate was followed by an increase in epidemic rate. This experiment, which spanned the summers of 1981 and 1982, established that dollar spot occurs in a series of steps. Plots were monitored for disease infections between 1 May and 18 September 1981. *Sclerotinia homoeocarpa* infection centers were counted when symptoms were visually detected. Daily rainfall and average daily air temperatures were monitored to examine their potential relationships to *S. homoeocarpa* infection and the appearance of symptoms. Weather conditions were presumed to be causally related to dollar spot and the intervals during which they occurred were referred to as infection periods. In 1981, dollar spot was first observed on 23 June, and the number of infection centers per plot increased throughout the season ending on 18 September. By 18 September, 40% of the turf stand was diseased. The epidemic had progressed in six steps. In each of the last four steps, the rate of increase in the number of new infection centers declined progressively during each step.

As noted previously, a relationship was sought by Hall (1984) between temperature and rainfall, and the steps in the epidemic. Days in which no measurable precipitation occurred were referred to as dry days, which occurred 79 times in 1981. These days had average daily temperatures ranging from 5 to 27°C (41 to 81 °F). Single wet days in which rainfall was recorded occurred on 10 occasions. These wet days had average daily temperatures ranging from 13 to 23°C (55 to 73 °F) in 1981. Two or more consecutive wet days occurred 13 times during the 1981 season. Six of these instances closely preceded or overlapped the beginning of a step in the epidemic, and each step was defined as being an infection period. Using 1981 data, a model was created and tested in 1982 to determine if rainfall and air temperature consistently preceded or coincided with an increase in the rate of disease development. The model stated that a step in the dollar spot epidemic will occur after two consecutive wet days if the average temperature for the period reaches or exceeds 22°C (72 °F) or after three or more consecutive wet days if the average temperatures for the period is 15°C (59 °F) or greater. These conditions defined a dollar spot infection period or step in the epidemic.

In 1982 the monitoring dates were between 26 July and 8 September, and the dollar spot epidemic was much less severe than that of 1981. Dollar spot was first observed on 26 July. By the time data collection ceased on 8 September, 10% of the turf area was diseased. It was then recognized that five steps in the epidemic had occurred. In 1982, there were eighty dry days, with average daily temperatures ranging from 8 to 25°C (46 to 77 °F). There were eight single wet days, with average temperatures ranging from 14 to 22°C (57 to 72 °F). It appeared as though none of these conditions were related to steps in the dollar spot epidemic. There also were 15 occasions in which two or more consecutive wet days occurred. Five of these 15 instances of consecutive wet days closely preceded or overlapped the onset of a step. Two exceptions to the model were observed in 1982. One step followed a period of four wet days with a daily average temperature of 12°C (54°F), while the model specified a minimum temperature of 15°C (59°F). Another step followed a period of two wet days with a daily average temperature of 16°C (61°F), while the model specified a minimum temperature of 22°C (72°C). Both of these exceptions occurred during periods when temperatures lower than those specified by the model had occurred. Both were small steps that occurred late in the epidemic.

To test the accuracy of the model in the field, the fungicide benomyl (methyl [1-[(butylamino)carbonyl]-1H-benzimidazol-2-yl] carbamate) was evaluated using two spray schedules (Hall, 1984). Benomyl was applied preventively every 14 or 15 days between 1 June and 7 September 1982 resulting in a total of seven sprays. In the second treatment, benomyl was applied curatively one or two days following a predicted infection period using the model. This curative approach resulted in two fungicide applications. The weather-timed curative fungicide application provided a level of control equivalent to the preventive program, thus demonstrating that the model was effective and reduced the need for numerous pre-plant infection sprays.

Burpee and Goulty(1986) tested the Hall (1984) model as well as that proposed by Mills and Rothwell (1982). Burpee and Goulty (1986) tested these models on a 7-yr-old ‘Penncross’ creeping bentgrass stand maintained as a golf course putting green in Ontario, Canada. Mills and Rothwell (1982) were golf course superintendents in Ontario, Canada that used hygrothermograph data collected at their courses to develop an empirical dollar spot prediction model. In the Mills and Rothwell (1982) model it was stated that if maximum daily temperature equaled or exceeded 25 °C and maximum percent relative humidity equaled or exceeded 90% for more than three days in any seven day period dollar spot should appear. Burpee and Goulty (1986) found that when the Hall (1984) model was used to forecast fungicide applications, acceptable disease control was not achieved because the model underestimated the number of infection periods. Conversely, Burpee and Goulty (1986) found that dollar spot occurrence was highly overestimated by the Mills and Rothwell (1982) model.

While all of the above factors contribute in some way to *S. homoeocarpa* infection, leaf wetness duration also is an important limiting factor (Ellram et al., 2007; Walsh, 2000; Williams et al., 1996). Leaf wetness duration, however, has not been used as a model parameter for predicting dollar spot epidemics. Williams et al.

(1996) studied the effects of removing dew from golf course fairways and putting greens in Lexington, KY in 1992 and 1993. On fairways this included mowing at 0700 hrs (7 AM) and 1400 hrs (2 PM), and there were treatments in which clippings were either collected or were allowed to remain. Another treatment involved mowing at 1400 hrs (2 PM) and dew removal in the morning using a mower with disengaged blades. All treatments on fairway height turf were imposed three days per week. On 9 and 23 July 1992, treatments that displaced leaf surface moisture on fairway height turf resulted in far fewer *S. homoeocarpa* infection centers than treatments in which leaf surface moisture was not displaced. On 17 June 1993, dollar spot reduction was greatest (i.e., there was 77% less blighting) when turf was mowed at 0700 hrs, when compared to mowing at 1400 hrs. They found no significant effect associated with collecting or removing clippings. In the putting green study, treatments were the same as in the fairway study with a few exceptions. In this study, greens were mowed five or six times per week, and mowing was performed at either 0800 hrs (8 AM) or 1300 hrs (1 PM). Reductions of dollar spot were observed in both years. In 1992, significant differences between mowing treatments were not observed until July. There was a 5.9 to 7.2% reduction in dollar spot with morning mowing versus afternoon mowing on two dates in July 1992. In 1993, there was on average a 50% reduction in dollar spot between plots mowed at 0800 hrs versus plots mowed at 1300 hrs.

Ellram et al. (2007) examined the relationship of leaf wetness duration and dollar spot by mowing and/or displacing dew on fairway height creeping bentgrass in the field in St. Paul, MN, and in a controlled greenhouse environment. Treatments included mowing or use of a squeegee to remove dew at 2200 hrs (10 PM); 0400 hrs (4 AM), and 1000 hrs (10 AM). Plots were either mowed daily or every other day. Plots mowed every other day had dew removed by a squeegee on days that plots were not mowed. It was determined that daily dew removal at 0400 hrs (4 AM) resulted in the least amount of diseased area (about 2% on average). Removal of dew every other day by mowing or squeegeeing at 0400 hrs and daily dew removal by mowing or squeegeeing at 2200 hrs resulted in an intermediate level of disease (about 4% on average). Daily mowing or squeegee treatments imposed at 1000 hrs, and treatments performed every other day at 2200 hrs resulted in the most disease (about 6% on average). Ellram et al. (2007) concluded that interrupting the leaf wetness duration around the middle of the leaf wetness period was most effective in reducing dollar spot. Field results were supported by the controlled environment portion of this study. In the greenhouse study, a mist chamber was used to establish and maintain leaf wetness. Pots of 'Penncross' were rotated in and out of these mist chambers to interrupt the leaf wetness period after 6, 12 or 18 hrs of mist. The diameters of the infection centers then were measured. Data showed that the mean diameter of the infection centers had increased as leaf wetness duration was increased from 6 to 18 hrs.

Pigati et al. (2010) evaluated the influence of simulated rain and mowing on the performance of fungicides targeting dollar spot. In this study, four fungicides (chlorothalonil, boscalid, iprodione, and propiconazole), two rain treatments (rain-free and simulated rain), and two mowing timings (morning and afternoon) were examined. Irrigation was applied 30 minutes following fungicide application to simulated-rain plots while rain-free plots were not watered. Plots were mowed either in the morning while dew was present or in the afternoon after the canopy had dried. When data were averaged over all four fungicide treatments in both years of the field study, a 54 to 65% reduction of dollar spot was observed in plots mowed in morning compared to those mowed in the afternoon. In non-fungicide treated control plots, dollar spot severity was reduced by morning mowing by 26 and 23% in 2007 and 2008, respectively.

Walsh (2000) studied the influence of leaf wetness duration and temperature on development of dollar spot on 'Penncross' creeping bentgrass in a controlled environment. Inoculated plants were placed in growth chambers at temperatures of 10, 17.5, and 25 °C (50, 63.5, and 77 °F). Using an ultrasonic mister, the chambers were maintained at a relative humidity of 94 to 96% to ensure leaf wetness. Pots were placed in the environmental chamber for 0, 12, 24, 36, or 48 hrs. When the treatment duration concluded, water was shaken from the leaf surfaces without disturbing the pathogen, and the pots then were transferred to a growth chamber until all other leaf wetness durations had ended. The interaction of leaf wetness and temperature on the size of infection centers was significant. The largest infection centers developed during 48 hrs of leaf wetness at an average temperature of 17.1°C (62 °F). Dollar spot symptoms did not appear on plants that remained dry (i.e., had a leaf wetness duration of 0 hrs). The smallest infection centers developed at 10°C (50 °F) and increased with temperature for each duration of leaf wetness, except for 10°C (50 °F) at 12 hrs of leaf wetness in which dollar spot did not appear. Using temperature (T) and leaf wetness duration (L), Walsh (2000) developed a regression equation to estimate the diameter of infections centers. The treatment L=0 was not included in the development of the equation because using L=0 resulted in an infection center diameter of less than 1. It was determined that the minimum temperature for disease development ranged from 10 °C (50 °F) with 22 hrs of leaf wetness to 12 °C (54 °F) with 12 hrs of leaf wetness. Estimated infection center diameter increased with T until the maximum was predicted between 21°C (70 °F) and 24 °C (75 °F), depending on leaf wetness duration.

According to Walsh (2000) leaf wetness duration is a limiting factor in dollar spot development. Because leaf wetness duration is a limiting factor, temperature was believed to be of utmost importance during nighttime dew periods in order for disease to develop. Disease did not develop at temperatures of 10 °C (50 °F) during 12 hrs of leaf wetness, but did develop at 17.5 °C (63.5 °F) during 12 hrs of leaf wetness. Therefore, it appeared to Walsh (2000) that a threshold temperature lies somewhere between 10 °C (50 °F) and 17.5 °C (63.5 °F). The model predicted that dollar spot activity begins at 15 °C (59 °F) with 16 hrs of leaf wetness. This predictive model estimated that dollar spot occurrence would take place 9 to 10 days after 1 May, when average air temperatures were greater than or equal to 16°C (61 °F). This estimate was consistent with previous beliefs that dollar spot development will begin at 15 °C (59 °F) (Bennett, 1937).

Walsh (2000) also examined the epidemiology of dollar spot in southern Ontario, Canada in creeping bentgrass grown on a sand-based green and a golf course fairway. Plots were established on these sites and *S. homoeocarpa* infection centers were counted to assess disease. Walsh (2000) used six epidemics over the three years to characterize symptom development. It was observed that dollar spot epidemics began on 14 June 1996, 17 June 1997, and 22 May 1998. It was noted in 1997 and 1998 that the epidemics began when irises (*Iris* sp.) and peonies (*Paeonia* sp.) were in bloom and when lilacs (*Syringa* sp.) were in full- to late-bloom. During the summers of 1996, 1997, and 1998, actively growing mycelia were observed on 37 of the 65 mornings in which dollar spot was assessed. It was noted that mycelia often were present after rain or periods of relative humidity greater than 85%.

We are unaware of any research-generated descriptions of the occurrences of dollar spot epidemics in the U.S.A. Monteith and Dahl (1932) observed that dollar spot could occur from late spring to early autumn in northern regions, but may occur at anytime of the year in southern regions of the U.S.A. Smith et al. (1989) however, stated that in the northern U.S.A. there were two seasonal dollar spot epidemics in most years. One epidemic occurs in the spring or early summer (May to July) and a second occurs in late summer through autumn (mid-August to October). They further state that dollar spot outbreaks are favored by high humidity, cool nights that promote heavy dew formation and temperatures ranging from 15 to 25°C (59 to 77°F). In the mid-Atlantic region, dollar spot epidemics also can occur in the aforementioned timings (McDonald et al., 2006). However, the spring-early summer epidemics are generally less severe and of shorter duration than late summer epidemics in Maryland (McDonald et al, 2006). Furthermore, late autumn and early winter epidemics also may occur in Maryland, however, this has not been reported in the literature (Dernoeden, personal communication).

Dollar spot primarily has been managed on golf courses with fungicides beginning with mercury-based chemicals in the 1930's (Monteith and Dahl, 1932). As the golf course industry advances into an era where minimal use of fungicides becomes increasingly critical, knowledge of how and when dollar spot epidemics are likely to develop could prove to be extremely valuable. While advances in dollar spot control continue to be made, there is still much to be learned about how this disease is influenced by environmental conditions. Prior research has determined that there are several factors involved in dollar spot epidemics, but the information has been cursory, sparse and not definitive. Developing an effective model often requires monitoring a variety of environmental factors. For example, Fidanza et al. (1996) monitored air temperature, relative humidity, leaf wetness duration, precipitation, soil temperature, soil moisture, and solar radiation to develop a warning model for brown patch (*Rhizoctonia solani* Kuhn) in perennial ryegrass (*Lolium perenne* L). The model predicted brown patch outbreaks when mean relative humidity was greater than 75% and minimum air temperature was greater than 16° C (61 °F). This model was 85% successful in predicting brown patch. Kaminski et al. (2006) were able to develop a model to predict the occurrence of dead spot (*Ophiospharella agrostis,* Dernoeden, Camara, O'Neill, van Berkum, et Palm) in creeping bentgrass grown on a sand-based rootzone. This model associated the appearance of dead spot with maximum air temperatures of greater than or equal to 27 °C (81 °F); soil temperatures of greater than or equal to 18 °C (64 °F); relative humidity of less than or equal to 80%; leaf wetness duration of less than or equal to 14 hours, and solar radiation of greater than or equal to 230 W m^{-2}. This model was able to predict 80% of bentgrass dead spot outbreaks.

Dollar spot outbreaks are favored by high humidity, cool nights that promote heavy dew formation and temperatures ranging from 15 to 25°C (59 to 77°F). Monteith and Dahl (1932) observed that dollar spot could occur from late spring to early autumn in northern regions, but may occur at anytime of the year in southern regions of the U.S.A. Smith et al. (1989) stated state that the incidence of dollar spot is seasonal with most infections occurring in late spring, early summer, and autumn. It was empirically determined that the spring or early summer epidemic was generally less severe and of shorter duration than the late summer epidemic in Maryland (McDonald et al, 2006). In Canada, dollar spot epidemics were described by Hall (1984) and Walsh (2000). Hall (1984) states that there is one epidemic that occurs in a series of steps in Ontario. Maryland is located in a transition zone climate where both warm and cool-season grasses may be grown. Unlike Canada, Maryland summers generally are characterized by supraoptimal temperature stress and periods of drought. To our knowledge there has been no quantification or other formal description of dollar spot epidemics in the U.S.A. A study of the epidemiology of dollar spot is thus warranted given the economic importance of this disease throughout the transition zone of the U.S.A. A secondary objective was to associate key environmental parameters such as air temperature, rainfall, leaf wetness duration and relative humidity with dollar spot incidence and severity. Development and testing of a dollar spot prediction model, however, were not goals of this research project.

Effects of Nitrogen Fertility on Dollar Spot Severity in Creeping Bentgrass

It has been well demonstrated that the application of nitrogen (N) to turfgrasses when dollar spot is active can reduce the severity of this disease (Lui et al., 1995; Landschoot and McNitt, 1997; Davis and Dernoeden, 2002). It generally is believed that the mechanism of dollar spot suppression by N is due to its ability to stimulate plant growth and thus enable plants to produce new tissue at a rate that exceeds the ability of the pathogen to blight (Couch, 1995). Other scientists believe that some N sources promote microbial activity, which in some way antagonizes or competes with *S. homoeocarpa* and reduces its capacity to blight. In the study by Landschoot and McNitt (1997), the suppression of dollar spot by synthetic organic and natural organic N fertilizers was examined. The fertilizers evaluated in this study were: Ringer Commercial Greens Super (10-2-6; feather meal, blood meal, wheat germ, bone meal, liquid fat, D-limonene, and potassium sulfate); Ringer Compost Plus (7-4-0; wheat middlings or enriched cattle feed, calcium carbonate, dried molasses, bone meal, urea, and liquid fat, *Bacillus subtilis* (Ehrenberg) and *Bacillus licheniformis* (Weigmann)); Sustane (5-2-4; composted turkey litter); Milorganite (6-2-0; activated sewage sludge); Harmony (14-3-6; poultry manure, urea, methylene urea, potassium sulfate, and ferrous sulfate); urea (46-0-0); and Nitroform (38-0-0; product of urea and formaldehyde, contains approximately two-thirds slow release N). This study was conducted in University Park, PA on an established stand of Penncross creeping bentgrass maintained as a golf course putting green. Applications of all fertilizers, except Nitroform, were made four times per year at 28 to 33 day intervals. Fertilizers were applied at a low rate of 24 kg N ha^{-1} and a high rate of 48 kg N ha^{-1}. Nitroform was applied only twice each year at 56 to 66 day intervals at a rate of 96 kg N ha^{-1}. One urea treatment was applied at 24 kg N ha^{-1} every 14 to 16 days for a total of eight applications per season. In 1992, it was observed that none of the fertilizer treatments provided any significant dollar spot suppression compared to non-fertilized or untreated control plots. In 1993, data showed that high rates of Ringer Compost Plus and urea applied on 28 to 33 day intervals were the only treatments that provided disease suppression compared to the control. In 1994, all fertilizer treatments, except for a low rate of Harmony, provided a greater level dollar spot suppression versus the non-fertilized control. It also was noted that all treatments in which high rates of N were used provided better dollar spot suppression than lower N rates. Landschoot and McNitt (1997) concluded that urea (a synthetic organic fertilizer) provided equal or better dollar spot control than the natural organic fertilizers. Landschoot and McNitt (1997) associated disease suppression with dark green turf, which suggested that the suppressive effects of fertilizers was related to N availability and not enhanced microbial activity.

Liu et al. (1995) examined the effects of organic and inorganic amendments on bacterial and fungal populations and dollar spot suppression in creeping bentgrass. This research was conducted on an 11-year-old Penncross putting green grown on native soil in Guelph, Ontario. The fertilizers evaluated in this study were Alginate (1-0-2; Norwegian kelp meal); ammonium nitrate (34-0-0); Bovamura (converted from dairy manure); Milorganite (6-2-0); Ringer Greens Super (10-2-6); Ringer Lawn Restore (9-4-4; feather meal, bone meal, and soybean meal); Ringer Turf Restore (10-

2-6; feather meal, bone meal, and soybean meal); Sandaid (1-0-2; granular sea plant meal); sewage sludge; and sulfur-coated urea (35-0-0). Chlorothalonil also was assessed to compare its effectiveness to the fertilizers. Applications of fertilizers were made every four weeks from early June to early September at the recommended label rates for each product. Another application of each fertilizer again was made in late November. The levels of N in the fertilizers evaluated were different and this may have confounded results. Plots were evaluated for the number of infection centers in July, August and September from 1991 to 1993. There generally were no significant differences in the number of *S. homoeocarpa* infection centers among treatments in early and mid-July. From late July to early September on average, however, ammonium nitrate and Ringer fertilizers significantly reduced dollar spot incidence on creeping bentgrass, with ammonium nitrate being the most effective in reducing disease severity. Bacterial and fungal populations were quantified from fresh turfgrass, thatch and soil (2cm below soil-thatch interface) using a dilution plate method. The highest populations of bacteria and fungi were found in plots treated with Ringer Greens Super. Microbial populations from plots treated with ammonium nitrate and sulfur-coated urea also were high. Liu et al (1995) concluded that the suppression of dollar spot by N fertilizers may be a result of increased turf growth from increased N levels. They also stated that the competitive and antagonistic effects of increased microbial populations accorded by the natural organic fertilizers may have been a factor in the disease suppression observed.

Davis and Dernoeden (2002) examined the influence of natural organic and synthetic N-sources on dollar spot severity. In that study, urea (46-0-0); sulfur-coated urea (37-0-0); Milorganite (6-2-0); Sustane Medium (5-2-4); Earthgro 1881 Select (8-2-4; poultry manure); Earthgro Dehydrated Manure (2-2-2; poultry manure); Ringer Lawn Restore (10-2-6); Com-Pro (1-2-0; composted biosolids); and Scotts All Natural Turf Builder (11-2-4; poultry manure) were compared. The fertilizers were applied at equal rates of N and at recommended timings, which was not done in previous studies. Turf was an established stand of Southshore creeping bentgrass grown on a native sandy loam and N-sources were applied primarily in the autumn and dollar spot levels were monitored the following spring. These N-sources were applied annually from 1994 to 2000 in October, November, December, and May at a rate of 50 kg N ha^{-1} (1.0 lb N/1000ft^2) in each application. In 1998, it was determined that there were no significant differences in dollar spot severity among N-sources, with the exception of Com-Pro which had intensified the disease. In 1999, plots treated with Ringer Lawn Restore had the fewest number of *S. homoeocarpa* infection centers on most rating dates, but there were no other significant differences among treatments in that year. In 2000, plots treated with Com-Pro again had the highest number of infection centers between 25 May and 23 June. Plots treated with sulfur-coated urea and Ringer Lawn Restore resulted in the fewest number of infection centers, but there were no other significant differences among all treatments. Davis and Dernoeden (2002) found that none of the natural organic products evaluated consistently reduced dollar spot compared to synthetic organic N-sources. Soil samples taken from the upper 2.5cm of the soil profile in all plots were examined for microbial populations and in 1999 there was no significant correlation between *S. homoeocarpa* infection centers and soil microbial activity. Correlation coefficient data from 2000 suggested that the suppression of dollar spot early in the season may have been related more to N availability than microbial activity. Similarly, Ellram et al. (2007) implied that elevated tissue N levels above 5% were associated with less dollar spot in creeping bentgrass, but no data were presented.

Kaminski and Dernoeden (2005) examined the impact of various N sources on dead spot (*Ophiosphaerella agrostis)* in a creeping bentgrass green grown on a sand-based rootzone. The N-sources evaluated were isobutylidene diurea (31-0-0); sulfur-coated urea (29-0-0); urea (46-0-0); ammonium sulfate (21-0-0); methylene urea (40-0-0); and Ringer Greens Super (10-2-6). Fertilizer treatments were applied at a rate of 24 kg N ha^{-1} (0.5 lb N/1000ft^2) on 6 and 22 September, 6 and 20 October and 3 November 2000. In 2001, the N-sources were applied at the aforementioned rate on 22 May, 8 June, and 13 July. In 2000, plots treated with ammonium sulfate exhibited the greatest reduction (30%) of *O. agrostis* infection centers. Ammonium sulfate also was the only N-source that prevented dead spot occurrence in the following year. Ammonium sulfate-treated plots were the fastest to recover, while plots treated with IBDU were slowest to recover. Data showed that readily available, water soluble N was more effective in promoting recovery from dead spot.

Previous studies have shown that dollar spot severity can be reduced using relatively high rates of N when the disease is active. In the studies by Landschoot and McNitt (1997), Liu et al (1995) and Davis and Dernoeden (2002), the rates of N applied generally would not be appropriate in the summer for cool-season grasses. In summer, it is common practice to apply small amounts of N to greens, tees and fairways in what are called spoon feeding programs (Dernoeden, 2002). This involves spraying 5.0 to 7.2 kg N ha^{-1} (0.10 to 0.15 lb N/1000ft^2) every 10 to 14 days. Spoon feeding promotes vigor and recovery from injury without over stimulating turf. It is conceivable that spoon feeding in the summer when dollar spot is active could reduce disease severity, while improving fungicide performance. To our knowledge, there have been no studies in which water soluble N-sources were assessed in a summer spoon feeding program for their effects on dollar spot severity. Therefore, the objective of this study was to assess six water soluble N sources (ammonium nitrate, ammonium sulfate, urea, potassium nitrate, calcium nitrate, and 20-20-20) applied at low rates throughout the summer for their effect on dollar spot severity. The N-sources were applied alone or in combination with a low rate of chlorothalonil to determine if dollar spot control could be improved versus either applied alone.

Chapter II: Seasonal Development of Dollar Spot Epidemics In Six Creeping Bentgrass Cultivars In Maryland

<u>*Synopsis*</u>

This three year field study evaluated the incidence and severity of dollar spot (*Sclerotinia homoeocarpa*) in six creeping bentgrass (*Agrostis stolonifera*) cultivars grown in a native soil and maintained as golf course fairways in College Park, MD. Area under the disease progress curve (AUDPC) data showed that dollar spot injury was greater in the cultivars Crenshaw and Backspin, when compared to Penncross, Providence, L-93 and 007. Crenshaw was more severely damaged than Backspin in two of three years. There were few consistent differences in dollar spot injury among Penncross, Providence, L-93 and 007. Hence, Crenshaw and Backspin are referred to as highly susceptible (HS) and the other four cultivars will be referred to collectively as moderately susceptible (MS) to dollar spot. In all three study years, there were two summer epidemics and a third autumn epidemic. The second epidemic was longest and most severe, and the third autumn epidemic was least severe and of shortest duration. Growing degree days (GDD) were calculated using a base temperature of 15°C and a biofix date of 1 April. The GDD model was accurate in predicting the onset of the first epidemic beginning in May of each year in the HS (60 to 70 GDD) and MS (105 to 114 GDD) cultivars. The first epidemic began earlier in the HS cultivars and became more rapidly severe than observed in MS cultivars. Average daily air temperatures in 2008 and 2009 (15 to 25°C) and 2010 (20 to 29°C) were in the ranges previously reported to be conducive for dollar spot during most days of the first and second epidemics. Lowest disease pressure in MS cultivars was observed in

2010, which was attributed to high average daily air temperatures and many (n=26) average night (1600 to 0559 hrs) air temperatures (ANT) ≥ 25°C. Average night temperature data indicated that dollar spot activity was limited or stopped at <12°C or > 25°C. During both summer epidemics, the number of *S. homoeocarpa* infection centers (IC's) increased following two or more days of average daily relative humidity (ADRH) > 85%; whereas, the number of IC's generally declined following two or more days of ADRH < 85%. It was not determined why the number of IC's declined periodically, despite conducive air temperature, RH, precipitation and leaf wetness durations. The third autumn epidemic appeared between late October and early December. During the autumn epidemic, dollar spot remained active for about 10 to 14 days, but these epidemics were less severe than either summer epidemic.

Introduction

Dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) is a major disease of turfgrasses that is problematic for golf course superintendents throughout most of the U.S. While many superintendents in the mid-Atlantic region regard Pythium blight (*Pythium* spp.) as being the most destructive disease on golf courses, more money is spent on fungicides for dollar spot control than on any other disease (Vargas, 2005). Creeping bentgrass (*Agrostis stolonifera* L.) is a commonly grown turfgrass species on golf course fairways in many regions of the U.S. One of the earliest descriptions of dollar spot was by Monteith and Dahl in 1932 who noted that the disease also was known as "small brown patch". They observed that the disease appeared as small, regular spots that ordinarily were not larger than a silver dollar. These spots often do not exceed 5 cm in diameter, but could coalesce to form larger areas of blighted turf when disease pressure was severe (Monteith and Dahl, 1932; Smiley et al., 2005). Infected leaves may dieback from the tip and/or may have bleached hour glass-shaped lesions (Smiley et al., 2005). On leaves of close cut creeping bentgrass, there may be small oblong spots, which are bleached or tan in color and surrounded by a reddish-brown border (Smith et al., 1989). Individual leaves of infected creeping bentgrass plants shrivel, curl, and turn a bleached white or straw color (Monteith and Dahl, 1932). In advanced stages, patches may become sunken and turf develops a pitted surface (Smith et al., 1989). During periods of high humidity when turf foliage is covered with dew, white, cottony mycelium may be seen on infected turf (Monteith and Dahl, 1932; Walsh, 2000; Smiley et al., 2005).

Several studies have focused on temperatures and growth of *S. homoeocarpa*. Bennett (1937) determined the optimum temperature for growth of an American strain of *S. homoeocarpa* grown on wheatmeal agar to be 30°C, with a maximum temperature for growth occurring at 35 to 36°C. Endo (1963) found that *S. homoeocarpa* mycelium grew on potato-dextrose agar at temperatures ranging from 4.5 to 32°C. Using inoculated 'Seaside' creeping bentgrass seedlings, Endo (1963) found dollar spot symptoms only developed on plants maintained at temperatures between 15.5 and 26.8°C. It also was noted that the fungus had not directly invaded roots at any temperature. At temperatures ranging from 21.0 to 26.8°C, roots of inoculated plants were necrotic and severely stunted, which was attributed to a toxin produced by the pathogen (Endo, 1963; Malca and Endo, 1965).

Couch and Bloom (1960) studied the influence of soil moisture on dollar spot severity on Kentucky bluegrass (*Poa pratensis* L.). In that study, inoculated plants maintained in soil at field capacity (FC) exhibited far less disease injury than plants maintained at ¾ FC, ½ FC, ¼ FC, and permanent wilting point. The largest distinction was made between FC and ¼ FC treatments, in which foliar blight was more than twice that of plants grown at FC. In field studies, McDonald et al. (2006) observed in late summer that dollar spot was more severe in creeping bentgrass allowed to wilt prior to irrigation versus daily irrigation. A significant effect of soil moisture on dollar spot only was observed in a second, late summer epidemic when soil moisture fell below 0.23 cm^3cm^{-3}.

Long leaf wetness durations generally are believed to promote dollar spot severity (Smith et al., 1989). Walsh (2000) studied the influence of leaf wetness duration and temperature on development of dollar spot in creeping bentgrass. Walsh (2000) found that the largest infection centers developed during long periods (48 hrs) of leaf wetness at an average temperature of 17.1°C, and that dollar spot symptoms did not appear on plants that remained dry, regardless of temperature. Walsh (2000) determined that the minimum temperature for disease development ranged from 10°C with 22 hrs of leaf wetness to 12°C with 12 hrs of leaf wetness.

Williams et al. (1996) examined the effects of removing dew from golf course fairways and putting greens on dollar spot severity. When surface moisture was displaced on fairway height turf, far fewer *S. homoeocarpa* infection centers developed than in treatments in which leaf surface moisture was not displaced. On the final rating dates in both years of this two year field study, there was 78% and

37% less dollar spot in treatments mowed at 0700hrs versus afternoon mowing at 1400hrs, respectively. On the final rating dates in putting green height creeping bentgrass, Williams et al. (1996) observed 38% to 40% less dollar spot in morning versus afternoon mowed turf. Ellram et al. (2007) found that the earlier leaf wetness was displaced by mowing the less dollar spot injury was incurred. In that study, disease severity in fairway height creeping bentgrass was reduced by about 50% by daily mowing at 0400hrs (about 2% plot area blighted) compared to 1000hrs (about 4% plot area blighted). Similarly, Pigati et al. (2010) found in non-fungicide-treated turf that morning mowing reduced dollar spot in fairway height creeping bentgrass by 23 to 26% in a two year field study.

Hall (1982) developed a dollar spot prediction model based on temperature and precipitation in Ontario, Canada. Hall (1982) referred to dollar spot as occurring in a series of steps in one annual epidemic. He defined a step as a point where a decline in the epidemic rate was followed by an increase in epidemic rate. The model stated that a step in the dollar spot epidemic will occur after two consecutive wet days (days in which precipitation occurs) if the average temperature for the period reached or exceeded 22°C or after three or more consecutive wet days if the average temperatures for the period was 15°C or greater. Hall (1982) tested the accuracy of the model by applying a fungicide curatively after conditions of the model were met. Using the model, Hall (1982) achieved equal control to that of a preventive program, and reduced the number of fungicide applications from seven to two. Burpee and Goulty (1986) tested Hall's (1982) model in Ontario. They reported that when the model was used to forecast fungicide applications, acceptable disease control was not achieved because the model underestimated the number of infection periods (Burpee and Goulty, 1986).

Walsh (2000) found that dollar spot development would not occur in the field when leaf wetness duration (LWD) was less than six hours, but in that study LWD's were typically greater than twelve hours. It was noted by Walsh (2000) that aerial mycelium often was present when relative humidity was greater than 85%. The presence of mycelium was found to contribute to about a 10% increase in disease injury. Based on field observations, Walsh (2000) developed a model to predict the onset of dollar spot using mean air temperature. This model simply stated that dollar spot would appear after 9 or 10 days of mean air temperatures exceeding 16°C following 1 May.

Monteith and Dahl (1932) observed that dollar spot could occur from late spring to early autumn in northern regions, but may occur at anytime of the year in southern regions of the U.S.A. Smith et al. (1989) state that the incidence of dollar spot is seasonal and that one epidemic occurs in the spring or early summer (May to July) and a second occurs in late summer through autumn (mid-August to October). It was empirically determined that spring or early summer epidemics generally were less severe and of shorter duration than late summer epidemics in Maryland (McDonald et al, 2006). Furthermore, late autumn and early winter epidemics also may occur in Maryland, however, this has not been reported in the literature (Dernoeden, personal communication).

Most research devoted to the study of dollar spot epidemics was conducted in Canada (Hall, 1984; Walsh, 2000). Both Hall (1984) and Walsh (2000) state that there is only one annual dollar spot epidemic in Ontario, which occurs in a series of steps. Conversely, it appears that two or more dollar spot epidemics may occur in Maryland and perhaps other regions in North America. We are unaware of any research-generated descriptions of seasonal occurrences of dollar spot epidemics in the U.S.A. A study of the epidemiology of dollar spot is thus warranted given the economic importance of this disease. Furthermore, it is unknown if dollar spot epidemics vary in their incidence and/or severity based on cultivar grown. Thus, the primary objectives of this study were to describe the influence of season on the incidence and severity of dollar spot in six creeping bentgrass cultivars in Maryland. Secondary objectives included determining if there were a growing degree day relationship with the advent of dollar spot symptoms in spring and to associate some environmental factors with the seasonal progress of the disease. It was not an objective of this study, however, to develop a dollar spot prediction model for the entire season.

Materials and Methods

This field study was conducted between 2008 and 2010 at the University of Maryland Paint Branch Turfgrass Research Facility in College Park, MD. Soil was a Keyport silt loam (fine, mixed, semiactive, mesic Aquic Hapludult) with an initial pH of 6.5 and 1.6% organic matter. Six bentgrass cultivars were seeded into separate 3m x 3m plots as described below using 100 kg seed ha^{-1} (2.0 lb seed/1000ft^2). The cultivars were 'Backspin', 'Crenshaw', 'L-93', 'Penncross', 'Providence', and '007'. The cultivars were selected based on National Turfgrass Evaluation Program

(Beltsville, MD) dollar spot tolerance data (Kevin Morris, Director of NTEP, personal communication). Presumptively, 'L-93' and '007' were considered to have good resistance, 'Penncross' and 'Providence' moderate resistance and 'Backspin' and 'Crenshaw' were judged to be highly susceptible. The soil was tilled, raked and plots were seeded on 5 September 2007. After seeding, each plot was raked in two directions and the seedbed was firmed with a hand-pushed roller. 'Stellar' perennial ryegrass (*Lolium perenne* L.) was seeded (250 kg seed ha^{-1}) into 1.5m wide alleys between each plot of creeping bentgrass. A starter fertilizer (18-24-12) was applied at a rate of 50 kg N ha^{-1} (1.0 lb N/1000ft^2) at seeding and the area was kept moist until seedlings emerged on or about 10 September. Seedlings were irrigated as needed to prevent wilt during the autumn. The area was treated with a tank-mix of mefenoxam 2MEC [Syngenta Crop Protection, Greensboro, NC; (R)-2[(2,6-dimethylphenyl) methoxyacetylamino] propionic acid methyl ester (0.77 kg a.i. ha^{-1}, 1.0 fl. oz/1000ft^2)], chlorothalonil 82.5WDG [Syngenta Crop Protection Inc., Greensboro, NC; 2,4,5,6-tetrachloroisophthalonitrile (8.8 kg a.i. ha^{-1}, 2.9 oz/1000ft^2)], and propiconazole 1.3 MEC [Syngenta Crop Protection Inc., Greensboro, NC; 1-[[2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl]methyl]-1,2,4-triazole (0.25 kg a.i. ha^{-1}, 0.5 fl. oz/1000ft^2)] on 13 September 2007 to prevent damping-off (mostly *Pythium* spp. and *Rhizoctonia solani* Kuhn).

Plots were first mowed to a height of 2.5cm (1.0") on 21 September 2007. Beginning on 24 September 2007, mowing height was reduced to 1.9cm (0.75") until the following spring when mowing height was lowered to 1.3cm (0.5"). In all years, plots were mowed three times weekly between 0700 and 0800 hrs during the growing season to a height of 1.3cm and clippings were removed. On 8 May 2008, 10 April 2009 and 1 April 2010, urea (46-0-0) was applied to all plots at a rate of 50 kg N ha^{-1} (1 lb N/1000ft^2). Nitrogen was applied at low rates (i.e., spoon feed program) typically used in the mid-Atlantic region every two weeks between 1 July and 27 August 2008, 25 June and 19 August 2009, and 15 June and 24 August 2010 at a rate of 7.3 kg N ha^{-1} (0.15 lb N/1000ft^2) using urea for a total of 36.5 to 43.8 kg N ha^{-1} $season^{-1}$. On 1 November 2008, 16 November 2009 and 18 November 2010, an additional 50 kg N ha^{-1} (1 lb N/1000ft^2, Lesco Novex 19-2-19 (Lesco Inc. Cleveland, OH), containing methylenediurea and dimethylenetriurea as the primary N-sources) was applied. Total amounts of N applied annually were 136.5 8 kg N ha^{-1} in 2008 and 143.8 kg N ha^{-1} in 2009 and 2010. Water from an overhead irrigation system was applied as needed to prevent drought stress. To ensure that irrigation water did not impact leaf wetness duration data collection, irrigation water was applied during afternoon hours.

In 2008, each plot was bisected; one half received randomly assigned fungicide treatment as described below and the other half was allowed to remain untreated. A fungicide-treated portion of each main plot was maintained in 2008 and 2009, but not in 2010, in the event dollar spot had destroyed non-fungicide-treated areas. Thus, healthy turf would be available if needed in all plots at all times. Plots were closely monitored for dollar spot development and when the fungicide-treated side showed symptoms of *S. homoeocarpa* infection it was sprayed with iprodione 2SC [3-(3,5-dichlorophenyl)-*N*-(1-methylethyl)-2, 4-dioxo-1-

imidazolidinecarboxamide](3.0 kg a.i. ha^{-1}, 4.0 fl. oz/1000ft^2); whereas, the other half remained untreated until data collection ceased.

Due to smooth crabgrass (*Digitaria ischaemum* Schreb. ex Schweigg.) encroachment the postemergence graminicide quinclorac 75DF [3,7-dichloro-8-quinolinecarboxylic acid; BASF Corp. Research Triangle Park, NC; 0.84 kg a.i. ha^{-1} (0.75 lb a.i./A)],was applied 10 July 2008 to control the weed. Pythium blight (*Pythium* spp.) was controlled preventively with mefenoxam 2MEC. Mefenoxam 2MEC was applied on 10 and 28 July 2008 at a rate of 0.77 kg a.i. ha^{-1} (1.0 fl. oz/1000ft^2). Pre-emergent herbicide applications were made in 2009 and 2010 to control smooth crabgrass. On 10 April 2009, dithiopyr 40WP [S,S'-dimethyl 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trofluoromethyl)-3,5-pyridinedicarbothioate (Dow AgroSciences, Indianapolis, IN)] was applied at a rate 0.56 kg a.i. ha^{-1} (0.50 lb a.i./A). On 1 April 2010, bensulide 4LF [S-(O,O-diisopropylphosphorodithioate) ester of N-(2-mercapto)benzenesulfonamide (PBI/Gordon Corporation, Kansas City, MO)] was applied at a rate of 10.6 kg a.i. ha^{-1} (9.5 lb a.i./A). Pythium blight (*Pythium* spp.) was present in adjacent perennial ryegrass on 23 July 2010 and the entire study area was treated with the fungicide propamocarb 6S [propyl *N*-[3-(dimethylamino)propyl]carbamate (Bayer Environmental Science, Research Triangle Park, NC) at a rate of 9.2 kg a.i. ha^{-1} (4.0 fl oz/1000ft^2)] to control the disease. On 7 July 2008, sulfentrazone [N-[2,4-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5oxo-1H-1,2,4-triazol-1-yl]phenyl]methanesulfonamide (FMC Corp. Philadelphia, PA; 0.15 kg a.i. ha^{-1}, 0.125 lb a.i./A)] was applied to control yellow nutsedge (*Cyperus esculentus* L.). Brown patch appeared on 21 July 2008, 12 June

2009, and 8 June 2010 and flutolanil 70WP [*N*-[3-(1-methylethoxy)phenyl]-2-(trifluoromethyl)benzamide (Bayer Environmental Science, Research Triangle Park, NC; 64.0 kg a.i. ha^{-1}, 3.0oz/1000 ft^2)] was applied to control the disease. Flutolanil was chosen since it has no activity on *S. homoeocarpa* (Dernoeden, personal communication).

Dollar spot pressure increased in the study area in late July 2008 and the non-fungicide half of 'Backspin' and 'Crenshaw' plots became severely blighted. Due to high blight levels in 'Backspin' and 'Crenshaw', the entire area of each plot of both cultivars was treated with iprodione 2SC (3.0 kg a.i./ha, 4.0 fl. oz/1000ft^2) on 29 July and 15 September to assist in turf recovery prior to winter. Data collection ceased on Backspin and Crenshaw until May 2009. There was a late autumn dollar spot epidemic beginning on 8 November 2008. To stop the epidemic and ensure a dense and healthy turf for use in 2009, the entire study area was treated with a tank-mix of chlorothalonil 82.5WDG (2,4,5,6-tetrachloroisophthalonitrile; 10.1 kg a.i. ha^{-1}, 3.2 oz/1000ft^2), propiconazole 1.3 MEC (0.5 kg a.i. ha^{-1}, 1.0 oz/1000ft^2), and boscalid 70WG [3-pyridinecarboxamide, 2-chloro-*N*-(4′-chloro(1,1′-biphenyl)-2-yl); BASF Corp. Research Triangle Park, NC; 0.43 kg a.i. ha^{-1}, 0.14 oz/1000ft^2)] on 14 November 2008. A tank-mix of iprodione 2SC (2.8 kg a.i. ha^{-1}, 4.0 fl. oz/1000ft^2), boscalid 70WG (0.43 kg a.i. ha^{-1}, 0.14 oz/1000ft^2), and myclobutanil 20EW [2-*p*-chlorophenyl-2-(1H-1,2,4-triazol-1-ylmethyl)hexanenitrile (Dow AgroSciences, Indianapolis, IN 1.5 kg a.i. ha^{-1}, 0.5 oz/1000ft^2)], however, had to be applied to the area on 1 December 2008 to stop the continuing late autumn epidemic. The fungicide application made on 1 December 2008 was the last dollar spot-targeted fungicide application made to the entire study area for the duration of the study.

In 2009, iprodione 2SC (3.0 kg a.i. ha^{-1}, 4.0 fl oz/1000ft^2) was applied perpendicular to one-half of the plots used in 2008, thus creating a quadrant (1.5 by 1.5 m) that received fungicide routinely in 2008 and one quadrant (1.5 by 1.5 m) that was not treated with fungicide during the summer of 2008. These perpendicular fungicide treatments (i.e., the half plot kept disease-free) were applied as dollar spot appeared as follows: Backspin and Crenshaw on 18 May; Penncross on 15 June; and L-93, 007, and Providence on 24 June. It was our intent in 2009 to collect data from both the fungicide-treated quadrant used in 2008 as well as a non-fungicide-treated quadrant in each plot of all six cultivars. However, due to a burgeoning data set, only data from the non-fungicide-treated quadrant (1.5m x 1.5m) were analyzed in 2009. In 2010, no fungicides were applied and the non-fungicide treated quadrant used in 2009 was used again to collect dollar spot data since turf had fully recovered without having to be treated with a fungicide at the end of the 2009 study season.

Dollar spot developed naturally and uniformly across the study area in all years. Dollar spot was evaluated 2 to 3 times wk^{-1} by counting the number of *S. homoeocarpa* infection centers (IC) in each non-fungicide-treated sub-plot. When disease unexpectedly appeared in November 2008, dollar spot was estimated visually using a 0 to 100% linear scale where 0 = no blighting and 100% = entire plot area blighted, rather than by counting IC's. Infection centers, however, were counted during 2009 and 2010 autumn epidemics.

Leaf wetness duration (LWD) was monitored daily between 5 June and 15 October 2008; 7 May and 9 December 2009; and 1May and 1 December 2010 using a CR-10 datalogger (Campbell Scientific, Logan, UT). The CR-10 was encased in a weatherproof aluminum box and was powered by a 12-V rechargeable lead battery connected to a solar panel. Leaf wetness duration was estimated using three electrical impedance sensors (Model 237, Campbell Scientific, Logan, UT) placed randomly on three different plots about 3 m (10 ft) apart. Leaf wetness duration data were downloaded using a laptop computer every week. Some LWD data could not be retrieved due to malfunction of the equipment in late summer 2008 and on approximately 15 dates during 2008 and 2009. Precipitation, air temperature and relative humidity data were obtained from a USDA weather station in the Beltsville Agricultural Research Center South Farm (BARC), which was located approximately 0.6 km from the study site.

Average daily and night air temperature, daily and night relative humidity, precipitation, and LWD were the primary environmental parameters monitored. Air temperatures and relative humidity were calculated using data obtained from the previously described BARC site. Relative humidity and air temperatures were measured every ten seconds and automatically averaged every 15 minutes at the BARC South Farm. Average daily temperature and average daily relative humidity were calculated by averaging the 15 minute data over a 24-hr period. Average night temperatures and average night relative humidity were calculated using data averaged every 15 minutes between 1800 and 0559 hr the following morning. An environmental variable called "optimum daily conditions" also was created by calculating the number of hours per 24hr day in which air temperature was between 18 and 25°C and relative humidity was greater than 85%. "Optimum night (1800 to 0559 hrs) conditions" were calculated similarly using a temperature range of 20 to 25°C and ≥ 85% RH.

Growing degree day (GDD) models measure accumulated heat and have been used to predict the emergence of some turfgrass weeds and diseases as reviewed by Fidanza et al., (1996); Kaminski et al., (2007); and Brosnan et al. (2010). Growing degree-days were assessed in this study to determine if a relationship existed between accumulation of heat and the first appearance of dollar spot symptoms (Ritchie and Nesmith, 1991). The base temperature (*Tb*) was chosen based on studies indicating that 15 to 16°C was the minimum temperature needed for dollar spot symptoms to appear in creeping bentgrass (Endo, 1963; Hall, 1984; Walsh, 2000). Base temperatures of 10 and 12°C also were also assessed. The biofix date was determined empirically by computing GDD using a Tb of 15°C beginning 1 April versus 1 May 2008, 2009 and 2010. The GDD data best fit was found using the April 1 biofix date. The mean daily temperatures data were obtained from BARC and represented averages of data collected every 10 seconds and averaged over 24 hrs. Using mean daily air temperatures (*Ta*), accumulation of degree-days began on 1 April and were calculated using the following equation:

$$GDD = \sum_{i=1}^{n} (Ta_i - Tb)$$

where Ta_i is the mean daily air temperature on day *i*; *Tb* is the base temperature of 15°C, and *n* is the number of days elapsed since 1 April. Any negative daily values were not used in the computation.

Days on which foliar mycelium was observed in the canopy in 2009 and 2010 was assessed. The amount of foliar mycelium was visually evaluated using a 1 to 5 scale where 1 = trace amounts of foliar mycelium; 3.0 = moderate amounts of foliar mycelium; and 5.0 = copious amounts of mycelium. The presence or absence of foliar mycelium generally was not assessed on Sunday's and on a few other dates.

Plots were 3m x 3m (10ft x10ft) and were arranged in a randomized complete block with four replications. Data were collected in non-fungicide-treated sub-plots (1.5 by 15 m) and were converted to the number of infection centers m^{-2}. Area under the disease progress curve (AUDPC) data were calculated using the trapezoidal method (Campbell and Madden, 1990), and all data were checked for violations of the assumptions of the analysis of variance (ANOVA) using the SAS Plot procedure (SAS version 9.2, SAS Institute, Cary, NC). Plots of the residuals of the AUDPC values did not show abnormalities and data were not transformed. All data were subjected to ANOVA using PROC Mixed (SAS, Cary, NC). Significantly different means were separated using Fisher's least significant difference test at $P < 0.05$.

Results

The "steps" in each summer epidemic and year are shown for all cultivars (Figures 4, 5, and 6). In all other figures, which contain environmental variables, IC data were averaged for Crenshaw and Backspin (i.e., HS cultivars) and among Penncross, Providence, L-93, and 007 (i.e., MS cultivars). Averaging data for HS and MS cultivars was used to simplify figures since there were few AUDPC differences among Penncross, Providence, L-93 and 007 and because Crenshaw and Backspin were clearly more susceptible to dollar spot than the aforementioned cultivars.

Precipitation and Average Daily Air Temperature

Prior to the appearance of *S. homoeocarpa* IC's in early to mid-May in each year, there were several rain events (Appendix I, Figures 1, 2, and 3). Rainfall was frequent and uniformly dispersed in 2008 (40 rain events > 1 mm from 15 May to 15 October 2008; total = 292 mm) and 2009 (50 rain events > 1mm from 1 May to 20 October 2009; total = 523mm). In 2010, June was relatively dry (7 rain events >1mm; total = 44 mm; most on 28 June = 16mm), but from 10 July to 22 October there were 29 rain events >1mm (total = 462 mm). Early May and after mid-to late September, average daily temperature ranged between 12 and 24°C in 2008 and 2009 (Appendix I, Figures 4 and 5). In 2010, during the same period, average daily air temperatures ranged from 10 to 22°C. Except in early May and after late September, average daily temperatures ranged between 15 and 25°C in 2008 and 2009. In 2010, average daily air temperatures generally ranged from 18 to 29°C.

To compare the accuracy of the Hall (1984) model, which is based on precipitation and daily air temperature, steps in Penncross epidemics were evaluated. 'Crenshaw' and 'Backspin' steps were not compared to the Hall (1984) model since only data from one epidemic in each year were available. There were very few, and mostly small, timing differences in steps among the MS cultivars. 'Penncross' was chosen to closely examine steps since it is among the most commonly grown and studied bentgrass cultivars. Using Hall's (1984) model, criteria for a step in a dollar spot epidemic were met a total of 11 times in 2008, but only 6 predicted steps corresponded to actual steps in the two summer epidemics. In 2009, Hall's (1984) model predicted 14 steps, but only 8 steps were observed in both epidemics. Criteria for Hall's (1984) model were met 9 times in 2010, but 14 steps were observed during the summer epidemics. Hall's (1984) model overestimated the number of steps in 2008 (n=5) and 2009 (n=6). In 2010, the model underestimated the number of steps (n= 6). Furthermore, the Hall (1984) model predicted disease three times in 2008; one time in 2009; and two times in 2010 in the first and second epidemics when the numbers of IC's were declining.

Leaf Wetness Duration (LWD)

Leaf wetness duration was measured in all three years. On days that it rained, LWD usually measured greater than 12 hours. In 2008, there was a malfunction in the equipment and LWD data only were obtained between 10 June and 17 July, which covered most of the first epidemic period (Appendix I, Figure 7). During the first 2008 epidemic, LWD generally exceeded 10 hrs on most dates. In May 2009, when dollar spot levels were building in Crenshaw and Backspin, LWD's typically were > 12hrs (Appendix I, Figure 8). When the disease was intensifying during the first epidemic in the MS cultivars, LWD generally ranged from 8 to 12 hrs. During the second 2009 epidemic, LWD were mostly in the range of 8 to 14 hrs. In 2010, LWD typically ranged 8 to 12 hrs for both epidemics (Appendix I, Figure 9). Leaf wetness durations often were > 10 hrs each day all summer in each year, regardless of whether dollar spot was on the increase or decrease. Even during periods of very long LWD (i.e. > 12hrs), dollar spot severity declined following peaks between the first and second epidemics in 2008 and 2009.

Foliar Mycelium

Foliar mycelium levels on mornings when evident were assessed in 2009 and 2010. Mornings when foliar mycelium was observed are marked by a number ranging from 1 (sparse) to 5 (copious) on precipitation (Appendix I. Figures 2 and 3) and LWD (Appendix I. Figures 8 and 9) figures.

In 2009, foliar mycelium was observed on 21 rating dates between 18 June and 17 August. Foliar mycelium generally appeared 2 to 3 days following a rain event in 2008, but on 16 July trace amounts of mycelium appeared, despite a lack of rain for more than two weeks (Appendix I. Figure 2). The amount of precipitation did not appear to influence the amount of foliar mycelium observed. Similarly, there was a wide range in LWD hrs in which foliar mycelium was observed in 2009. On most dates, foliar mycelium appeared when there were > 9 hrs of LWD (Appendix I. Figure 8). However, there were four dates (26 June, 7 and 29 July, and 9 August) when LWD ranged from 1 to 6 hrs. Heavy mycelium (i.e., rating of 4) was observed on 7 July, despite only about 1 hr of LWD and no rain during the week. The number of IC's generally increased following the appearance of foliar mycelium during the first epidemic. However, between 8 and 17 August, foliar mycelium was detected on seven rating dates, but IC counts were declining. This period corresponded with the end of the first epidemic.

In 2010, foliar mycelium was detected on only nine dates between 4 May and 7 August (Appendix I. Figure 3). On most dates, foliar mycelium appeared one to three days after rain. As observed in 2009, there did not appear to be a relationship between the amount of rain and observed foliar mycelium levels. On all dates in 2010, the presence of foliar mycelium was associated with > 9 hrs of LWD and increases in IC's (Appendix I. Figure 9).

Growing Degree Days (GDD)

The growing degree day (GDD) model developed used a base temperature of 15°C and a biofix date of 1 April. For the HS cultivars, dollar spot symptoms appeared after 59, 62 and 70 GDD in 2008, 2009 and 2010, respectively (Figure 1). For the MS cultivars, dollar spot appeared after 112, 114 and 105 GDD in each of the three respective years. There were 4 to 6 rain events in the 7 day period prior to the onset of dollar spot in HS cultivars in 2008 and 2009, but only 2 rain events in a similar period prior to onset of disease in 2010 (Appendix I. Figures 1, 2, and 3).

The GDD also were calculated using a base temperature of 10 and 12°C and a biofix date of 1 April. At 10°C, dollar spot appeared between a range of 171 to 227 and 269 and 344 GDD for the HS and MS cultivars, respectively (Figure 2). At 12°C, dollar spot appeared between a range of 113 to 150 and 189 to 234 GDD for the HS and MS cultivars, respectively (Figure 3). Hence, the best fit was 15°C and a biofix date of 1 April.

Summer Epidemics 2008

Low levels of dollar spot already were present in plots of the HS cultivars when disease monitoring began on 23 May. It was estimated that the initial IC's probably appeared on or about 20 May 2008. In HS cultivars, dollar spot severity appeared to lag (i.e., the number of IC's remained static) for a few days, but then became very severe from late May onwards and peaked about 9 July 2008 (Figure 4). Dollar spot slowly developed in MS cultivars in early June and the first epidemic also peaked on 9 July 2008 for these cultivars. Thereafter, dollar spot declined and data collection ceased in HS cultivars on 1 August due to severe damage. Plots of HS cultivars were treated with a fungicide to stop the disease and promote recovery; HS cultivars were not evaluated again in 2008. Similarly, in MS cultivars, dollar spot activity ceased about the same time as observed in HS cultivars and turf began to recover. Thus, ended the first summer epidemic in 2008. Steps in the first epidemic had been nearly identical among all cultivars. The AUDPC data collected during the first epidemic period (i.e., 23 May to 1 August) showed that there were no significant dollar spot differences between HS and among MS cultivars (Table 1). Dollar spot, however, was significantly greater in HS versus MS cultivars.

Complete recovery from dollar spot damage in MS cultivars did not occur prior to the advent of the second epidemic beginning on or about 4 August 2008. Again there were no AUDPC differences among MS cultivars and the steps were nearly identical (Table 1, Figure 4). Dollar spot injury peaked between 8 and 12 September among all MS cultivars and thereafter turf began to recover. The steps in the second epidemic among the MS cultivars were similar if not identical. The second epidemic had been more severe than the first among MS cultivars.

Summer Epidemics 2009

The spring of 2009 was warmer than 2008 and dollar spot began earlier than in the previous year. Dollar spot again appeared earlier in the HS cultivars. Also, as was observed in 2008, there was a lag phase followed by a rapid increase in disease in the HS cultivars. Since the HS cultivars were damaged severely, and much more rapidly than observed in 2008, these plots again were treated with a fungicide on 29 July to stop the epidemic. Since the first epidemic peaked much earlier in HS cultivars, AUDPC values were calculated for the first epidemic rating period (i.e., 10 May to 29 June) prior to applying fungicide to the HS cultivars. The AUDPC's for the early rating period showed that Crenshaw had been more severely injured than Backspin, but there were no differences among MS cultivars (Table 2).

The first epidemic in MS cultivars occurred between 10 May and 24 August 2009. The AUDPC values showed that Penncross had sustained more injury than L-93 and 007, and that Providence was injured more than 007. There were no IC differences between L-93 and 007 or between L-93 and Providence (Table 2). Steps in the first epidemic again were nearly identical among MS cultivars. Unlike 2008, there was no clear single peak in the first epidemic among MS cultivars. There were three large steps on or about 26 June, 20 July and 3 August 2009. Thereafter, dollar spot subsided and all cultivars began to recover as noted by decreasing numbers of IC's between 9 and 25 August. The recovery period was short and another large increase in dollar spot began on or about 27 August, which marked the beginning of the second epidemic.

The second 2009 epidemic (i.e., 27 August to 20 October 2009) again was more severe than the first epidemic among MS cultivars (Table 2). More dollar spot developed in Penncross and Providence versus 007, but there were no IC differences among L-93 and the other three MS cultivars. The steps in the second epidemic were the same among MS cultivars and dollar spot peaked on or about 29 September 2009.

Summer Epidemics 2010

Spring 2010 was the warmest of the three years and perhaps one of the warmest in a century. As a result, dollar spot appeared about 16 and 6 days earlier in HS cultivars than was observed in 2008 or 2009, respectively. The first epidemic progressed from 4 May to 2 July in the HS cultivars. As observed in 2009, dollar spot was more severe in Crenshaw than Backspin (Table 3). There was a slightly longer and more gradual increase in dollar spot (i.e., 8 to 25 May) in HS cultivars in 2010, compared to the previous two years (i.e., about 6 to 11 days). Dollar spot peaked in the HS cultivars on or about 2 July and the number of IC's dropped rapidly as dollar spot declined and the HS cultivar began to recover. The HS cultivars, however, had been severely pitted by *S. homoeocarpa* and were not evaluated for the remainder of the study.

The first and second epidemics could not be clearly delineated among MS cultivars in 2010. However, there was a large drop in IC counts on 6 July, which indicated dollar spot had subsided as seen in HS cultivars. Data collected during the first 2010 epidemic indicated that there were no AUDPC differences observed among

MS cultivars and the steps again were similar among all six cultivars. The recovery period between epidemics in 2010 was more short-lived than in the previous two years and it was estimated that the second epidemic had begun on or about 9 July in the MS cultivars. Unlike 2008 or 2009, there was no clear single peak in the second epidemic. During the second 2010 epidemic, there were two larger peaks on or about 27 July and between 18 and 25 August. Infection center counts declined in all cultivars except 007 after 25 August. There was another peak in 007 plots on or around 16 September. The steps in the second epidemic again were similar among the MS cultivars. The AUDPC data showed that 007 had been more severely damaged than Penncross, but no differences were found among the other cultivars (Table 3). As was observed in 2008 and 2009, the second had been the more severe of the two epidemics. Dollar spot severity in 2010, however, was less than in previous years, although AUDPC values were similar to 2008 and 2009. This was because the second 2010 epidemic encompassed 102 days in 2010, but only 72 and 54 days in 2008 and 2009, respectively. As discussed below, the lower level of dollar spot in 2010 versus the other two years was attributed to high average night temperatures.

Average Night Temperatures (ANT)

Dollar spot appeared with the advent of ANT > 12°C in HS cultivars in mid-May 2008 (Figure 7). When IC counts were static during the May lag phase in HS cultivars, ANT ranged 9 to 24°C. However, once ANT increased consistently from 12 to 15°C the disease began to increase rapidly. Dollar spot appeared in MS cultivars when ANT was continuously above 14°C. When dollar spot was peaking between 20

June and 9 July, ANT ranged from 16 to 24°C. When dollar spot subsided between 11 July and 1 August, ANT ranged 18 to 25°C, and when the disease was peaking in the second epidemic ANT range was 15 to 28°C (mostly 16 to 24 °C). Dollar spot IC counts dropped rapidly between 12 and 23 September, at which time ANT ranged 11 to 27°C. The ANT fell below 12°C on most dates after 3 October and at this time IC counts were low and turf had nearly recovered. Hence, between peaks in the first and second epidemic, when IC's were declining, the ANT was conducive to promote active dollar spot. When dollar spot first appeared in May and then declined in late September 2008 following the second epidemic, ANT were ≤ 12°C on 12 of the final 25 rating dates, which appeared to play a role in limiting disease activity.

Dollar spot appeared first in HS cultivars in early May 2009 when night temperatures were above 12°C (Figure 8). During the lag phase in the first epidemic of HS cultivars in 2009, ANT generally was below 12°C, which was similar to what was observed in 2008. In MS cultivars, dollar spot remained in a lag phase for a long period from 22 May to 15 June, when ANT ranged 14 to 22°C. Dollar spot increased in intensity throughout the first epidemic and ANT generally ranged from 18 to 25°C at that time. When IC counts declined following the first epidemic, ANT fell to as low as 13°C on 2 September. The decline in IC count following the first epidemic in MS cultivars was short lived in 2009 and the second epidemic began to increase in intensity as ANT climbed to a range of 15 to 23°C. Dollar spot ceased to be active and IC counts declined rapidly as ANT fell below 12°C on 15 out of 19 of the final rating dates after 1 October. Hence, at the beginning and end of both epidemics in 2008 and 2009, the ANT was usually below 12°C. However, dollar spot was both active and inactive at selected times throughout summer when ANT ranged mostly from 16 to 25°C.

April and May 2010 were unusually warm and dollar spot appeared earlier than it had in 2008 or 2009. The HS cultivars exhibited a more gradual increase in 2010. This was attributed to ANT being above 12°C on most nights in May, except on May 9 and 10 (6°C), and ranged from 12 to 20°C (Figure 9). The MS cultivars, however, exhibited a relatively long lag phase throughout May. The number of IC increased in MS cultivars as ANT rose consistently above 15°C between 17 June and 28 July. In HS cultivars, dollar spot was most severe when ANT ranged from 20 to 25°C. Data could not be collected after 30 July in HS cultivars due to severe damage. There was a drop in the number of IC's on 26 June, 6 July and 15 July in MS cultivars, corresponding to dates when ANT was > 25°C. In MS cultivars, dollar spot peaked in the first epidemic around 2 July, but IC counts dropped as ANT increased to > 25°C shortly thereafter. Dollar spot pressure generally was low throughout the first epidemic when ANT often was ≥ 25°C. Thereafter, in MS cultivars, there were increases in IC's when ANT dropped below 25°C and decreases in IC's when ANT exceeded 25°C. There were 23 nights between 20 June and 22 August in which ANT reached or exceeded 25°C. Thereafter, ANT fluctuated from 11 to 27°C (mostly 13 to 23°C) between 27 August and 27 September and IC counts were relatively low (15 to 25 m^{-2}). Infection center counts decreased rapidly after 28 September, when ANT consistently fell below 12°C.

Average night temperature data collected over the three year period indicated that dollar spot symptom expression was limited or inactive when ANT was below

12°C or above 25°C. Dollar spot was most severe in all three years when ANT ranged from about 16 to 24°C; however, when dollar spot activity was limited or inactive during the period between the first and second epidemic in 2008 and 2009, similar ANT's were recorded. Thus, despite good soil moisture from irrigation or rain and suitable ANT's, dollar spot could be both severe and inactive during and between summer epidemics.

Average Daily Percent Relative Humidity (ADRH)

Average nighttime relative humidity (1800 to 0559) was invariably above 85% most summer nights in all three years (Appendix I, Figures 13, 14 and 15). Hence, average daily percent RH (ADRH) was examined more closely by plotting these data against IC's in the summer epidemics as was done for ANT.

In 2008, ADRH frequently fluctuated above and below 85% from mid-May to mid-October (Figure 10). During mid-May when dollar spot was in the lag phase for HS cultivars, ADRH generally was below 85% (Figure 10). Steps marking an increase in dollar spot after a decline usually were preceded by two or more days when ADRH exceeded 85%. Most notably, during the period when IC counts were decreasing following the first and second epidemics in 2008, the ADRH often was below 85%. When dollar spot was increasing and then peaking during the second epidemic, ADRH generally was at or above 85% between 27 August and 12 September. Thereafter, IC counts declined when there were five dates (between 15 and 23 September) when ADRH was at or below 85%. Average percent daily RH increased above 85% on most dates between 20 September and 1 October and on 8

October a small increase in IC's was observed. By this time, ANT < 12°C became a factor limiting dollar spot development.

During the lag phase from 10 May to 8 June, 2009 in HS cultivars, ADRH often was below 85% (Figure 11). Increases in ADRH > 85% for two or more days usually was associated with an increase in IC's; similarly two to three days when ADRH fell below 85% usually was followed by a decrease in IC's. A decrease in IC's followed the second epidemic peak, during which time ADRH fell below 85% on 6 out of 11 days between 29 September and 4 October. However, there were many days between the end of the first epidemic (7 August) and the beginning of the second (27 August) when ADRH exceeded 85% and IC counts decreased or increased only in small numbers.

Dollar spot became apparent in early May 2010. During the period from 4 May to 10 June, when there was a longer and more gradual lag phase in HS cultivars, ADRH fluctuated above and below 85% (Figure 12). Average daily RH frequently was above 85% between 25 May and 16 June, when the first of three peaks in IC counts were observed in HS cultivars. In both HS and MS cultivars, increases in IC's were preceded by two or more days when ADRH was above 85%. Conversely, as was observed in previous years, a drop in ADRH below 85% for two or more days was followed by a decrease in IC's. This trend continued until late September when there were numerous days when ADRH was greater than 85%, but IC's were decreasing, which likely was due to ANT falling below 12°C.

Optimum Daily Conditions

As previously noted, average daily air temperatures ranged mostly 15 to 25°C when dollar spot was active and severe in 2008 and 2009 (Appendix I. Figures 4 and 5). In 2010, average daily temperatures were higher than in 2008 or 2009 and ranged from 18 to 29°C (Appendix I. Figure 6). Dollar spot generally increased when two or more days of ADRH were above 85% (Figures 10, 11 and 12). Hence, there may be a relationship between the number of hours when RH is above 85% and when temperatures are conducive to dollar spot. Thus, an "optimum conditions" criterion was developed to determine if there were a relationship between temperature and RH. Optimum daily conditions (ODC) were defined by the number of hours per 24-hour day when temperatures were between 18 and 25°C and ADRH > 85%.

Increasing ODC hrs per day in 2008 appeared to follow an increase in IC counts in both epidemics (Figure 13). The ODC often exceeded 10 hrs per day, when IC counts were dropping in MS cultivars following the first epidemic. Conversely, there was an increase in IC's marking the beginning of the second epidemic, but ODC's generally were less than 5 hrs between 4 and 22 August. Following the peak in the second epidemic between 13 and 23 September 2008, ODC generally were less than 5 hrs per day. Following five days of ODC's ranging from 4 to 24 hrs there was a small increase in IC's on 8 October. Thereafter, IC counts again declined when there were ≤5 hrs ODC.

In 2009, increases in IC's usually were associated with ODC's ranging from 5 to 15 hrs in MS and HS cultivars during the first epidemic (Figure 14). Declines in steps during this period were associated with two or more days when ODC were < 2 hrs. From 7 to 18 August, the IC number became static in MS cultivars and ODC was < 5 hrs during this period. Despite large fluctuations of ODC between < 1hr and 24 hrs (mostly 5 to 12 hrs), the number of IC's peaked on 12 September. After 12 September, IC counts declined and ODC generally were < 3hrs. The number of IC's increased slightly on 8 October following a period of 9 to 24 hrs ODC from 26 to 30 September (except 29 September). Thereafter, turf showed rapid recovery and ODC typically was ≤5hrs.

In 2010, ODC ranged from 9 to 24hrs when dollar spot IC's were increasing in late May (Figure 15). When dollar spot peaked in HS cultivars, ODC were mostly 6 to 10 hrs. In MS cultivars, IC counts decreased on 5 July, which was preceded by four days of < 2 hrs ODC. Thereafter, dollar spot increased in MS cultivars from 8 July to 25 August and during this period ODC ranged from 5 to 24 hrs (mostly 7 to 13 hrs ODC). Data from all three years indicated that dollar spot was promoted by as little as 5 hrs ODC. However, there were dates when ODC > 8 hrs (range 8 to 24 hrs ODC) were associated with a decline in IC counts between summer epidemics in 2008 and 2009.

Optimum Night Conditions (ONC)

As noted previously, ANT below 12°C and above 25°C limited dollar spot activity (Figures 7, 8 and 9). Average night RH generally was > 85% during the periods of the first two epidemics in all years (Appendix I. Figures 13, 14 and 15). Optimum night conditions were defined as the number of hours of night (1800 to 0559 hrs) temperatures between 20 and 25°C and relative humidity > 85%.

In 2008, three or more nights of 8 to 10 hrs of ONC generally were associated with an increase in IC's during both the first and second epidemics (Appendix I. Figure 16). Between 15 and 25 June there were only 0 to 6 hrs of ONC, which preceded a decline in IC number on 27 June. During the period between 7 and 17 August, IC number was static and ONC were 0 to 3 hrs. On 18 August 2008 the ONC increased to 6 hrs preceding an increase in IC number on 21 August. After the peak of the second epidemic in MS cultivars and concomitant reduction in IC's and turf recovery on or about 12 September, ONC generally (except 13 September when ONC=10 hrs and 27 September when ONC =12 hrs) ranged from 0 to 6 hrs. Thus, 2008 data generally indicated that > 6 to 8 hrs of ONC promoted dollar spot, while < 6hrs ONC limited dollar spot.

During the lag phase in 2009 and the first step in HS cultivars (i.e., 10 May to 8 June), ONC generally were less than 4hrs (Appendix I. Figure 17). As dollar spot increased in HS cultivars, there were some dates when ONC were below 2 hrs and some dates when ONC were above 8 hrs. In MS cultivars, dollar spot began to intensify when ONC were 7 to 9 hrs on 19, 20 and 21 June. The number of IC's, however, continued to increase when ONC usually (except 26 June when ONC = 9 hrs) was less than 4 hrs from 22 June to 10 July. There were reductions in IC's when ONC fell to 3 hrs or less from 12 to 15 July and 1 hr or less from 30 August to 5 September. However, as the second epidemic was peaking there were only two dates when ONC exceeded 8hrs; whereas, ONC generally were less than 2 hrs from 16 to 29 September (9 to 10 hrs on 23 and 24 September). Three or more dates with > 6hrs ONC were not consistently observed when dollar spot was increasing in HS cultivars in the first epidemic or in MS cultivars in the second epidemic. Furthermore, during the second epidemic in the MS cultivars, there were > 8hrs ONC on many dates, regardless of IC's being on the increase or decrease. Hence, ONC did not effectively account for the increases in the observed number of IC's in 2009. There were several dates, however, when declines in IC numbers were associated with ONC < 4hrs for three or more days in September

In 2010, ONC were less than 4 hrs during the lag phase (4 to 24 May) in HS cultivars (Appendix I. Figure 18). After 24 May, ONC increased to 6 hrs or more from 1 to 5 June, but then fluctuated to as little as 0 hrs to > 10 hrs ONC between 6 June and 27 July as the number of IC's was increasing in both HS and MS cultivars. A notable reduction in IC's was observed on 6 July in both HS and MS cultivars, which was preceded by five nights (i.e., 30 June to 4 July) in which ONC were < 1 hr. Declining numbers of IC's in MS cultivars occurred after 23 August and until data collection ceased on 22 October. Most dates during this period had < 2hrs of ONC. Therefore, ONC did not adequately describe the observed increases and decreases in dollar spot in 2009 and 2010.

Autumn Epidemics

In each year dollar spot reappeared a third time after late October. Data are presented for the MS cultivars only and disease is plotted against ANT. The 14 November 2008 appearance of dollar spot was unexpected and plots were evaluated by estimating the percent of plot area blighted; whereas, IC counts were obtained in 2009 and 2010. Plots were rated only two (2009 and 2010) or three (2008) times in each autumn epidemic since the study area was no longer being monitored daily due to the advent of cold weather.

Dollar spot was observed on 8 November 2008, but plots inadvertently were not rated for disease until 14 November. Highest blight ratings were obtained on 14 November in Penncross, L-93 and Providence, but dollar spot continued to increase in 007 plots until 1 December, despite low ANT (mostly -5 to 8°C) (Figure 16). The increase in dollar spot severity in 007 was surprising since the entire study area was treated with fungicides following rating on 14 November. Since dollar spot was active in 007, the site again was treated with fungicides on 1 December. The appearance of dollar spot on or about 8 November, however, was preceded by three nights (i.e., 5 to 7 November) when ANT was between 13 and 17°C; ANT reached 14 C again on November 15. Thereafter, ANT ranged mostly from -5 to 7°C, but increased to 12 and 13°C on 11 and 16 December, respectively. The AUDPC values show that 007 had been more severely blighted than the other three cultivars (Table 1).

In 2009, dollar spot was first noted in the study area on 5 December (Figure 17). The number of IC slightly increased until 18 December, when data collection ceased. The ANT ranged from -5 to 8°C between 5 and 18 December, which should not have been conducive to dollar spot. However, ANT of 12°C was observed on 3 December. According to AUDPC values, there were no dollar spot severity differences among the cultivars (Table 2).

In 2010, foliar mycelium and new IC's were observed in the study area on 29 October (Figure 18). The number of IC's increased only slightly between 29 October and 9 November. Between 24 and 29 October, ANT ranged from 10 to 22°C and on most nights ANT exceeded 12°C. Despite ANT falling consistently below 9°C after 29 October, a slight increase in the number of IC's was observed on 9 November, at which time data collection ceased. There were no AUDPC differences among the cultivars (Table 3).

Discussion

Dollar spot epidemics were assessed in six creeping bentgrass cultivars maintained as a golf course fairway in 2008, 2009 and 2010. Crenshaw and Backspin were most severely injured and are referred to as highly susceptible (HS) cultivars. Penncross, Providence, L-93 and 007 generally exhibited similar levels of dollar spot injury and are referred to as moderately susceptible (MS) cultivars. In all three study years, there were two summer to early autumn epidemics and a third autumn epidemic. The second epidemic was longest and most severe and the third epidemic was least severe and of shortest duration.

Monteith and Dahl observed that dollar spot could occur from late spring to early autumn. Smith et al (1989) stated that there were two dollar spot epidemics in turfgrasses that develop between May and October in the northern U.S., but Hall (1984) and Walsh (2000) report that only one epidemic occurs in Ontario, Canada. The nature of dollar spot epidemics has not been determined in other regions of North America or elsewhere. This is the first study to quantify three epidemics in a single year. A step in a dollar spot epidemic was defined as a point where a decline in epidemic rate is followed by an increase in rate (Hall, 1984). Other than differences in resistance, it was previously unknown if bentgrass cultivars would behave differently during a dollar spot epidemic. That is, it was unknown if different turfgrass cultivars exhibit different steps or different peaks and valleys in an epidemic.

Data collected in all years revealed that the steps in all epidemics were similar, if not identical, for all cultivars evaluated, regardless of being HS or MS. Crenshaw was more severely blighted than Backspin in two (2009 and 2010) of the three years as measured by AUDPC. Among MS cultivars, there were no consistent differences in susceptibility. Penncross was more severely damaged than 007 in the first and second epidemics in 2009; whereas, 007 was more severely damaged than Penncross in the second epidemic in 2010. Dollar spot developed in May of each year. The disease appeared up to two weeks earlier and increased in severity more rapidly in HS compared to MS cultivars. It is likely that MS cultivars recognized presence of the pathogen and were able to trigger defense mechanisms more rapidly than HS cultivars. Peaks in disease damage, however, occurred at a similar time among all cultivars in the first epidemic.

Crenshaw and Backspin were so severely damaged following the first epidemic they could not be evaluated for dollar spot until the following May. Conversely, MS cultivars showed greater resiliency and usually had mostly, if not fully, recovered before the third autumn epidemic. Fungicide use was required to promote recovery of HS cultivars following the first epidemic, however, all cultivars were treated with fungicides in November 2008 following the unexpected development of dollar spot in the first observed autumn epidemic. The cultivar 007 became "puffy" each year and was at times more severely damaged by scalping than by dollar spot. Puffy is a condition where thatch swells in response to moisture and high relatively humidity in summer causing a mower to sink into the turf surface and thus remove excess foliage. The ability of all cultivars to recover provides evidence that the pathogen does not extensively invade stems, but otherwise severely blights foliage and tillers. Plants were able to recover from axillary buds on stem bases. It was previously shown that *S. homoeocarpa* does not infect roots, but root injury occurred in some cases, which was attributed to an unknown mycotoxin(s) produced by the pathogen (Endo, 1963; Malca and Endo, 1965).

Walsh (2000) estimated that dollar spot would appear after 1 May in Ontario following 9 to 10 days when average air temperatures were greater than or equal to 16°C. This estimate was consistent with previous beliefs that dollar spot development begins at 15°C (Endo, 1963; Hall 1984). Growing degree days were accurate in predicting the onset of the first epidemic beginning in May of each year. The T_{base} of 15°C was used based on the aforementioned research (Endo, 1963; Hall, 1984; Walsh, 2000). The biofix date was determined empirically. Dollar spot appeared earlier in HS (60 to 70 GDD) than MS (105 to 114 GDD) cultivars. We are aware of only one other study involving the use of GDD in describing the development of a turf pathogen and disease. Kaminski and Dernoeden (2006) used GDD in their study of dead spot (*Ophiosphaerella agrostis* Dernoeden, Camara, O'Neil, van Berkum, et Palm) in creeping bentgrass. The GDD were used to describe the period in which pseudothecia production and patch diameter began to increase. They cautioned that GDD determined in Maryland may not apply to other geographic locations and thus needed to be corroborated in other regions.

Hall's (1984) developed a dollar spot prediction model based on "wet days" and average air temperature. This model states that a step in an epidemic will occur after two consecutive wet days when average air temperatures are ≥22ºC or after three consecutive wet days when average air temperatures are ≥15ºC. In the current study, there were at least two rain events in the seven day period in all three years prior to dollar spot symptom expression in May. Rainfall in all years, except June 2010, was frequent and uniformly dispersed. Comparing criteria of the Hall (1984) model with steps in the epidemics in Penncross, it was determined that the model had a 60% accuracy. Burpee and Goulty (1986) found the Hall (1984) model to be ineffective in programming fungicide applications since it overestimated the number of infection periods. In the current study, the Hall model underestimated five to six steps in 2008 and 2009, and overestimated six steps in 2010. One to three times in all study years, the model predicted an increase in dollar spot when IC's were declining. These findings generally corroborate those of Burpee and Goulty (1986).

Before infection can occur, the temperatures must approach 16°C (Endo, 1963). Except in early to mid-May and after late September, average daily air temperatures typically ranged between 12 to 24° C in 2008 and 2009 and 10 to 22°C in 2010. In summer, when dollar spot was active and most severe, the average daily air temperature ranged between 15 and 27°C in 2008 and 2009. Average night temperatures (ANT) were similar and ranged from 15 to 25°C in 2008 and 2009. In 2010, average daily air temperatures were consistently higher in summer and generally ranged from 20 to 29°C. Furthermore, there were 26 nights when ANT exceeded 25°C. In 2010, dollar spot pressure was typically severe in the HS cultivars in the first epidemic. However, for MS cultivars, disease pressure was low in both 2010 epidemics, especially the second. For example, when dollar spot peaked in the second epidemic in 2008 and 2009, IC counts usually exceeded 70 IC m^{-2}; however, in 2010 the number of IC's did not exceed 40 IC m^{-2} at any time in MS cultivars. The low dollar spot activity in 2010 in MS cultivars was attributed to high average daily air and particularly high ANT as discussed below. Bennett (1937) found that infection could continue at temperatures as high as 32°C, but data from the current study do not support his lab investigations. Indeed, Bennett (1937) may not have been working with the same pathogen found causing dollar spot in the U.S. (Powell and Vargas, 1999 and 2007). In lab studies, in which temperatures were maintained constant (i.e., no diurnal fluctuation), infection by *S. homoeocarpa* was shown to occur between 15 and 27°C, with optimum being 20 to 27°C (Endo, 1963). Walsh (2000) reported 25°C to be optimum for *S. homoeocarpa* growth and subsequent disease. Hence, except in early May and after late September, the average daily air temperatures recorded in the current study were the same as those previously reported as being conducive or optimum for infection and symptom expression.

Average night air temperatures may be more important in describing the influence of temperature on epidemics than average daily air temperature. This presumption is based on the likelihood that dew develops in the early evening (about 1900 hrs in summer) and that leaf wetness is required for infection and disease progress (Walsh 2000). Hence, it was assumed that the pathogen was most invasive in the nighttime and early morning hours when the canopy was moist. In early May, dollar spot typically began first in HS cultivars and exhibited a lag phase when ANT fluctuated between < 10°C and > 20°C. Similarly, after mid-September (2008 and 2010) and after mid-October (2009) as dollar spot IC counts declined and turf recovered, the ANT usually was ≤ 12°C. As ANT became consistently above 14 or 15°C, IC counts increased during the first epidemic. During high disease pressure periods in both summer epidemics in 2008 and 2009, ANT typically ranged between 14 and 25°C. In general, however, ANT was in the range of 15 to 25°C when IC counts declined between the first and second epidemics. The ANT was anomalous in 2010 and featured many nights (n = 26) when ANT exceeded 25°C, which appeared to limit pathogen activity as much as ANT < 12°C. Conversely, there were only two dates in both 2008 and 2009 in which ANT was above 25°C. Hence, the old adage that it can get "too hot for dollar spot" was largely supported by ANT data collected in summer 2010.

According to Walsh (2000), LWD is a limiting factor in dollar spot development, but temperature is of utmost importance during nighttime dew periods in order for the disease to develop. For example, dollar spot did not develop at temperatures of 10°C (50 °F) during 12 hrs of leaf wetness, but did develop at 17.5 °C (63.5 °F) during 12 hrs of leaf wetness (Walsh, 2000). Walsh (2000) also reported that dollar spot would not occur in the field when LWD was less than six hours. In the current study, LWD generally ranged from 6 to 12 hrs each night throughout the summer. On days that it rained, LWD typically was > 12 hrs. However, even during periods of > 12hrs of LWD, dollar spot severity declined following the peak between the first and beginning of the second epidemic in 2008 and 2009.

Walsh (2000) observed that the presence of aerial mycelium often was preceded by periods of rain and/or high RH (i.e., >85%). Aerial mycelium also was associated with an increase in disease severity by Walsh (2000). Foliar mycelium levels were assessed in 2009 and 2010. In general, foliar mycelium appeared one to three days following a rain event and when LWD were > 9hrs. Rainfall amount did not appear to influence the amount of foliar mycelium observed. Since the site was irrigated to prevent wilt, it appeared that precipitation was most important in terms of promoting aerial mycelium and perhaps by increasing LWD and elevating RH. Increases in dollar spot IC's usually followed the appearance of foliar mycelium. However, between 5 and 22 August 2009, there were eight dates when foliar mycelium appeared and IC counts were declining at the end of the first epidemic in MS cultivars. Foliar mycelium was not observed after late August in either 2009 or 2010, despite numerous dates when LWD exceeded 9 hrs and there had been several rain events. Walsh (2000) reported that aerial mycelium was observed on 37 of 65 rating dates (57%) during epidemics in the three year study. Conversely, in the current study, aerial mycelium only was observed on 30 of 87 observation dates (34%) in the summers of 2009 and 2010. However, aerial mycelium was monitored less frequently after 1 September in the current study, but was performed at least three times weekly.

Relative humidity > 85 % promotes dollar spot (Walsh, 2000). Endo (1963) reported that dollar spot severity peaks at temperatures ranging from 21 to 27°C, when night RH is ≥ 85% . Average nighttime relative humidity invariably was above 85% most summer nights in all three years. Hence, average daily % RH (ADRH) was examined more closely. Increases in ADRH > 85% for two or more days usually were associated with increases in IC's. Conversely, two or more days when ADRH fell below 85% usually was followed by a decrease in IC's. This was typically observed from about late May until mid-to-late September. By late September, there were numerous days when ADRH was > 85%, but IC's were decreasing, which was attributed to ANT falling below 12°C. This is the first field study that has indicated that two or more consecutive days of average daily RH > 85% may be an important requirement for the appearance of dollar spot symptoms.

Despite apparently favorable environmental conditions for dollar spot in summer, disease activity declined or stopped periodically, especially between the first and second epidemics in 2008 and 2009. Both RH and temperature were evaluated together as "optimum conditions criteria" to determine their possible interrelationship with dollar spot. Optimum daily conditions (ODC) were defined by the number of hours per 24-hour day when temperatures were between 18 and 25°C and ADRH > 85%. Optimum night conditions (ONC) were defined by the number of hours at night (1800 to 0059 hrs) when temperatures were between 20 and 25°C and RH was > 85%. There was no consistent relationship between dollar spot and ONC in 2009 and 2010. Dollar spot IC's, however, generally increased when there were ≥ 5 hrs of ODC ; whereas, the number of IC's often declined or remained static when ODC were < 5 hrs. Conversely, declines in IC's between epidemics (i.e., between 8 July and 1 August in 2008 and 9 and 25 August 2009) occurred when there were > 7 hrs ODC (Figures 13 and 14). Again, it appeared that ANT below 12°C during early to mid-May in the first epidemic and during the decline in IC's following the second epidemic after late September was a major factor limiting dollar spot activity.

Data indicated that factors other than average daily air temperature, high night humidity (≥85%), ANT, ADRH, LWD and precipitation also govern the ability of the pathogen to infect creeping bentgrass during the summer. More specifically, it was not determined why IC's declined and turf recovered in summer when air temperature, soil moisture, LWD, and RH appeared conducive if not optimum for dollar spot. It is conceivable that the disease cycles, although *S. homoeocarpa* does not produce spores in nature (Fenstermacher, 1980). Turf scientists have pondered the reason why dollar spot patches do not increase beyond a few cm in diameter in close cut bentgrass turf; while, *R. solani* and *Pythium* spp. can produce patches in excess of 30 cm in a single night. *Sclerotinia homoeocarpa* is believed to produce mycotoxins that injure bentgrass roots (Malca and Endo, 1965). It is conceivable that *S. homoeocarpa* produces mycotoxins or staling substances that accumulate at some point in time and prevent pathogen growth and thus limit patch size. Perhaps it is staling substances that are responsible for limited disease progress in summer following peaks, despite favorable environmental conditions for infection. It also is possible that factors related to the host in some way impact infection. Typically, however, cool-season grasses are growing slowly in summer and thus would likely be more susceptible to damage and/or delayed recovery during periods of supraoptimal temperature stress. Perhaps inherent defense mechanisms, triggered by unknown factors, are responsible for the phenomenon of limited dollar spot activity periodically in summer, despite conducive environmental conditions for disease.

A third, autumn dollar spot epidemic was observed in late October (2010), mid-November (2008) and in early December (2009). Walsh (2000) determined that dollar spot development can occur at temperatures as low as 10 and 12°C if there were 22 hrs and 12 hrs LWD; respectively. The ANT for a three to five night period prior to the appearance of autumn symptoms and/or aerial mycelium (2010) ranged from 10 to 22°C in 2008 and 2010, but only reached 12°C for one night, two days prior to the appearance of symptoms in 2009. Hence, ANT data support the findings of Walsh (2000). The third autumn epidemic in each year was the least severe and of shortest duration. The third epidemic appeared to last a period of 10 to 21 days. However, infrequent monitoring of the site, limited data collection, and the use of fungicides on 17 November 2008 precluded a more accurate description of the length of each autumn epidemic.

Table 1. Area under the disease progress curve (AUDPC) for *S. homoeocarpa* infection center counts in six creeping bentgrass cultivars, 2008.

	AUDPC		
Cultivar	23 May - 1 Aug.	4 Aug. - 15 Oct.	14 Nov. - 18 Dec.
Penncross	1081b*	2438a	130b
L-93	598b	2337a	227b
007	421b	2683a	385a
Providence	756b	2103a	202b
Backspin	2102a	**	**
Crenshaw	2527a	**	**

*Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test at $P \leq 0.05$.

** Cultivar too severely blighted to be evaluated.

Table 2. Area under the disease progress curve (AUDPC) for *S. homoeocarpa* infection center counts in six creeping bentgrass cultivars, 2009.

	AUDPC			
Cultivar	10 May - 29 June	10 May - 24 Aug.	27 Aug. - 20 Oct.	5 Dec. - 18 Dec.
Penncross	172c*	1731a	2346a	153a
L-93	43c	959bc	2073ab	110a
007	45c	839c	1572b	120a
Providence	90c	1367ab	2436a	193a
Backspin	738b	**	**	**
Crenshaw	1166a	**	**	**

*Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test at $P \leq 0.05$.

**Cultivar too severely blighted to be evaluated.

Table 3. Area under the disease progress curve (AUDPC) for *S. homoeocarpa* infection center counts in six creeping bentgrass cultivars, 2010.

	AUDPC		
Cultivar	4 May - 6 July	9 July - 22 Oct.	29 Oct. - 9 Nov.
Penncross	458c	1859b	132a
L-93	305c	2100ab	125a
007	275c	2676a	142a
Providence	360c	2150ab	152a
Backspin	1168b	**	**
Crenshaw	2013a	**	**

* Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test at $P \leq 0.05$.

** Cultivar too severely blighted to be evaluated.

Figure 1. Growing degree days (GDD) for predicting the onset of dollar spot epidemics in moderately (MS) and highly (HS) susceptible cultivars using a base temperature of 15°C and a bio-fix date of 1 April in 2008, 2009, and 2010.

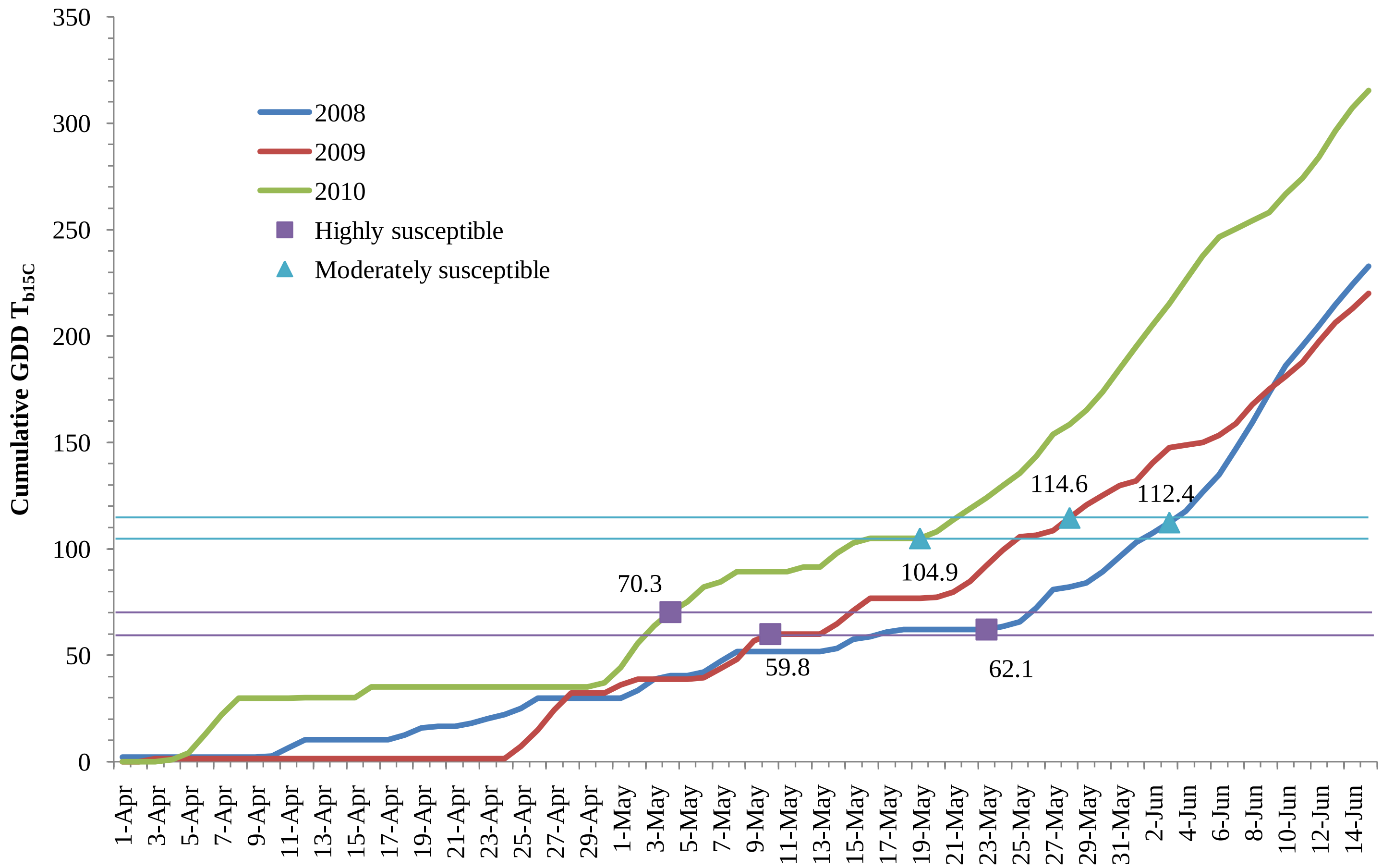


Figure 2. Growing degree days (GDD) for predicting the onset of dollar spot epidemics in moderately (MS) and highly (HS) susceptible cultivars using a base temperature of 10°C and a bio-fix date of 1 April in 2008, 2009, and 2010.

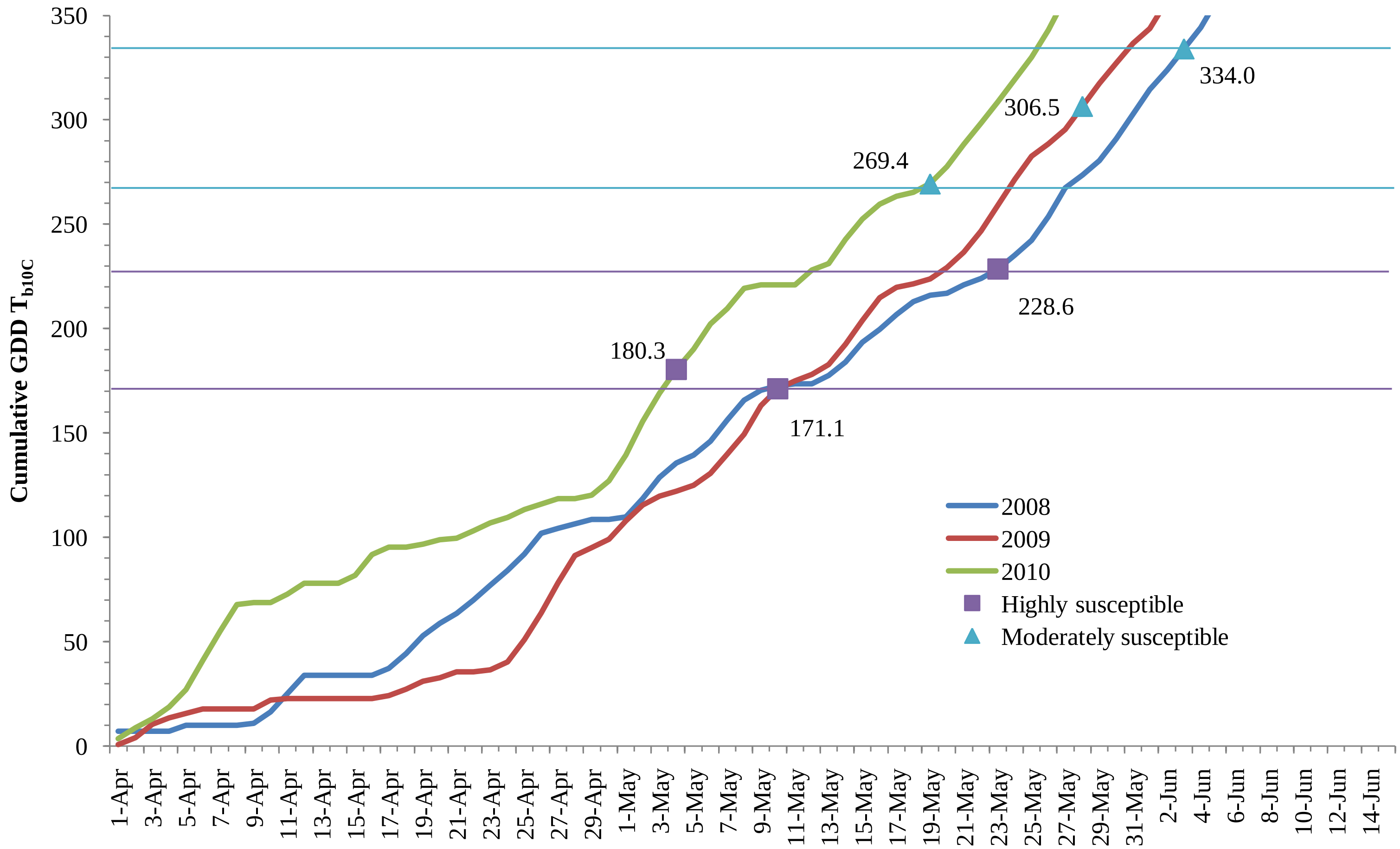


Figure 3. Growing degree days (GDD) for predicting the onset of dollar spot epidemics in moderately (MS) and highly (HS) susceptible cultivars using a base temperature of 12°C and a bio-fix date of 1 April in 2008, 2009, and 2010.

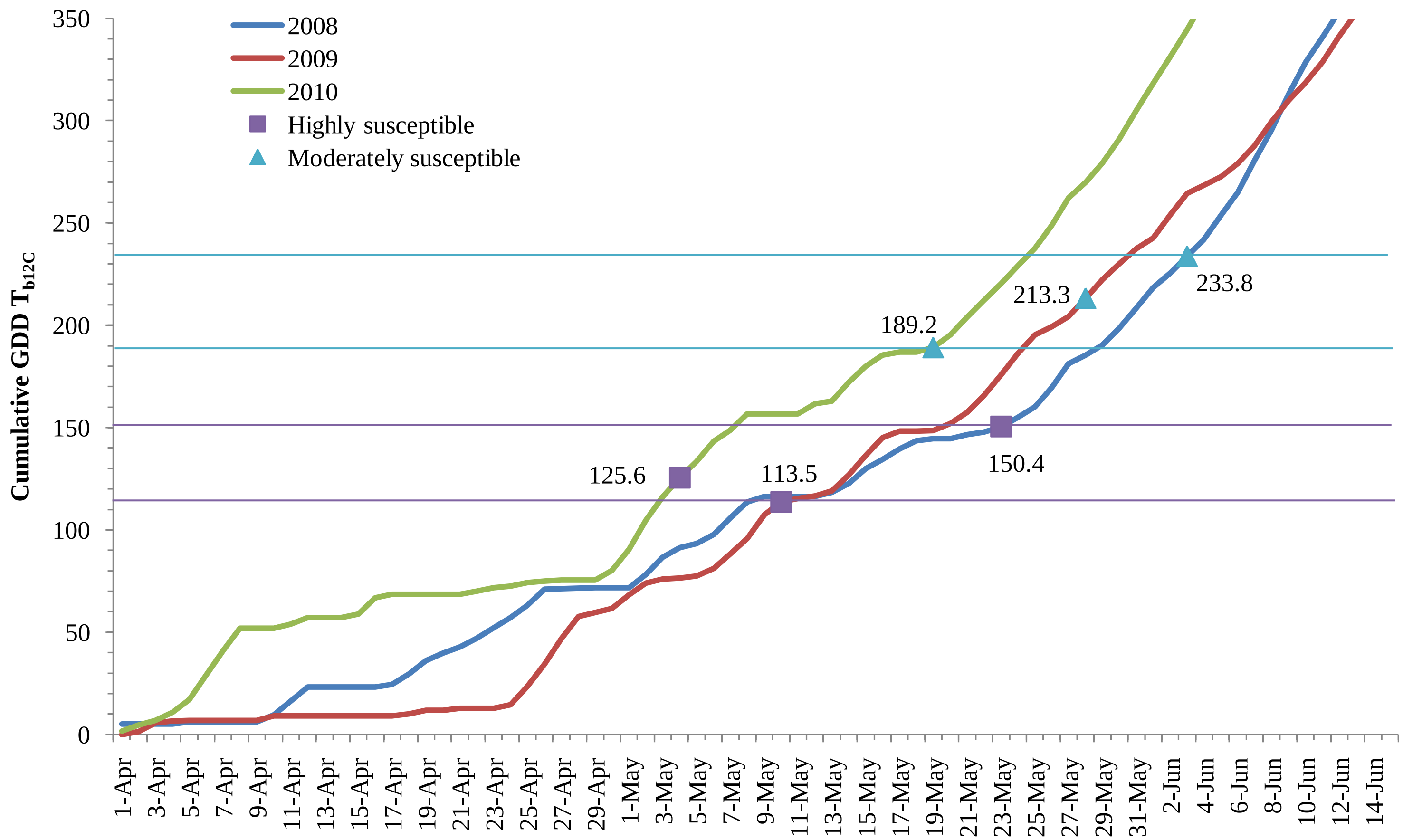


Figure 4. Number of *S. homoeocarpa* infection centers in plots of six creeping bentgrass cultivars between 1 May and 15 October, 2008. *Denotes that data collection ceased due to extensive injury to the cultivar.

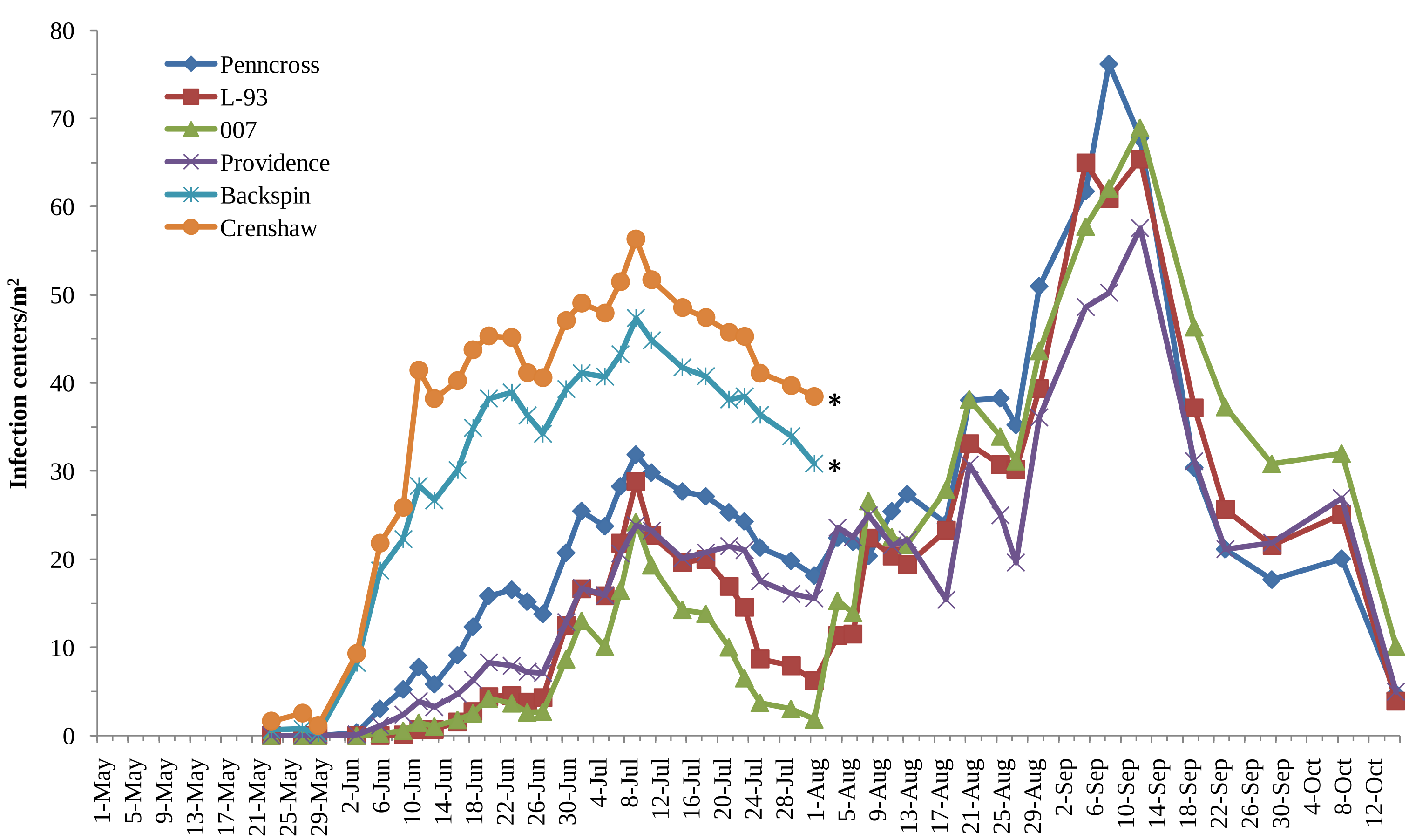


Figure 5. Number of *S. homoeocarpa* infection centers in plots of six creeping bentgrass cultivars between 1 May and 20 October, 2009. *Denotes that data collection ceased due to extensive injury to the cultivar.

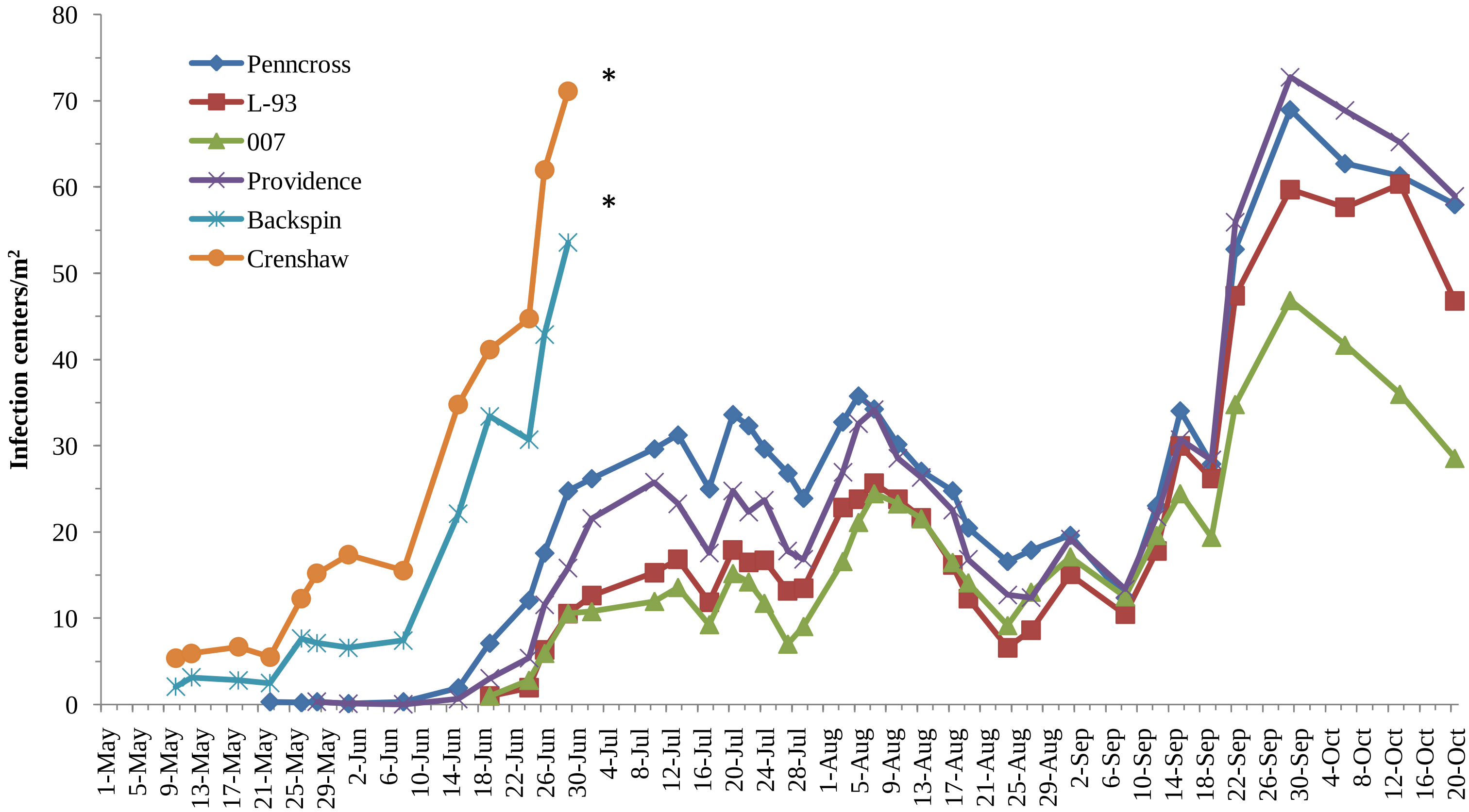


Figure 6. Number of *S. homoeocarpa* infection centers in plots of six creeping cultivars between 1 May and 22 October, 2010. *Denotes that data collection ceased due to extensive injury to the cultivar.

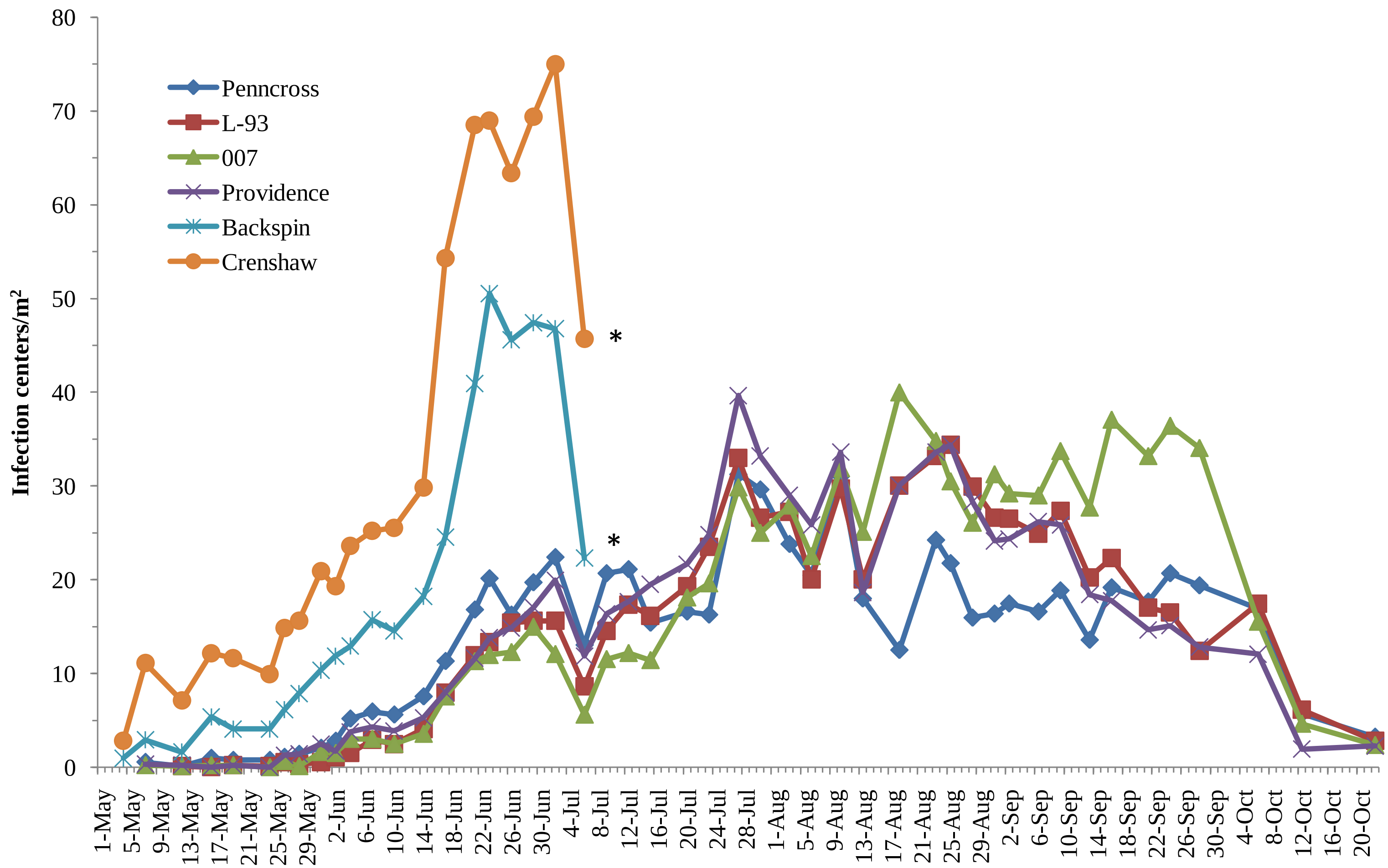


Figure 7. Average night (1800 hrs to 0559 hrs) temperatures (°C) between 1 May and 15 October, 2008.

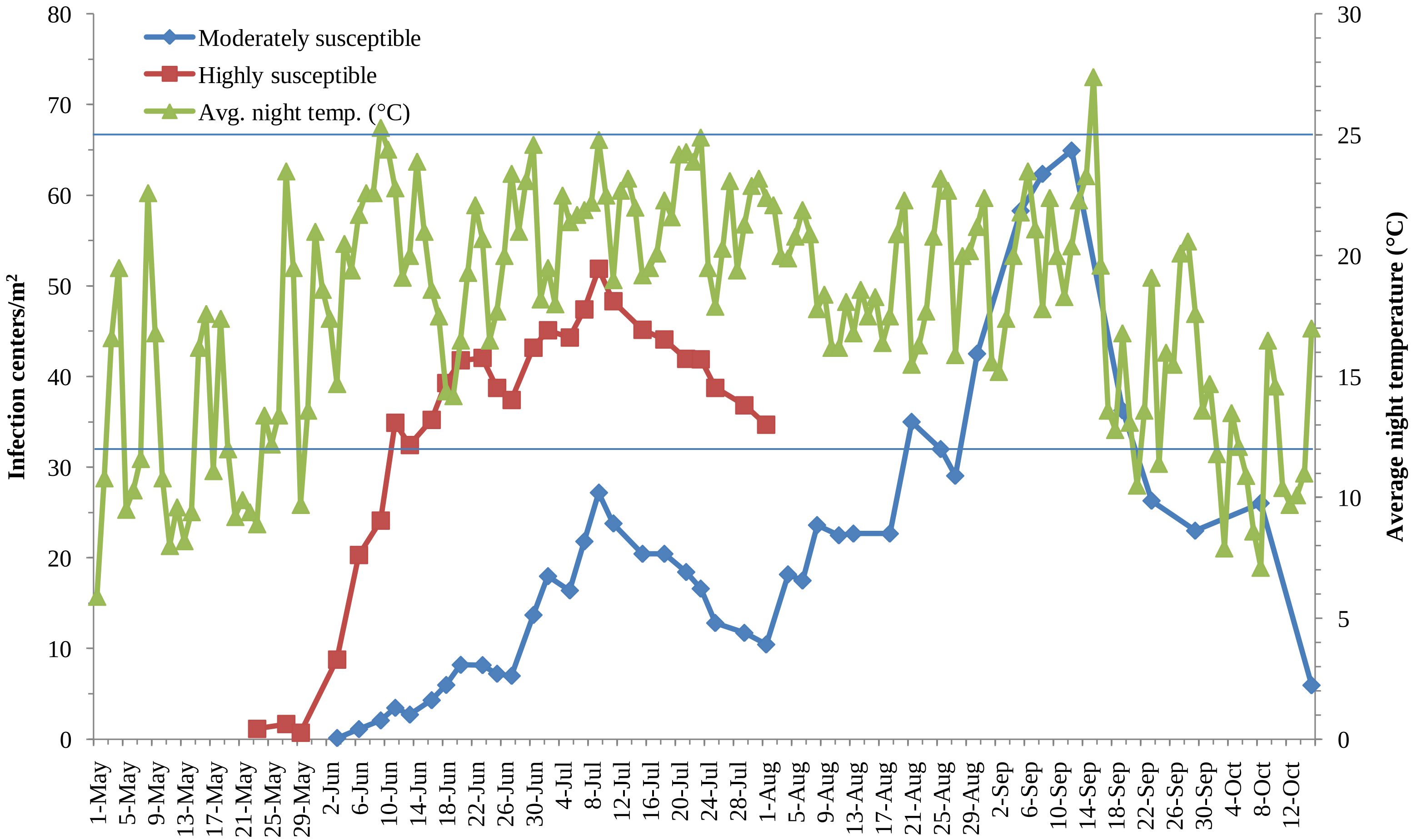


Figure 8. Average night (1800 hrs to 0559 hrs) temperatures (°C) between 1 May and 20 October, 2009.

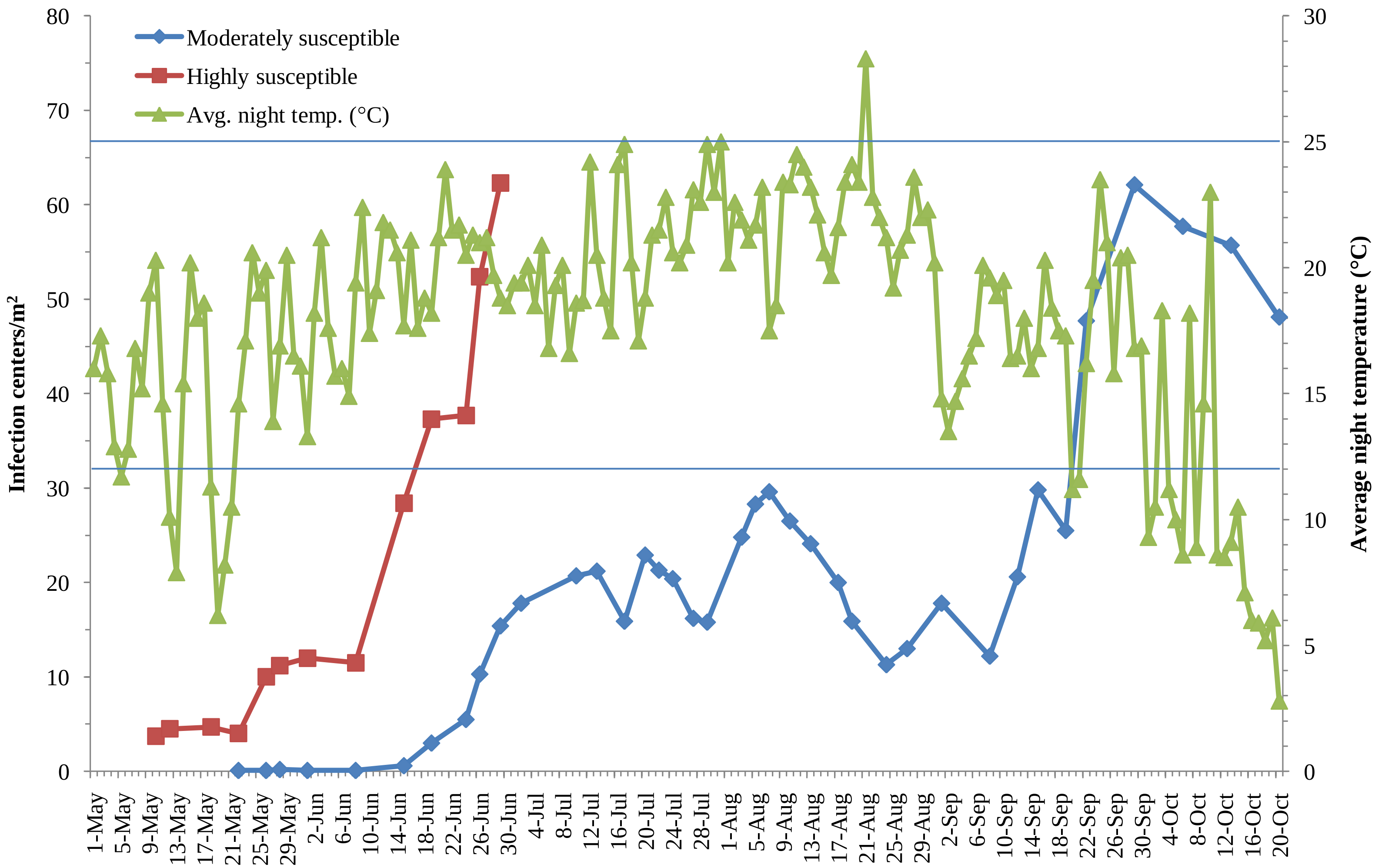


Figure 9. Average night (1800 hrs to 0559 hrs) temperature (°C) between 1 May and 22 October, 2010.

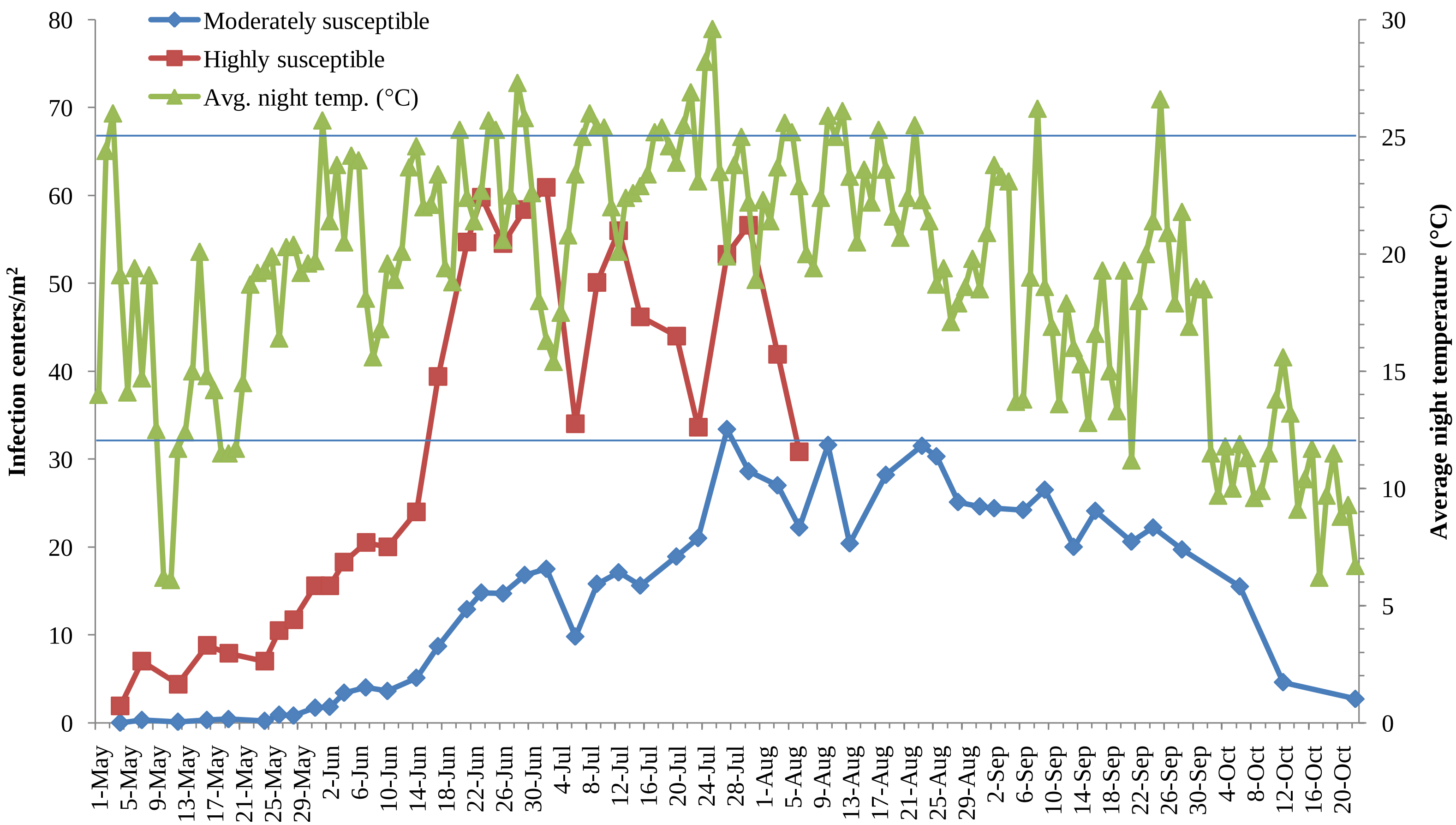


Figure 10. Average daily percent relative humidity (RH) between 1 May and 15 October, 2008.

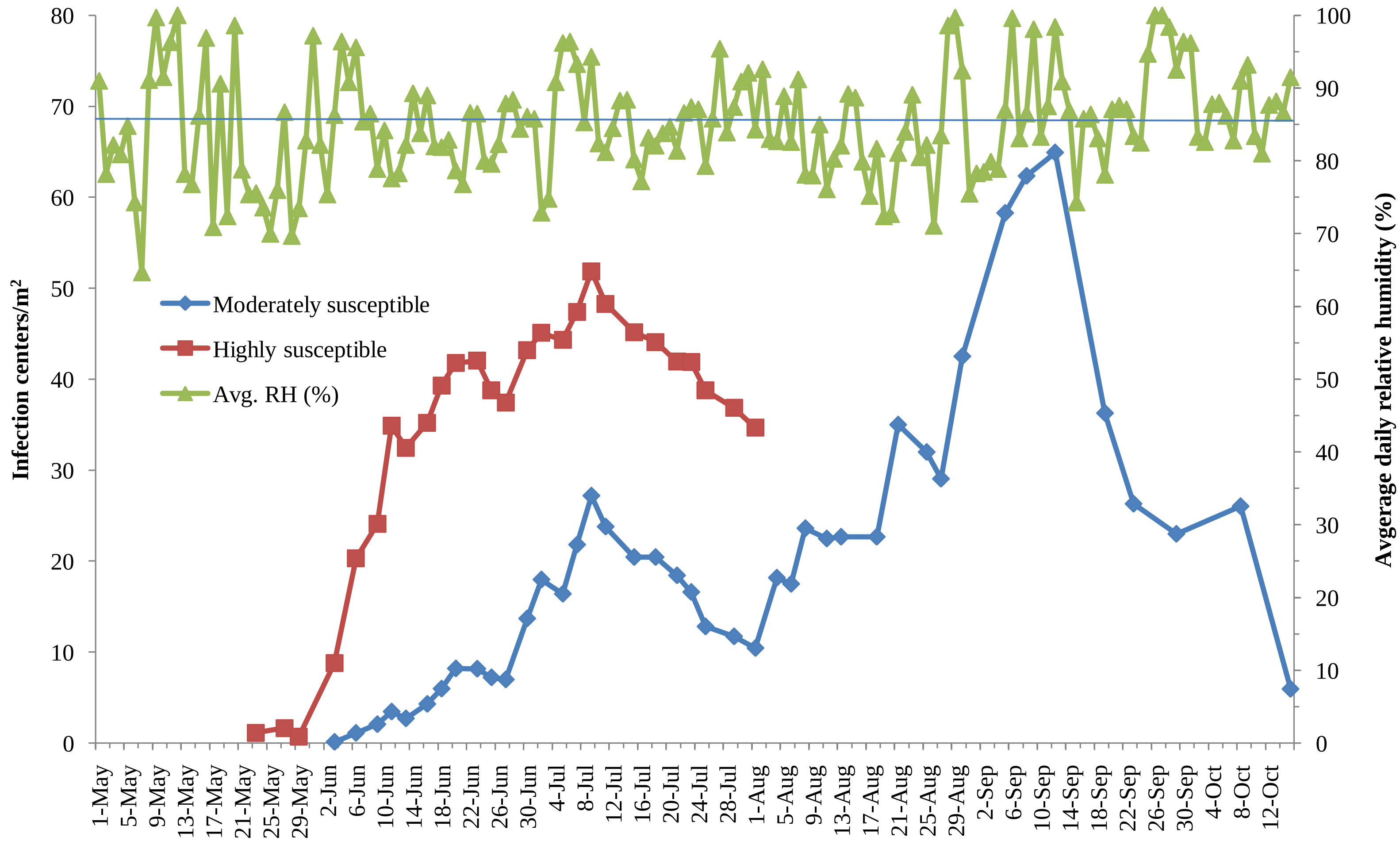


Figure 11. Average daily percent relative humidity (RH) between 1 May and 20 October, 2009.

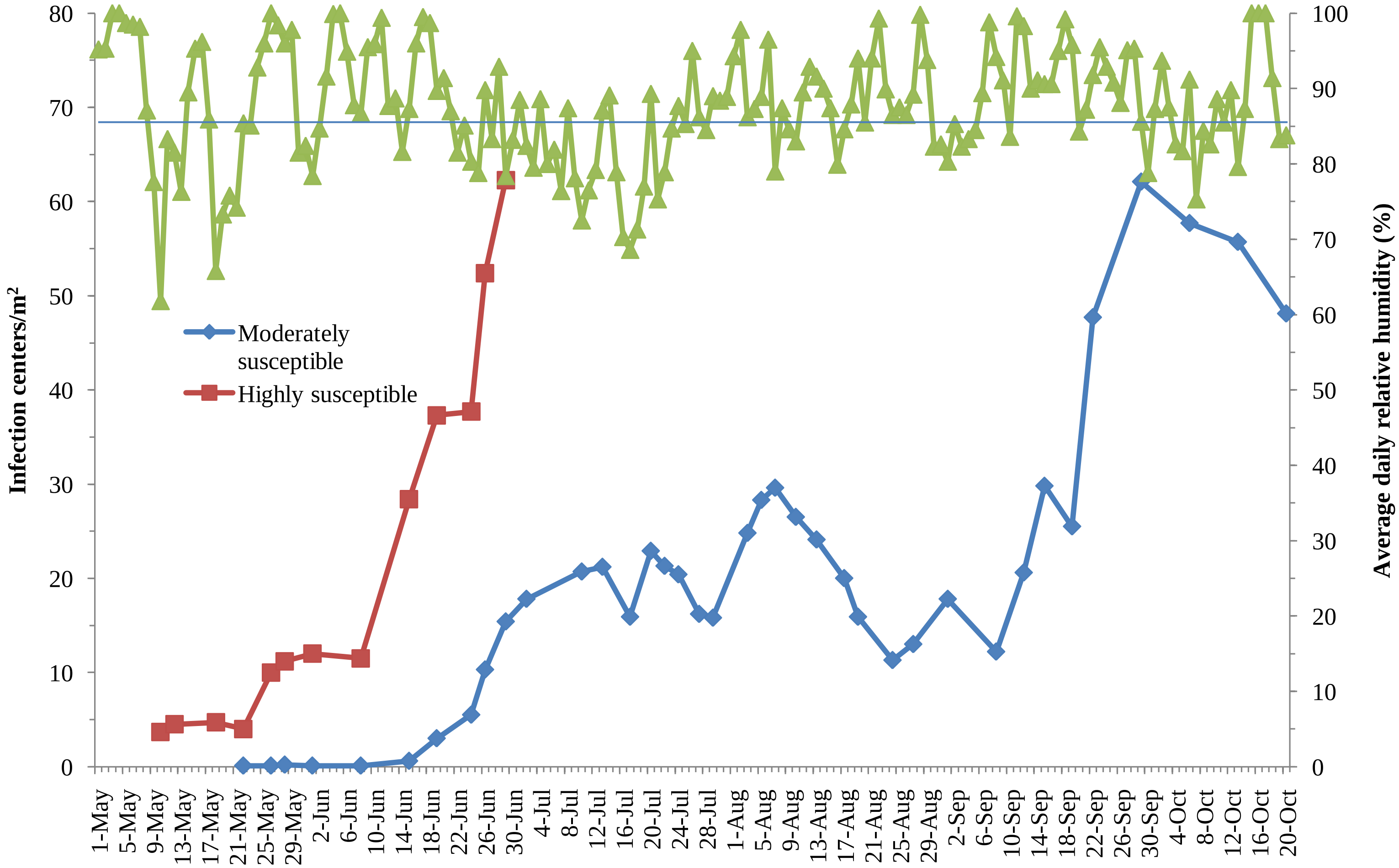


Figure 12. Average daily percent relative humidity (RH) between 1 May and 22 October, 2010.

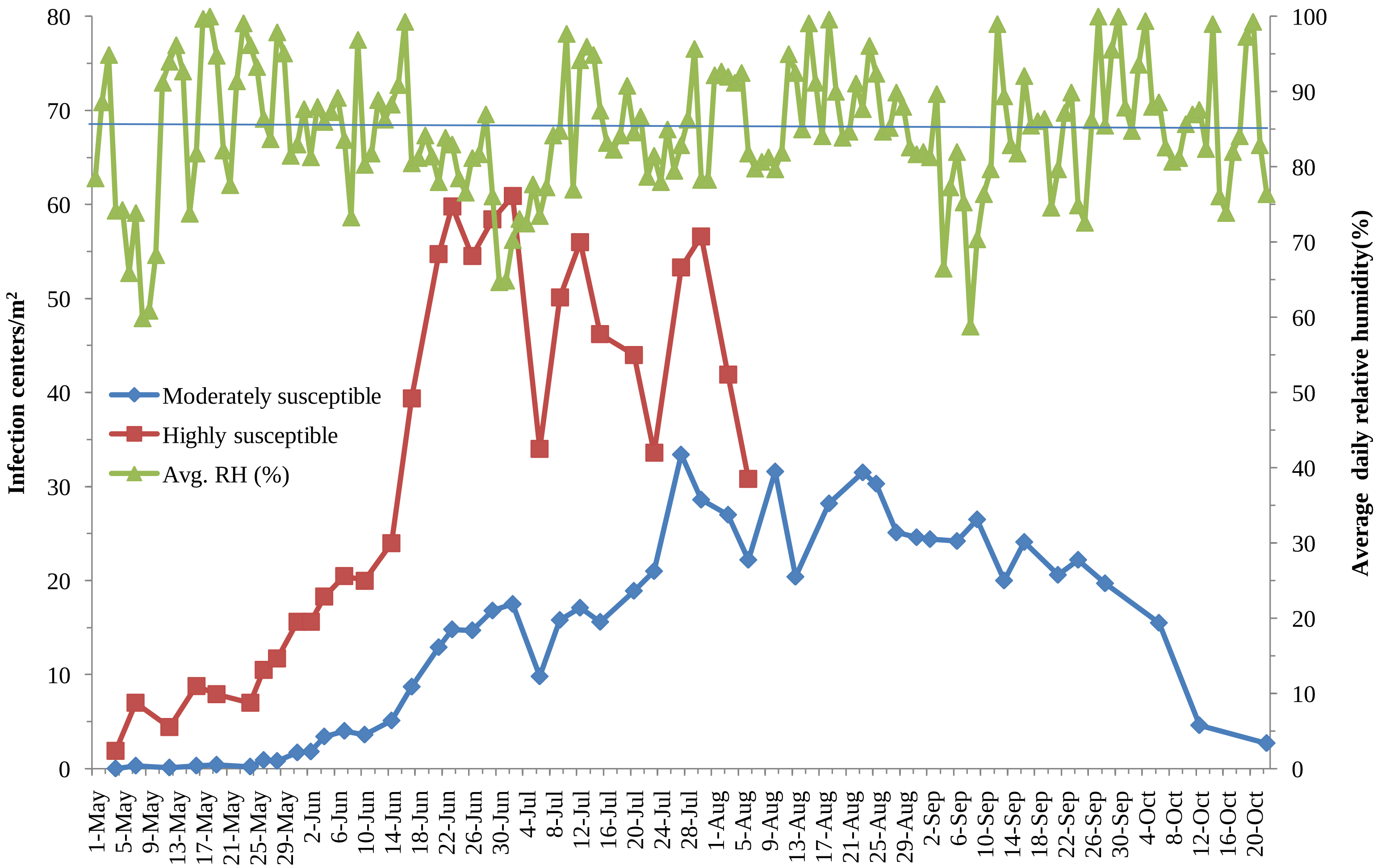


Figure 13. Optimum daily conditions as defined by hours of average temperature between 18 and 25°C and average relative humidity (RH) >85% between 1 May and 15 October, 2008.

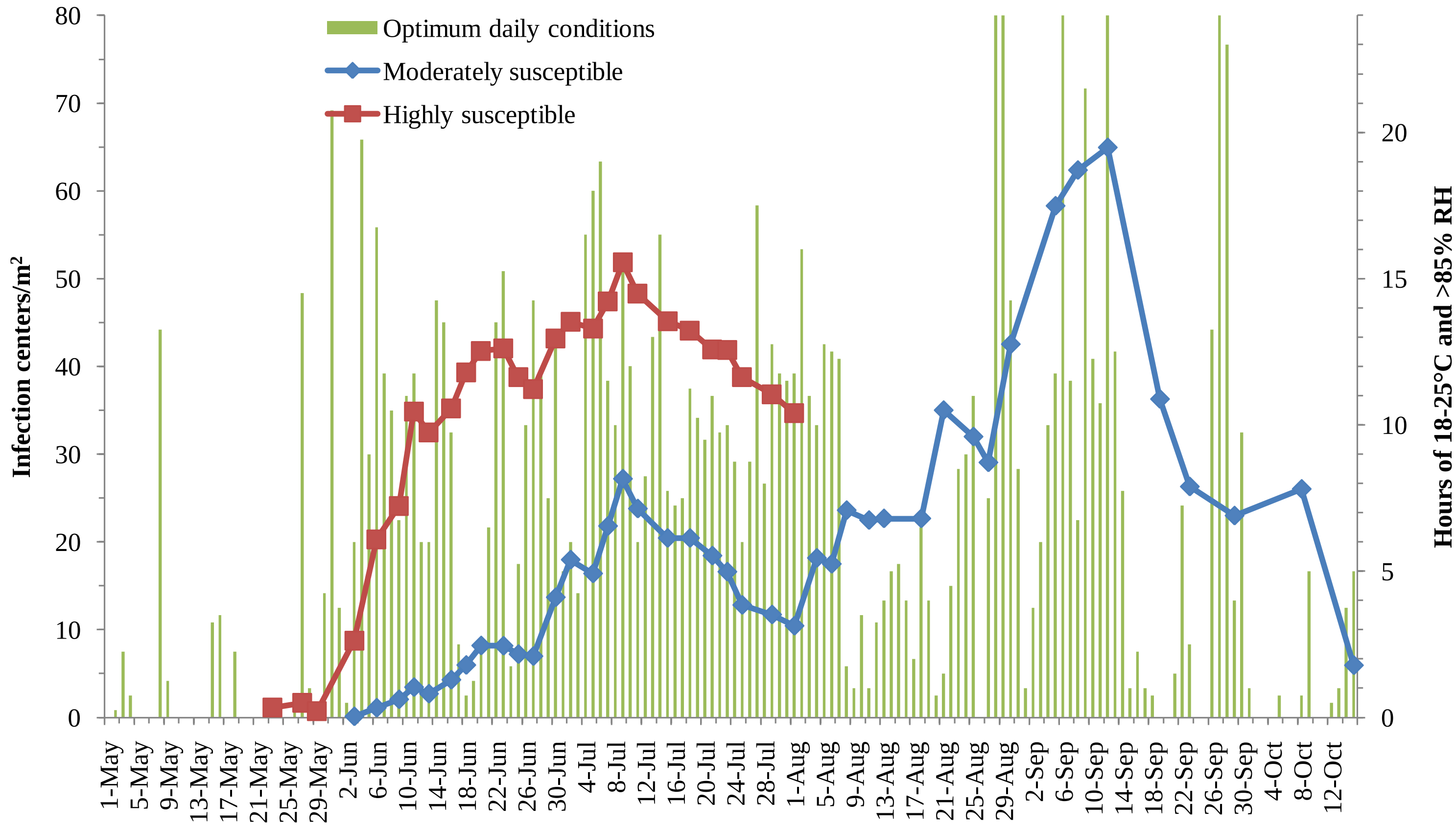


Figure 14. Optimum daily conditions as defined by hours of average temperature between 18 and 25°C and average relative humidity >85% between 1 May and 20 October, 2009.

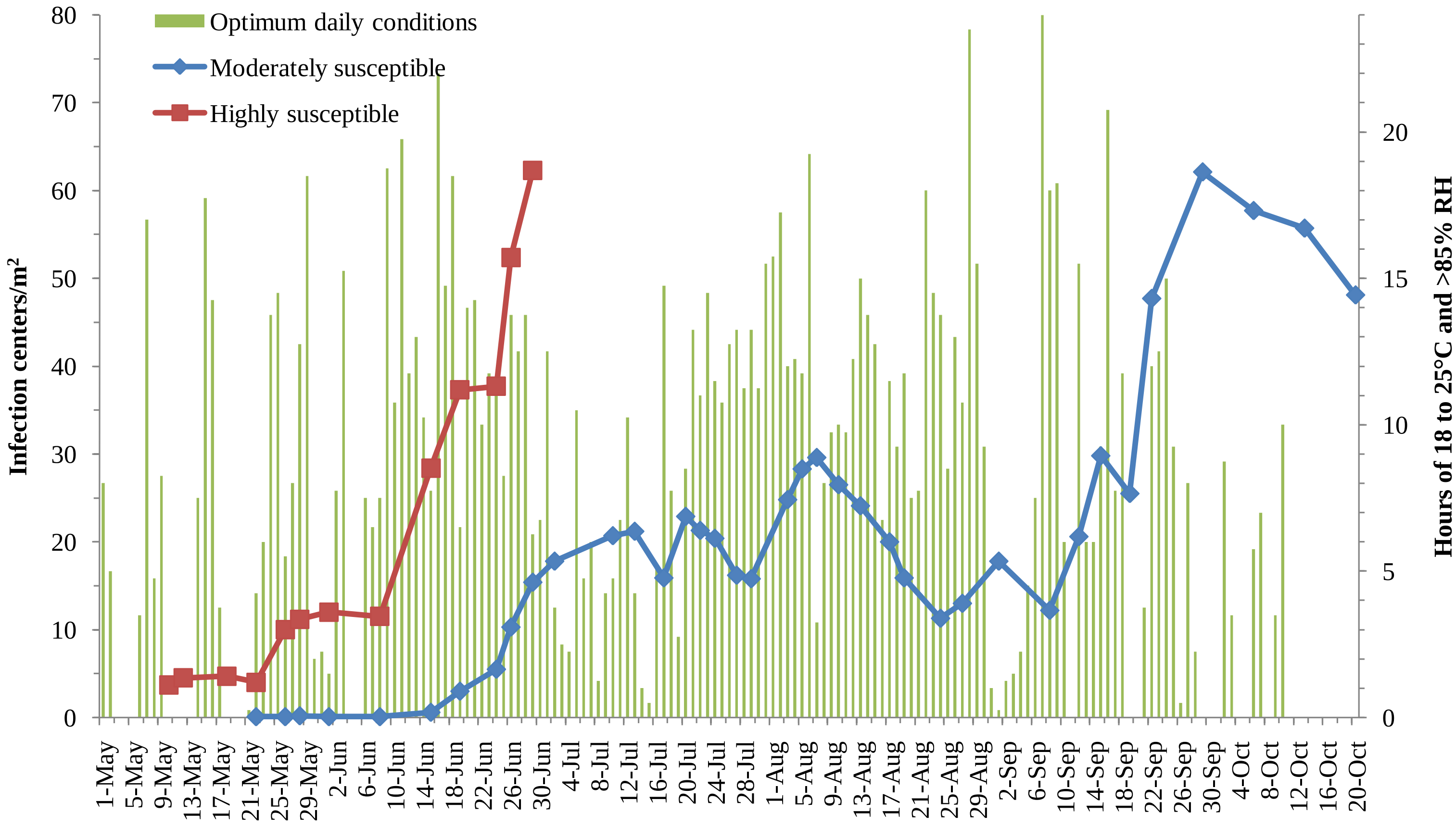


Figure 15. Optimum daily conditions as defined by hours of average temperature between 18 and 25°C and average relative humidity >85% between 1 May and 22 October, 2010.

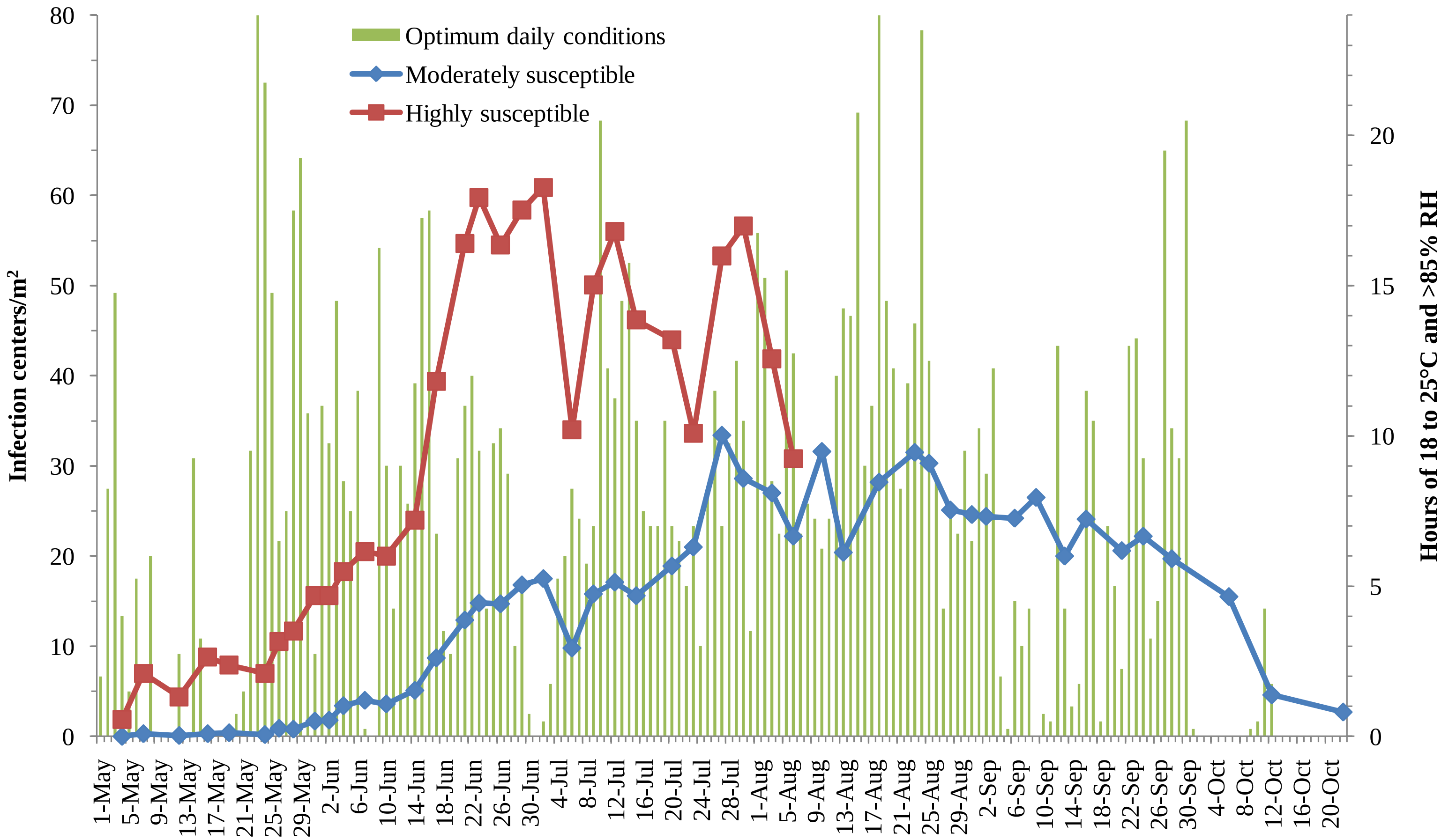


Figure 16. Percent plot area blighted by *S. homoeocarpa* plots of four creeping bentgrass cultivars between 14 November and 18 December, 2008.

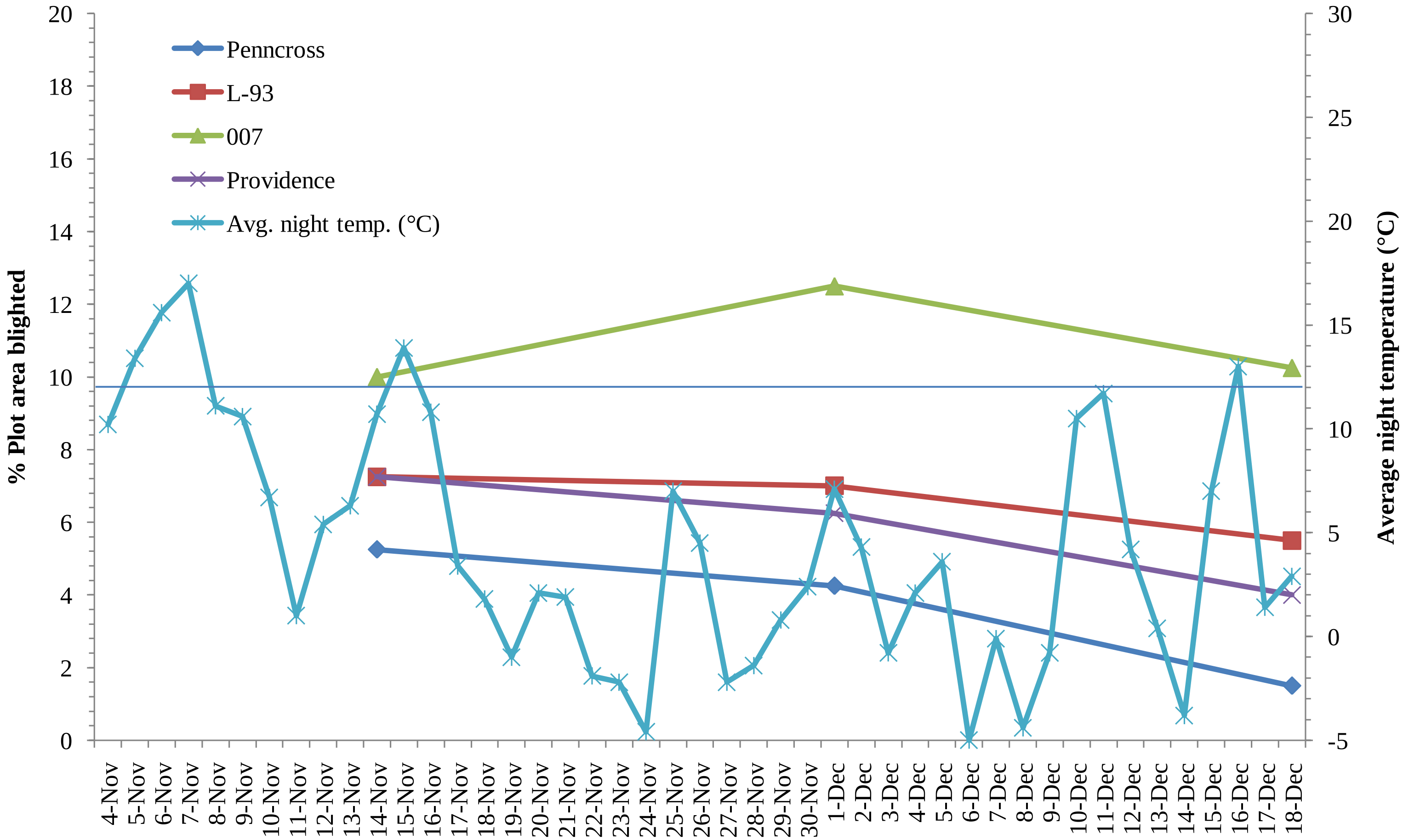


Figure 17. Number of *S. homoeocarpa* infection centers in plots of four creeping bentgrass cultivars between 1 and 18 December, 2009.

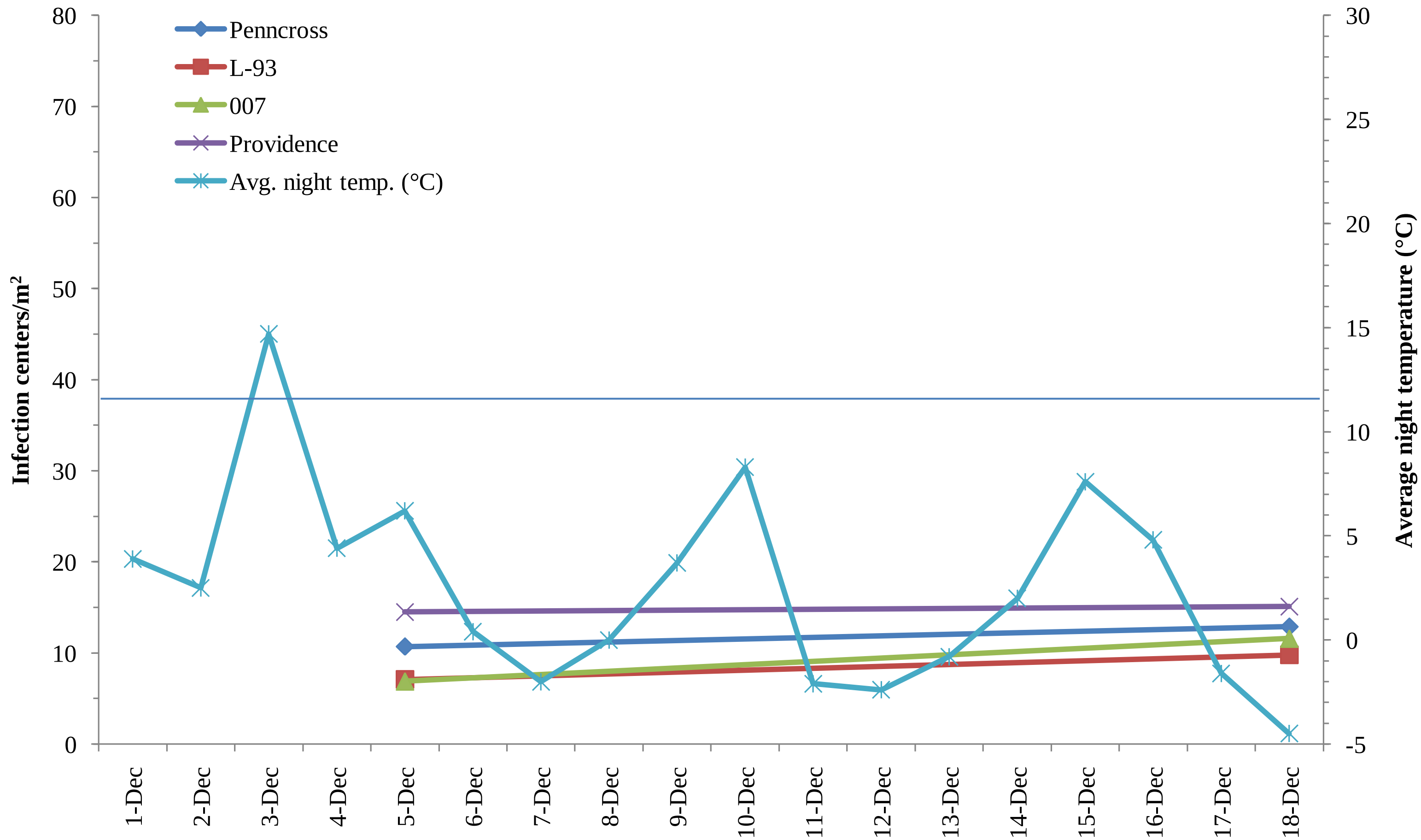
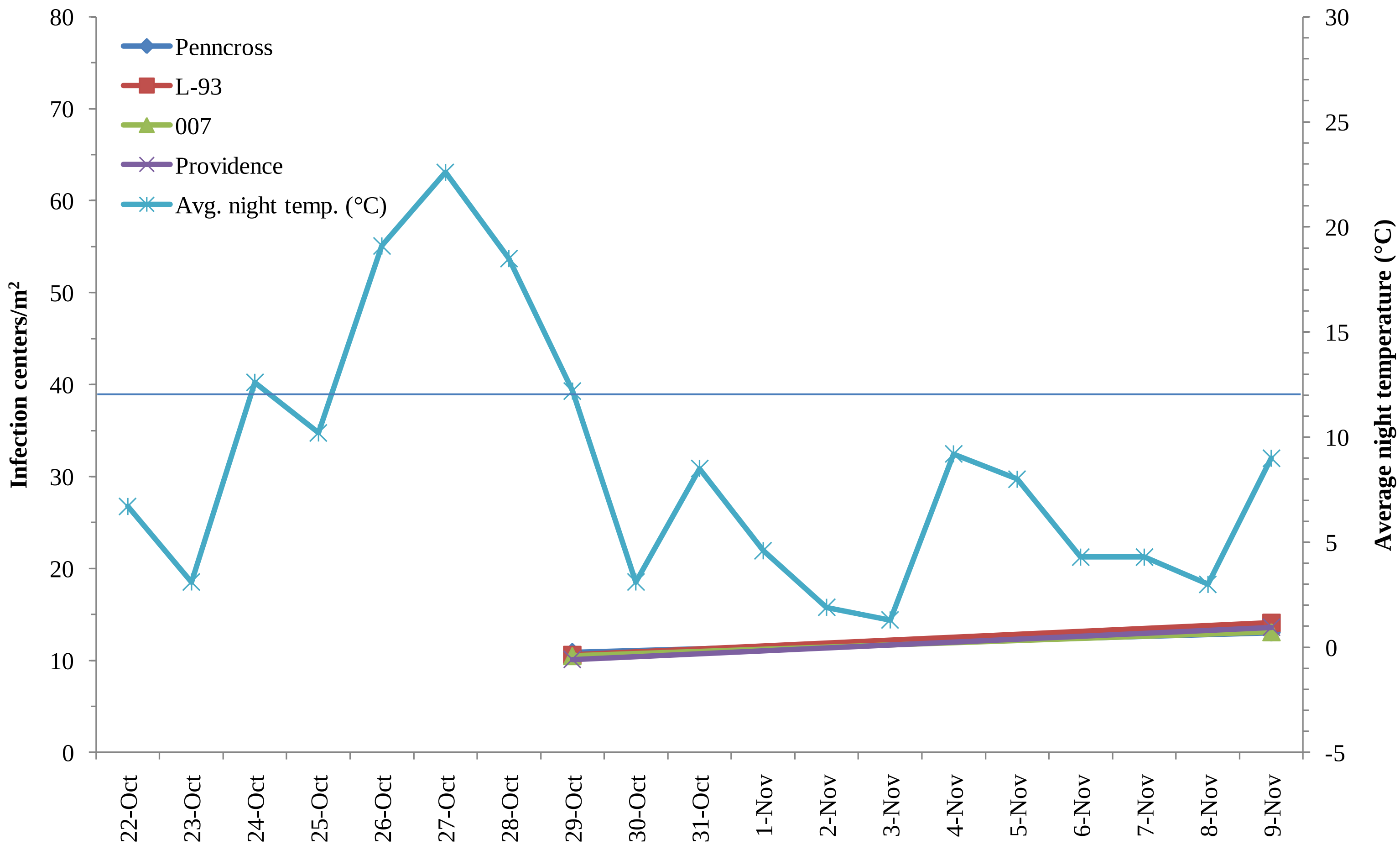


Figure 18. Number of *S. homoeocarpa* infection centers in plots of four creeping bentgrass cultivars between 29 October to 9 November, 2010.



Chapter III: Influence of Summer Spoonfeeding Six Nitrogen Sources on Dollar Spot Severity in Creeping Bentgrass

Synopsis

Dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) injury can be suppressed by applications of nitrogen (N) fertilizer to creeping bentgrass (*Agrostis stolonifera* L.). Previous studies evaluated applications of relatively high rates of N (≥ 24 kg N ha^{-1}) for dollar spot suppression. In this study, ammonium nitrate, ammonium sulfate, urea, potassium nitrate, calcium nitrate, and 20-20-20 were applied to fairway height CBG on two week intervals at 7.3 kg N ha^{-1} in the summer of 2008 and 2009. The N sources were applied alone or tank-mixed with a low rate of the contact fungicide chlorothalonil (1.6 kg a.i. ha^{-1} in 2008 and 3.2 kg a.i. ha^{-1} in 2009). Treatments were initiated prior to the onset of dollar spot symptoms. It was hypothesized that N + chlorothalonil would improve the level or longevity of dollar spot control. Area under the disease progress curve (AUDPC) revealed that only ammonium sulfate had reduced dollar spot in both years; whereas, ammonium nitrate and 20-20-20 did not reduce dollar spot over the season in any year. There was a trend for less dollar spot control in plots treated with N + chlorothalonil versus the low chlorothalonil rate alone in 2008, but in 2009 the deleterious effect was significant. It is likely that N stimulated plant growth and thus the contact fungicide was more rapidly removed from plants by mowing compared to plots treated with chlorothalonil alone. Ammonium nitrate, urea and 20-20-20 did not burn or otherwise reduce turf color on any rating date in 2008 or 2009. Ammonium sulfate was most injurious and elicited a

burn within hours of application. The injury was unacceptable and persisted for 7 to 28 days with multiple applications in each year. Potassium nitrate and calcium nitrate also caused foliar burn and reduced color, but usually only for 7 days and generally was not as severe as the injury induced by ammonium sulfate. In 2010, the penetrant fungicides iprodione (1.5 kg a.i. ha^{-1}) and triticonazole (0.3 kg a.i. ha^{-1}) were paired with either ammonium sulfate or urea and applied to fairway and putting green height creeping bentgrass. Unlike previous years, treatments were applied after dollar spot had become active in 2010. At both sites, there were no AUDPC differences among ammonium sulfate, urea and the untreated control. Similarly, there were no AUDPC differences among ammonium sulfate or urea + either iprodione or triticonazole. Lack of any seasonal effects of N in 2010 was attributed to treatments being applied after dollar spot had become active. In fact , dollar spot exceeded the threshold (i.e., 15 IC's $plot^{-1}$) in all but iprodione-treated plots within nine days after each study was initiated at both sites and before treatments could be applied a second time. In conclusion, it was shown that applying 7.3 kg N ha^{-1} of ammonium sulfate every two weeks reduced dollar spot in 2008 and 2009. Urea, potassium nitrate, and calcium nitrate reduced dollar spot in 2009, but ammonium nitrate and 20-20-20 did not reduce dollar spot on any date in either 2008 or 2009. Spoonfeeding, however, did not reduce dollar spot to an agronomically significant level at any time in 2008 or 2009, and had no effect on dollar spot when initiated after symptoms appeared in 2010. Furthermore, tank-mixing N with a low chlorothalonil rate generally reduced fungicide effectiveness.

Introduction

It has been well documented that the application of nitrogen (N) to turfgrasses when dollar spot is active can reduce the severity of this disease in creeping bentgrass (Lui et al., 1995; Landschoot and McNitt, 1997; Davis and Dernoeden, 2002). It generally is believed that the mechanism of dollar spot suppression by N is due to its ability to stimulate growth and thus enable plants to recover more rapidly from disease injury (Couch, 1995; Landschoot and McNitt, 1997). Other scientists propose that some N sources and composts promote microbial activity, which antagonize or compete with *S. homoeocarpa* and reduce the capacity of the pathogen to blight (Lui et al., 1995; Nelson and Craft, 1992).

Landschoot and McNitt (1997) examined dollar spot suppression using synthetic organic and natural organic N fertilizers on a stand of fairway height creeping bentgrass. The fertilizers evaluated included Ringer Commercial Greens Super (10-2-6; feather meal, blood meal, wheat germ, bone meal, liquid fat, D-limonene, and potassium sulfate); Ringer Compost Plus (7-4-0; wheat middlings or enriched cattle feed, calcium carbonate, dried molasses, bone meal, urea, and liquid fat, *Bacillus subtilis* (Ehrenberg) and *Bacillus licheniformis* (Weigmann); Sustane (5-2-4; composted turkey litter); Milorganite (6-2-0; activated sewage sludge) and others, which were compared to urea (46-0-0). The fertilizers were applied on roughly a 30 day interval between late May and late August over a three year period at a low (24 kg N ha^{-1}) versus a high (48 kg N ha^{-1}) rate. In the first year, none of the fertilizer treatments suppressed dollar spot. In the second year, only the high rate of Ringer Compost Plus and urea provided disease suppression. In year three, nearly all fertilizer treatments provided a greater level of dollar spot suppression versus the non-fertilized control. For all fertilizers, the high N rate generally provided better dollar spot suppression than the low N rate. Landschoot and McNitt (1997) concluded that natural organics vary in their ability to suppress dollar spot, but were not superior to synthetic organic sources of N in reducing dollar spot. Landschoot and McNitt (1997) correlated disease suppression with `darker green turf color, indicating that as N availability increased dollar spot severity decreased.

Liu et al. (1995) evaluated the effects of organic and inorganic amendments on bacterial and fungal populations and dollar spot suppression in putting green height creeping bentgrass. Among the fertilizers evaluated were ammonium nitrate (34-0-0); Bovamura (converted from dairy manure); Milorganite (6-2-0); Ringer Greens Super (10-2-6); Ringer Lawn Restore (9-4-4; feather meal, bone meal, and soybean meal); Ringer Turf Restore (10-2-6; feather meal, bone meal, and soybean meal); and sulfur-coated urea (35-0-0). The levels of N in the fertilizers and other products evaluated were different, which may have influenced results. Ammonium nitrate, Ringer Turf Restore and Ringer Greens Super significantly reduced dollar spot from late July to early September, with ammonium nitrate being most effective. Bacterial and fungal levels were quantified from leaves, thatch and soil, and highest populations were found in plots treated with Ringer Greens Super. Microbial populations from plots treated with Ringer Turf Restore, Ringer Lawn Restore, ammonium nitrate and sulfur-coated urea also were high. Liu et al (1995) conclusions were equivocal. They stated that the dollar spot suppression observed may have been the result of increased turf growth provided by N, but that microbial activity promoted by the natural organic fertilizers may have been a factor.

Davis and Dernoeden (2002) examined the influence of the natural organic and synthetic organic N-sources on dollar spot severity in fairway height creeping bentgrass. Urea (46-0-0); sulfur-coated urea (37-0-0); Milorganite (6-2-0); Sustane Medium (5-2-4); Earthgro 1881 Select (8-2-4; poultry manure); Earthgro Dehydrated Manure (2-2-2; poultry manure); Ringer Lawn Restore (10-2-6); Com-Pro (1-2-0; composted biosolids); and Scotts All Natural Turf Builder (11-2-4; poultry manure) were compared. Fertilizers were applied at 150 kg N ha^{-1} in the autumn and 50 kg N ha^{-1} in spring. Ringer Lawn Restore and urea were most consistent in reducing dollar spot severity from May to early June, when disease pressure was low to moderately severe; whereas, Com-Pro had intensified the disease. No N source reduced dollar spot over the entire season. None of the natural organic products consistently reduced dollar spot compared to the synthetic organic N-sources. In one of two sampling years, there was a strong negative correlation between the amount of foliar N and dollar spot severity early in the season when dollar spot pressure was low to moderately severe. That is, the suppression of dollar spot likely was mostly from stimulated growth early in the season following the 50 kg N ha^{-1} application in May of each year. Similarly, Ellram et al. (2007) implied that elevated tissue N levels above 5% were associated with less dollar spot in creeping bentgrass, but no data were presented.

Previous studies have shown that dollar spot severity can be reduced by applying relatively high rates ($\geq$ 24 kg N ha^{-1} $application^{-1}$) of N. In the aforementioned studies, the rates of N applied generally would not be appropriate in summer for creeping bentgrass. In summer, it is a common practice to apply small amounts of N to greens, tees and fairways in what are called spoonfeeding programs (Dernoeden, 2002). This involves spraying 5.0 to 7.3 kg N ha^{-1} (0.10 to 0.15 lb N/1000ft^2) every 10 to 14 days. Spoonfeeding promotes vigor and recovery from injury without over stimulating turf. It is conceivable that spoonfeeding in summer when dollar spot is active could reduce disease severity and thus improve fungicide performance.

There have been no published studies in which different N sources were assessed in a summer spoonfeeding program for their effects on dollar spot severity. Therefore, the objective of this study was to assess six water soluble N sources (i.e., ammonium nitrate, ammonium sulfate, urea, potassium nitrate, calcium nitrate, and 20-20-20) applied at 7.3 kg N ha^{-1} throughout the summer for their effect on dollar spot severity. The N sources were applied alone or tank-mixed with a low rate of chlorothalonil. Chlorothalonil was selected because it is the most commonly utilized contact fungicide that targets dollar spot and is indispensible for use in *S. homoeocarpa* resistance management programs (McDonald et al., 2006b). The objective of using a low chlorothalonil rate was to determine if the N sources would reduce dollar spot severity enough to allow for a lower input of chlorothalonil. That is, would mixing chlorothalonil with an N source increase the level or length of control versus chlorothalonil applied alone? Aside from economy, finding ways to use chlorothalonil more efficiently are needed due to rate restrictions imposed on this fungicide (USEPA, 1999). It was our hypothesis that the N sources would reduce dollar spot severity and thus improve the performance of a low chlorothalonil rate. Ammonium sulfate has been shown to suppress several turfgrass diseases, which has been attributed to its ability to rapidly acidify soil (Smiley et al., 2005). Thus, it also was postulated that ammonium sulfate could be more efficacious in suppressing dollar spot than the other N sources evaluated.

Materials and Methods

All studies were conducted at the University of Maryland Paint Branch Turfgrass Research Facility in College Park, MD. Soil for the fairway height creeping bentgrass sites was a Keyport silt loam (fine, mixed, semiactive Aquic Hapludult) with pH's ranging from 5.9 to 6.1 and 18 to 22 grams of organic matter kg^{-1} soil (1.8 to 2.2% OM). For the putting green site, turf was grown on a sand-based rootzone (97% sand, 2% silt, 2% clay; 1.0% OM; initial pH = 6.5) constructed using USGA recommendations in 1999 (USGA Green Section Staff, 1993).

Six water soluble nitrogen (N) sources were evaluated as follows: ammonium nitrate (34-0-0); ammonium sulfate (21-0-0); urea (46-0-0); potassium nitrate (13.5-0-38); calcium nitrate (15.5-0-0); and 20-20-20 (PRO-SOL Ozark, AL, 3.90% ammonia N, 5.80% nitrate N, and 10.30% urea N). Nitrogen was applied at a rate of 7.3 kg N ha^{-1} (0.15 lb N/1000ft^2) on two week intervals to simulate a golf course fairway spoonfeeding program. The treatments were applied preventively (i.e., pre- plant infection) before symptoms were evident. The N sources were diluted in water and applied as described below for the fungicides.

For comparative purposes, chlorothalonil 6F (Daconil Weather Stik, Syngenta Crop Protection Inc., Greensboro, NC) was applied at the lowest label rate of 1.6 kg a.i. ha^{-1}(1.0 oz/1000ft^2) in 2008. In 2009, the rate was increased to 3.2 kg a.i. ha^{-1} (2.0 fl oz/1000 ft^2), but according to the label this is considered a low preventive rate for intensively mowed turf (Anonymous, 2010). A high preventive chlorothalonil rate (6.6 kg a.i. ha^{-1}; 4.0 fl. oz/1000ft^2) also was assessed alone in 2008 and 2009. The low chlorothalonil rate and N sources were applied alone or tank-mixed in 468 liters water ha^{-1} (50 GPA) using a CO_2 pressurized backpack sprayer (262 kPa; 35 psi) equipped with one TeeJet flat fan nozzle (Spraying Systems, Wheaton, IL). Approximately 30 minutes following application, and after chlorothalonil had dried on foliage, the site was irrigated with approximately 4mm to water-in the N sources. Treatments were applied every two weeks from 18 June to 13 August and from 28 May to 5 August in 2008 and 2009, respectively. The fungicides were applied in alternate weeks in 2010 as described below.

2008 and 2009 Sites

Study sites were mature fairway height stands of ‘Crenshaw’ (2008) and ‘Providence’ (2009) creeping bentgrass. These areas were mowed three times weekly to a height of 1.3 cm (0.5”) using a Jacobsen Greens King IV (Textron Inc., Providence, RI) triplex mower and clippings usually were removed. The sites were irrigated as needed to prevent wilt using an overhead irrigation system. The study areas received 100 kg N ha^{-1} from urea in the autumn prior to each summer. An additional 50 kg N ha^{-1} from urea was applied to each site between 1 and 10 April of each year prior to initiating treatments in late May or June.

2010 Sites

Data collected in 2008 and 2009 showed that none of the N sources improved chlorothalonil performance, but instead generally reduced its efficacy. Thus, in 2010, two penetrant fungicides and two N-sources were evaluated. The 2010 study was conducted on fairway and putting green height creeping bentgrass. The fairway height 'Crenshaw' was established in the previously described silt loam soil in September 2009 and was mowed three times weekly as described previously. The 'Providence' putting green was a mature stand and was mowed five times weekly to a height of 3.8mm (0.150") using a Jacobsen Greens King IV(Textron Inc., Providence, RI) and clippings were removed. Urea was applied to each study area in the autumn (100 kg N ha^{-1}) and in early April (50kg N ha^{-1}) prior to initiating the study as previously described. The two N-sources assessed in 2010 were ammonium sulfate and urea. The two penetrant fungicides evaluated were triticonazole 1.67 SC [(5*E*)-5-[(4-chlorophenyl)methylene]-2,2-dimethyl-1-(1*H*-1,2,4-triazol-1-ylmethyl)cyclopentanol, BASF Corp., Research Triangle Park, NC] and iprodione 2SC [3-(3,5-dichlorophenyl)-*N*-(1-methylethyl)-2, 4-dioxo-1-imidazolidinecarboxamide]. Triticonazole was applied at a rate of 0.3 kg a.i. ha^{-1} (0.5 fl. oz/1000ft^2), which was the lowest label use rate and was less than the recommended rate (0.6 to 1.2 kg a.i. ha^{-1}) for targeting dollar spot. Iprodione was applied at 1.5 kg a.i. ha^{-1}(2.0 fl. oz/1000ft^2), which was the low label rate for targeting dollar spot.

The N sources (7.3 kg N ha^{-1}) were applied on 14 day intervals beginning in late May after dollar spot had already become active (i.e., post plant infection). Due to foliar burning from ammonium sulfate, the N-sources and fungicides were applied separately in alternate weeks. Alternation allowed for the N sources to be watered-in immediately after applied and thus prevented foliar burning with ammonium sulfate. Fungicide applications were initiated 19 May for the 'Crenshaw' fairway followed in one week by application of the N-sources. Fungicide treatments were initiated in the 'Providence' green on 26 May followed by N sources one week later. Thus, treatments were applied weekly to both sites by alternating fungicides and N sources until 14 July. That is, N sources and fungicides were applied on a two week interval in alternate weeks. Sites were not irrigated within 24 hrs following fungicide application.

Disease developed naturally and uniformly in all sites and years and was assessed by counting the number of *S. homoeocarpa* infection centers (IC's) in each plot once weekly. Most golf course superintendent maintaining creeping bentgrass greens or fairways in the mid-Atlantic region would apply a fungicide as soon as trace levels of dollar spot (i.e., ≤ 3 IC's 2.25 m^{-2}) were discerned. As a reference point for discussion and not economic purposes, a 15 IC's $plot^{-1}$ (2.25 m^2) threshold was used. Plots also were evaluated for overall quality and color using a visual scale of 0 to 10 where 0 = brown or dead turf; 7 = minimum acceptable color or quality and 10 optimum green color and density. Color ratings were used as a means of assessing fertilizer burn or injury. All plots were 1.5m by 1.5m (5ft by 5ft) and were arranged in a randomized complete block design with four replications. In 2008 and 2009, there were two treatment factors: N source, having seven levels (six N sources and no N) and fungicide with two levels (with or without fungicide). This 7 x 2 factorial setting plus a treatment of the high chlorothalonil rate resulted in 15 treatment combinations. In 2010, there were three N levels (two N sources and no N) and three fungicide levels (two fungicides and no fungicide) or a 3 x 3 factorial. Data were analyzed using the SAS Mixed procedure. Main and interactive effects of N source and fungicide were examined first. Some pre-planned orthogonal contrasts were also tested (Steel and Torrie, 1980; Gomez and Gomez, 1984). Plots of residuals of infection center data displayed patterns of variance with treatment means that did not meet homogeneity of variance assumptions. Therefore, variances were not pooled and analysis of variance was performed using separate estimates of variance for fungicide level using REPEATED statements in the MIXED procedure. Area under the disease progress curve (AUDPC) data were calculated using the trapezoidal method (Campbell and Madden, 1990). Data were subjected to analysis of variance (ANOVA) and significantly different means were separated at $P \leq 0.05$ using Fisher's least significant difference test by the SAS MIXED procedure.

Results

2008

Neither the main effect for N sources nor N source x fungicide interaction ($P = 0.1188$) was significant (Table 1). Individual rating date and AUDPC data appear in Table 2. Pre-planned orthogonal contrasts are shown in Table 3.

Treatments were initiated on 18 June and dollar spot was first observed on 25 June (Table 2). The AUDPC data showed that ammonium sulfate was the only N source that reduced dollar spot over the study period, when compared to the unfertilized control (hereafter control). The AUDPC data also showed that plots treated with calcium nitrate + chlorothalonil had more disease than plots treated with the low rate of chlorothalonil alone. Ammonium nitrate and calcium nitrate applied alone did not reduce dollar spot severity on any rating date compared to the control. Ammonium sulfate (3, 9, and 30 July; and 6 and 19 August) reduced dollar spot on five dates. Potassium nitrate (9 July and 6 August), urea (9 July and 6 August) and 20-20-20 (30 July and 6 August) reduced dollar spot compared to the control on only two dates. There was a non-significant AUDPC trend for more dollar spot in plots treated with N + chlorothalonil versus the low chlorothalonil rate alone. There were, however, more IC's in plots treated with calcium nitrate + chlorothalonil versus the low chlorothalonil rate alone on 28 July and 6 and 19 August.

A threshold of 15 IC $plot^{-1}$ was chosen to discuss relative differences among treatments. All plots treated with an N source alone rapidly exceeded the threshold between 3 and 9 July (i.e., between the first and second application of treatments). Plots treated with the low chlorothalonil rate alone maintained control within the threshold until 30 July 9 (i.e., 21 days longer versus N alone). Plots treated with all N sources + chlorothalonil were within the threshold as late as 15 July and all were above the threshold by 28 July. Hence, while some N sources applied alone or tank mixed with the low chlorothalonil rate reduced dollar spot compared to the control on selected dates and over the season (i.e., AUDPC), none of the tank-mixes had provided increased longevity or level of control and thus provided no economic advantage in terms of dollar spot suppression. Conversely, the high rate of chlorothalonil provided effective dollar spot control ($\leq$ 2.5 IC $plot^{-1}$) for the entire study period.

One hypothesis was that inclusion of N with a low chlorothalonil rate would improve the level and/or length of dollar spot control. Except on 25 June, contrasts showed that the N sources collectively had reduced dollar spot compared to no N ($P \leq 0.10$; Table 3). Ammonium sulfate previously was shown to reduce the severity of several turf diseases, which has been attributed to its ability to rapidly acidify soil (Smiley et al., 2005). Thus, ammonium sulfate was a focus of the pre-planned contrasts. Ammonium sulfate reduced dollar spot more than any other N source on only one date (19 August; Table 3). Turf color ratings were used as a means of assessing potential fertilizer burn as well as the level of foliar greenness. Generally, ratings < 6.9 = objectionable and/or unacceptable color or injury; 7.0 = minimum acceptable color; 8= good summer color and 10 = optimum green color. Turf quality also was assessed. Turf quality ratings take into consideration turf color, density and the presence or absence of disease. Since the presence of dollar spot compromised the effects of fertilizer injury, the quality data are not shown or discussed, but can be found in Appendix II. Tables 1 and 2.

All plots exhibited good (>8.6) turf color one week (i.e., 25 June) after treatments were initiated (Table 4). One day following the second application, plots treated with ammonium sulfate were injured and exhibited reduced color (color 7.2 to 7.4) compared to the control (color 8.1), This injury dissipated in one week and all plots had color ratings equal to or better than the control on 9 July. On the day of the third application (i.e., 30 July), ammonium sulfate- treated plot exhibited severe injury (color 5.9 to 6.2) within hours. Similarly, plots treated with potassium nitrate and calcium nitrate exhibited reduced color (color 6.6 to 7.4) compared to the control

(8.3), but the level of discoloration was greater in ammonium sulfate-treated plots. Turf recovered one week later and all plots had color equivalent to or better than the control on 6 and 12 August. Within 24 hours of the fifth application (i.e., 14 August), plots treated with ammonium sulfate (color 5.4 to 5.5), potassium nitrate (6.5 to 7.1), and calcium nitrate (5.9 to 6.0) were injured and color ratings were lower than observed in the control (7.8). Ammonium sulfate generally caused more injury than either of the aforementioned nitrate N sources at this time. Five days later (i.e., 19 August), all plots were assigned color ratings equal to or better than the control. Due to high levels of dollar spot, color ratings were lower in all plots that did not receive chlorothalonil (treated with N alone and the control, when compared to plots treated with chlorothalonil. Data collected over the season (AUCC) showed that ammonium sulfate alone, ammonium sulfate + chlorothalonil and calcium nitrate alone had reduced color compared to the control. Ammonium nitrate alone, urea alone, urea + chlorothalonil, 20-20-20 + chlorothalonil and both the low and high rate of chlorothalonil had improved color compared to the control over the study period.

2009

Treatments were initiated 28 May and dollar spot was first evaluated on 23 June 2009. Because none of the N sources improved the performance of the lowest label rate of chlorothalonil (1.6 kg ha^{-1}) in 2008, the rate of chlorothalonil was increased to 3.2 kg a.i. ha^{-1} in 2009. The aforementioned amount is still considered a low rate of chlorothalonil (Anonymous, 2010). The AUDPC data showed that ammonium sulfate, urea, potassium nitrate and calcium nitrate reduced dollar spot severity over the season, when compared to the control (Table 5). Ammonium sulfate reduced dollar spot on three dates (17 July; and 3 and 14 August) compared to the control. Urea (14 August), potassium nitrate (17 July), and calcium nitrate (17 July) reduced dollar spot compared to the control on only one date.

The AUDPC data showed that plots treated with ammonium nitrate + chlorothalonil, ammonium sulfate + chlorothalonil, calcium nitrate + chlorothalonil, and 20-20-20 + chlorothalonil had higher levels of dollar spot than plots treated with low chlorothalonil rate alone (Table 5). On 23 July and 3 August, higher numbers of IC's were observed in plots treated with ammonium nitrate + chlorothalonil, ammonium sulfate + chlorothalonil, potassium nitrate + chlorothalonil, calcium nitrate + chlorothalonil compared to the low chlorothalonil rate alone. Urea + chlorothalonil and 20-20-20 + chlorothalonil treated plots had higher numbers of IC's versus the low chlorothalonil rate alone on 3 August.

The threshold (i.e., 15 IC's plot^{-1}) was exceeded in plots treated with each N source alone by 23 July (i.e., 56 days since the study was initiated and after four applications of all treatments) (Table 5). It was at this time that the dollar spot epidemic began to increase rapidly. For example, IC's increased in the control from 15.4 to 54.1 IC's plot^{-1} in the six day period between 17 to 23 July. Plots treated with the low chlorothalonil rate alone and all N sources + chlorothalonil (except urea) remained within the threshold for only one week longer (i.e., 3 August). As was observed in 2008, the high rate of chlorothalonil applied alone had provided excellent control between 23 June and 14 August and these plots remained within the threshold when last rated on 21 August (i.e., 12.2 IC's; 16 days since last applied). Hence, as was observed in 2008, the N sources reduced dollar spot, but did not improve the performance of the low chlorothalonil rate.

Orthogonal contrasts again showed that the N sources collectively had reduced dollar spot on most rating dates and over the season (i.e., AUDPC) (Table 6). However, when mixed with the low chlorothalonil rate, the N sources had reduced efficacy on 23 July ($P \leq 0.05$) and 3 August ($P \leq 0.001$) and over the season (AUDPC; $P \leq 0.01$). Ammonium sulfate provided better dollar spot control than the other N sources on 23 July ($P \leq 0.05$) and 29 July ($P \leq 0.10$) over the season ($P \leq 0.05$). Ammonium sulfate, however, also reduced efficacy when tank-mixed with the low chlorothalonil rate on 23 June ($P \leq 0.10$), and 23 July ($P \leq 0.05$) , 3 August ($P \leq 0.01$) and over the season ($P \leq 0.05$).

As was observed in 2008, ammonium nitrate (except 14 August), urea and 20-20-20 did not reduce color compared to the control on any rating date in 2009 (Table 7). While ammonium sulfate, and calcium and potassium nitrate caused foliar burn and reduced color, ammonium sulfate generally was more injurious than the aforementioned nitrate N sources. Within one or two hours of the first application (i.e., 28 May), significant foliar injury (color 6.4 to 6.9) was noted in ammonium sulfate-treated plots. While turf color of calcium and potassium nitrate-treated plots was similar to the control, plots sprayed with potassium nitrate alone had lower color ratings than plots sprayed with potassium nitrate + chlorothalonil on 15 June. Conversely on 15 June, plots treated with calcium nitrate + chlorothalonil had lower color ratings than plots treated with calcium nitrate alone. Four days following the third application (i.e., 29 June), ammonium sulfate-treated plots again were injured and were assigned lower color ratings (color 6.2 to 6.4) than the control (8.1). About one week later on 7 July, all plots had color equivalent to or better than the control. Lower color ratings compared to the control again were observed in ammonium sulfate-treated plots one day (10 July) following the fourth application. Ammonium sulfate-treated plots continued to exhibit unacceptable color (6.8 to 6.9) one week later on 17 July. At this time, plots treated with potassium nitrate (color 6.6) alone had lower and unacceptable color ratings, when compared to plots treated with potassium nitrate + chlorothalonil or calcium nitrate + chlorothalonil (7.4). Treatments again were applied on 23 July and on 25 July, ammonium sulfate (color 6.0) and calcium nitrate (6.4 to 6.8)-treated plots again exhibited low and unacceptable color, when compared to the control (7.2). The final application was made on 5 August and on 7 August plots treated with ammonium sulfate, potassium nitrate and calcium nitrate alone had lower color ratings (color 6.0 to 6.2) than the control (6.9). One week later on 21 August, all plots had color ratings equal or higher than the control. The seasonal AUCC ratings showed that ammonium sulfate, ammonium sulfate + chlorothalonil, potassium nitrate, and calcium nitrate had reduced color compared to the control. The AUCC data also showed that ammonium sulfate had been more injurious than calcium and potassium nitrate. All other treatments, except calcium nitrate + chlorothalonil, were associated with higher seasonal color ratings than the control. Highest or best color was exhibited by plots treated with the high rate of chlorothalonil.

2010

Dollar spot appeared earlier in 2010 than in either 2008 or 2009. The early and unexpected appearance of disease resulted in treatments not being initiated until dollar spot was active. There were two study sites: Crenshaw maintained as a fairway and Providence maintained as a green. The ANOVA showed that were no significant differences between N sources and there was no N source x fungicide interaction (Table 8).

In Crenshaw, there were no AUDPC differences between N sources and the control (Table 9). On 23 and 30 July, however, there were fewer IC's in ammonium sulfate versus urea-treated plots. There were no AUDPC differences among ammonium sulfate or urea + iprodione versus iprodione alone. Similarly, there were no AUDPC differences among ammonium sulfate or urea + triticonazole versus triticonazole alone. There was, however, a non-significant trend for more dollar spot in plots treated with ammonium sulfate + fungicide versus either fungicide applied alone. There were significant differences on individual rating dates. There were more IC's in plots treated with ammonium sulfate + iprodione versus iprodione alone on all five rating dates in June. There were more IC's in plots treated with ammonium sulfate + triticonazole versus triticonazole alone on 24 May, and 4, 11 and 24 June. On 4 and 18 June, there were more IC's in plots treated with urea + iprodione versus iprodione alone. Conversely, there were fewer IC's in plots treated with urea + triticonazole versus triticonazole alone on 23 and 30 July.

Contrasts for Crenshaw treatments are shown in Table 10. Ammonium sulfate reduced dollar spot on 30 June, and 23 and 30 July. Urea reduced dollar spot on 30

June ($P \leq 0.10$) and 9 July when compared to the control. Ammonium sulfate reduced the efficacy of iprodione on four out of nine rating dates and reduced triticonazole efficacy on four dates (24 May; 4, 11, 24 June when compared to the fungicide applied alone. Urea reduced the efficacy of iprodione on one out of nine rating dates (4, June) compared to iprodione alone. Conversely, urea + triticonazole reduced IC number versus triticonazole alone on two of three rating dates in July compared to triticonazole alone.

In Providence, there were no individual rating date or AUDPC differences among plots treated with either N source alone or the control (Table 11). Except on 9 July, there were no individual rating dates or AUDPC differences among plots treated with N + fungicide versus either fungicide alone. There was a non-significant trend for fewer IC's in plots treated with N + iprodione and urea + triticonazole. On 9 July, there were fewer IC's in plots treated with ammonium sulfate or urea + iprodione versus iprodione alone.

There were few contrast differences. In plots treated with ammonium sulfate + iprodione (30 July) and urea + iprodione (23 and 30 July) there were fewer IC's compared to plots treated with iprodione alone (Table 12). On 30 July, there were fewer IC's in plots treated with ammonium sulfate + triticonazole versus triticonazole alone.

As previously noted dollar spot was active when treatments were initiated in 2010. In Crenshaw, treatments were applied on 19 May and the threshold (15 IC's $plot^{-1}$) was exceeded six days later (i.e., 24 May) in all plots except those treated with iprodione (Table 9). In Providence, treatments were initiated on 26 May and the threshold (15 IC's) was exceeded in plots treated with ammonium sulfate, urea, and triticonazole alone, ammonium sulfate + triticonazole and urea + triticonazole as well as the control by 4 June and prior to the second application of treatments on 9 June (Table 11). At the rates evaluated, iprodione provided better dollar spot control than triticonazole on all rating dates in both Crenshaw and Providence (except 28 May).

Discussion

Previous studies have shown that applications of relatively high N rates (i.e., > 24 kg N ha^{-1}) reduce dollar spot severity in creeping bentgrass (Liu et al., 1995; Landschoot and McNitt, 1997; Davis and Dernoeden, 2002). This study was designed to determine if spoonfeeding low rates of N (7.3 kg N ha^{-1}) with water soluble N sources would reduce dollar spot severity. The N sources were applied alone or in combination with a low chlorothalonil rate in 2008 (1.6 kg a.i. ha^{-1}) and 2009 (3.2 kg a.i. ha^{-1}). It was hypothesized that spoonfeeding would reduce dollar spot severity and thus improve the longevity or level of dollar spot control provided by chlorothalonil. The research demonstrated that spoonfeeding with some N sources reduced dollar spot severity, but using N in combination with the low chlorothalonil rate generally reduced the level of dollar spot control provided by the fungicide. It is likely that N stimulated growth of leaves coated with the contact fungicide, which were more rapidly removed by mowing compared to turf in plots treated with chlorothalonil alone. Hence, the performance of the low chlorothalonil rate was more rapidly diminished by mowing off fungicide-coated leaves in N-treated plots.

As much as 35% of chlorothalonil can be displaced from bentgrass tissue when subjected to rain within an hour of application (Carroll et al., 2001). The fact that the site was irrigated within about 30 minutes after the N sources and fungicides had been applied probably was not a factor since irrigation would similarly have impacted disease levels in plots treated with chlorothalonil alone. The high chlorothalonil rate evaluated corresponded to the low post-plant infection rate or a high pre-plant infection rate and provided effective dollar spot control in 2008 and 2009 (Anonymous, 2010). Since the high chlorothalonil rate was effective there would be no advantage to mixing it with N. Indeed, future research should determine if spoonfeeding diminishes the effectiveness of higher rates of chlorothalonil.

Another hypothesis was that ammonium sulfate would provide better dollar spot control versus the other N sources evaluated. Ammonium sulfate was the only N source that reduced dollar spot severity over the season in 2008 and 2009. Conversely, ammonium nitrate and 20-20-20 were the only N sources that did not reduce dollar spot over the season in either year. Ammonium sulfate has been shown to suppress dead spot (*Ophiosphaerella agrostis* Dernoeden , Camara, O'Neil, van Berkum et Palm; spring dead spot (*Ophiosphaerella korrae* (J. Walker & A. M. Smith), take all (*Gaeumannomyces graminis* (Sacc.) Arx & D. Olivier var. *avenae* [E.M. Turner] Dennis) and yellow patch (*Rhizoctonia cerealis* Van der Hoeven) in turfgrasses (Dernoeden et al., 1991; Dernoeden, 1987; Hill et al., 1999; Kaminski and Dernoeden, 2005). The ability of ammonium sulfate to reduce the severity of the aforementioned diseases was linked to its ability to acidify soil rapidly. Soil pH was not monitored in this study, but it seems likely that soil acidification was a factor in the dollar spot suppression observed along with growth stimulation accorded by N. Since ammonium nitrate and 20-20-20 did not suppress dollar spot it would appear that factors other than stimulation of growth by N were involved in the disease suppression observed. Of the N sources studied, calcium and potassium nitrate are alkaline reacting; whereas, all other N sources would have acidified soil over time. Hence, factors other than growth stimulation by N or soil acidification may be responsible for some of the suppression documented. As previously noted, tissue N levels elevated above 5% were associated with less dollar spot in creeping bentgrass (Ellram et al. 2007). It is possible that creeping bentgrass plants may be able to more efficiently accumulate N in acidic soil. It also is conceivable that microbial interactions, as influenced by soil pH, may have played a role in the suppression observed. Future research similar to the current study should involve the measure of soil pH and tissue N levels.

The 2010 study was conducted to determine if the effectiveness of a penetrant fungicide would also be diminished by spoonfeeding. In the case of penetrants, some molecules enter plants and either become localized as in the case of iprodione or move acropetally as in the case of triticonazole (Smiley, et al. 2005). Hence, some molecules of a penetrant would be retained in tissues longer and be more protected from the elements longer than would a contact fungicide, even if leaves were removed by mowing periodically. As previously noted, there were no AUDPC differences among urea, ammonium sulfate and the control or among plots treated with N + fungicide versus either fungicide alone in 2010. There were, however, IC differences on some rating dates in Crenshaw, but not in Providence. On four or five out of nine rating dates in Crenshaw plots treated with ammonium sulfate + fungicide, there were more IC's compared to plot treated with either fungicide alone.

On two rating dates there were more IC's in Crenshaw plots treated with urea + iprodione versus iprodione alone. Conversely, there were two dates when there were fewer IC's in Crenshaw plots treated with urea + triticonazole versus triticonazole alone. Thus, except for urea + triticonazole in Crenshaw, it generally appeared that spoonfeeding reduced fungicide effectiveness. There were no dollar spot differences among plots treated with N + fungicide versus fungicide alone in Providence, but there was a trend for more dollar spot in plots treated with ammonium sulfate + triticonazole versus triticonazole alone. Unfortunately, the 2010 studies were initiated after dollar spot had become active and was rapidly increasing in severity. The low rate of N thus had no effect on the disease once dollar spot was active and on the increase. The curative activity of iprodione was significantly better than triticonazole at the rates evaluated. This was expected since the rate of triticonazole (0.3 kg a.i. ha^{-1}) evaluated was below the label use (0.6 to 1.2 kg a.i. ha^{-1}) for targeting dollar spot.

The N sources were mixed in water and sprayed onto the turf and were not watered-in for about 30 minutes so that the chlorothalonil had time to dry. Waiting for chlorothalonil to dry on leaves before watering-in some of the N sources was expected to cause some level of burning or injury. Color ratings were thus used as a measure of turf injury or foliar burning. Ammonium nitrate (except 14 August 2009), urea and 20-20-20 did not injure or reduce color compared to the control in 2008 or 2009. Ammonium sulfate was most injurious having reduced color ratings, often to below acceptable ($\geq$ 7.0) levels, on 10 of 21 rating dates and over the season (i.e., AUCC) in 2008 and 2009. Potassium nitrate and calcium nitrate also were injurious, but generally were not as injurious as ammonium sulfate. Ammonium sulfate typically elicited injury for 7 to 14 days, whereas, calcium and potassium nitrate usually reduced color for less than 7 days. . Injury in ammonium sulfate-treated plots initially appeared (i.e., within in 1 to 2 hrs) as a grayish-wilt and progressed to necrosis of leaves within 24 hrs. The injury in calcium and potassium nitrate-treated plots was mostly in the form of a tip burn and thus the reduction in color was short-lived and was removed within a few days by mowing.

Data suggested that tank-mixing chlorothalonil with calcium and potassium had safened the aforementioned nitrate sources. This is corroborated by generally higher color ratings in plots treated with calcium or potassium nitrate + chlorothalonil, when compared to nitrate N alone on several rating dates in 2009. Also in 2009, plots treated with potassium nitrate alone had lower color ratings over the season (AUCC), when compared to plots treated with potassium nitrate + chlorothalonil.

The discoloration or burning observed by some N sources likely was due mostly to a salt effect. Water soluble N sources increase the concentration of salt in a solution. The salt index is used as a measure of salt concentration or osmotic pressure of a solution. Salt index is based on equal amounts of plant nutrients; the higher the number the greater the burn potential of a fertilizer (Carrow et al., 2001). Salt indexes based on N applied for the N-sources are as follows: ammonium sulfate (index = 3.25) has a higher salt index than ammonium nitrate (index = 2.99), urea (index = 1.62) , potassium nitrate (index = 1.58) and calcium nitrate (index = 4.19) (Carrow et al., 2001). The 20-20-20 fertilizer contained a roughly equal concentration of N (about 10% each) from ammonium nitrate and urea and thus would have a relatively low salt index. It is interesting to note that while potassium nitrate has a lower salt index than calcium nitrate, both nitrate N sources generally elicited similar levels of foliar injury. Similarly, calcium nitrate has a higher salt index than ammonium sulfate, but the latter N source was more injurious than either calcium or potassium nitrate. Finally, no burning was observed with ammonium nitrate yet it has a higher salt index than potassium nitrate and a similar index compared to ammonium sulfate. Therefore, factors other than salt index contributed to the foliar injury observed. In the case of ammonium sulfate, acidity may have been a factor. Except for 20-20-20 (ammonium nitrate + urea), those N sources causing turf burning contained $\leq$ 21 % N; whereas , ammonium nitrate (34%) and urea (46%N) contain higher N percentages. Thus, greater amounts of ammonium sulfate, potassium nitrate, and calcium nitrate were mixed L^{-1}, which could have resulted in a more salty solution, compared to ammonium nitrate or urea solutions. However, when the aforementioned fertilizers were mixed in water as used in the study and tested for electrical conductivity, no large differences were discerned. Hence, it was not determined precisely why some of the N sources caused injury, based on salt index. The exact nature of the burn elicited, especially for potassium nitrate, is unknown. Because the N sources were applied in alternate weeks and watered in immediately, no burning or discoloration was associated with either ammonium sulfate or urea in 2010.

Many golf course superintendents in the mid-Atlantic region apply low label rates of fungicides in early summer to control dollar spot. These low rates performed well as long as dollar spot pressure was low. However, once dollar spot began to increase to increase in severity the low chlorothalonil rates became ineffective in about a week. In numerical terms, once dollar spot increased from about 15 to 50 IC's in control plots in a one week period, plots treated with the low chlorothalonil rate went from having about ≤ 15 IC's to > 35 IC about one week later. In these studies, fungicide rates were not adjusted upwards appropriately to meet the increasing levels of disease severity. In reality, most golf course superintendents would have increased fungicide rate at the time even trace levels of dollar spot became evident.

Despite the negative effect of spoonfeeding on the performance of low chlorothalonil rates under increasing disease pressure, it remains agronomically wise to continue to spoonfeed. Spoonfeeding enhances turf vigor and recovery from environmental stress and mechanical injury. This study did not address the impact of spoonfeeding on the performance of higher preventive or curative fungicide rates. Thus, future research should evaluate spoonfeeding in concert with initially higher pre-plant infection rates and adapt study parameters by increasing fungicide rate as needed to meet changing levels in disease severity. Future research involving ammonium sulfate, calcium nitrate and potassium nitrate should consider watering them into the turf immediately after application and applying the fungicide in the alternate week or next day. Alternating treatment weeks would allow N sources to be watered-in thus avoiding burn potential, while eliminating potential wash-off losses of fungicide (s).

Table 1. Analysis of variance of area under the disease progress curve (AUDPC) data from 2008 and 2009. The AUDPC values were based on the number of *S. homoeocarpa* infection centers plot^{-1}.

		2008 'Crenshaw'	2009 'Providence'
Source of Variation[y]	df	*P* > F	*P* > F
Nitrogen source	6	0.4754	0.1877
Fungicide	2	<0.0001	<0.0001
Nitrogen source x fungicide	6	0.1188	0.0010
Contrast[z]			
No N vs. all N sources	1	0.0188	0.0048
All N sources + chlorothalonil vs. chlorothalonil only	1	0.3216	0.0037
Ammonium sulfate vs. all other N sources	1	0.1447	0.0495
Ammonium sulfate + chlorothalonil vs. chlorothalonil only	1	0.2153	0.0226

[y]Main effect values of the factorial analysis.

[z] Pre-planned orthogonal contrasts of N source and the low rate of chlorothalonil (1.6 kg a.i./ha).

Table 2. *Sclerotinia homoeocarpa* infection centers as influenced by six nitrogen sources and chlorothalonil in 'Crenshaw' creeping bentgrass between 25 June and 30 July, 2008.

	Infection centers (no. plot^{-1})					
Treatment[w]	25 June	3 July	9 July	15 July	28 July	30 July
Ammonium nitrate	0.5a[z]	4.2ab	41.5ab	39.5a	63.5a	61.2ab
Ammonium nitrate + chlorothalonil[x]	0.0a	0.0b	0.0c	3.8bc	25.2cde	24.8de
Ammonium sulfate	0.0a	0.8b	23.2b	26.5a	43.0abc	41.2bcd
Ammonium sulfate + chlorothalonil[x]	0.0a	0.0b	1.8c	7.8b	24.5cde	26.2de
Urea	1.2a	4.2ab	23.2b	29.0a	52.0a	46.8abc
Urea + chlorothalonil[x]	1.2a	0.0b	0.5c	1.0bc	23.5de	22.2ef
Potassium nitrate	0.0a	5.8ab	25.0b	28.2a	50.2ab	54.8abc
Potassium nitrate + chlorothalonil[x]	0.0a	0.0b	0.0c	1.5bc	18.0de	21.2ef
Calcium nitrate	0.0a	7.5ab	29.8ab	29.2a	49.0ab	48.2abc
Calcium nitrate + chlorothalonil[x]	0.0a	1.0b	1.2c	7.8b	31.8bcd	24.8de
20-20-20	0.5a	7.8ab	31.0ab	30.0a	45.2ab	39.2cd
20-20-20+chlorothalonil[x]	0.0a	0.8b	0.0c	2.8bc	16.5ef	10.0fg
Low rate chlorothalonil[x]	0.2a	0.0b	0.0c	2.0bc	12.8ef	15.5ef
High rate chlorothalonil[y]	0.0a	0.0b	0.0c	0.0c	2.5f	1.5g
Untreated	1.0a	12.5a	48.8a	46.1a	65.2a	65.4a

[w] Treatments were applied 18 June; 2, 16 and 30 July; and 13 August, 2008.

[x]The low rate of chlorothalonil was 1.6 kg a.i. ha^{-1} (1.0 fl oz/1000ft^2).

[y]The high rate of chlorothalonil was applied at 6.4 kg a.i. ha^{-1} (4.0 fl oz/1000ft^2).

[z] Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test, $P \leq 0.05$.

Table 2 (cont). *Sclerotinia homoeocarpa* infection centers and area under the disease progress curve (AUDPC) values as influenced by six nitrogen sources and chlorothalonil in 'Crenshaw' creeping bentgrass between 6 and 29 August, 2008.

	Infection centers (no. plot^{-1})					AUDPC
Treatment[w]	6 Aug.	12 Aug.	14 Aug.	19 Aug.	29 Aug.	disease x time
Ammonium nitrate	76.2ab	97.0a	73.0a	105.2ab	105.2a	3863ab
Ammonium nitrate + chlorothalonil[x]	22.2de	42.8c	26.8b	12.0d	40.0c	1036cd
Ammonium sulfate	61.2b	85.8ab	57.5a	75.8b	78.2ab	2806b
Ammonium sulfate + chlorothalonil[x]	28.8cd	50.0c	32.0b	15.8cd	49.0bc	1248cd
Urea	69.5b	98.0a	68.0a	112.2ab	91.5a	3431ab
Urea + chlorothalonil[x]	23.2de	42.0c	28.5b	15.0cd	40.0c	1025cd
Potassium nitrate	68.0b	95.0a	62.5a	94.8ab	77.2a	3307ab
Potassium nitrate + chlorothalonil[x]	25.5cde	40.5c	24.5b	16.5cd	42.5c	997cd
Calcium nitrate	77.2ab	90.5a	65.0a	83.0ab	91.2a	3264ab
Calcium nitrate + chlorothalonil[x]	35.8c	53.0bc	33.5b	23.5c	48.2bc	1417c
20-20-20	60.5b	89.2a	56.0a	82.8ab	100.0a	3110ab
20-20-20+chlorothalonil[x]	23.0de	37.2c	20.5b	13.8cd	38.2c	867d
Low rate chlorothalonil[x]	16.2e	36.8c	30.5b	13.0d	44.5bc	865d
High rate chlorothalonil[y]	0.2f	2.2d	0.8c	0.2e	1.8d	49e
Untreated	97.2a	115.0a	80.5a	124.0a	118.0a	4457a

[w]Treatments were applied 18 June; 2, 16 and 30 July; and 13 August, 2008.

[x]The low rate of chlorothalonil was 1.6 kg a.i. ha^{-1} (1.0 fl oz/1000ft^2).

[y]The high rate of chlorothalonil was 6.4 kg a.i. ha^{-1} (4.0 fl oz/1000ft^2).

[z] Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test, $P \leq 0.05$.

Table 3. Pre-planned orthogonal contrasts among nitrogen sources and the low chlorothalonil rate (1.6 kg a.i./ha) treatments and their effect on the number of *S. homoeocarpa* infection centers in 'Crenshaw' creeping bentgrass, 2008.

	No N vs. all N sources			All N sources + chlorothalonil vs. chlorothalonil only			Ammonium sulfate vs. all other N sources			Ammonium sulfate + chlorothalonil vs. chlorothalonil only		
Date[z]	No N	All N	P-value	All N sources + chlorothalonil	Chlorothalonil only	P-value	Ammonium sulfate	All other N sources	P-value	Ammonium sulfate + chlorothalonil	Chlorothalonil only	P-value
AUDPC	4457	3297	0.0188	1098	865	0.3216	2806	3395	0.1447	1248	865	0.2153
25 June	1.0	0.4	0.1349	0.2	0.2	0.4705	0.0	0.4	0.2159	0.0	0.2	0.3672
3 July	12.5	5.0	0.0293	0.3	0.0	0.9399	0.8	5.9	0.0966	0.0	0.0	1.0000
9 July	48.8	29.0	0.0034	0.6	0.0	0.9336	23.2	30.1	0.1686	1.8	0.0	0.8486
15 July	46.1	30.4	0.0070	4.1	2.0	0.7359	26.5	31.2	0.2271	7.8	2.0	0.4780
28 July	65.2	50.5	0.0691	23.2	12.8	0.1292	43.0	52.0	0.1843	24.5	12.8	0.1932
30 July	65.4	48.6	0.0298	21.5	15.5	0.3875	41.2	50.0	0.1616	26.2	15.5	0.2419
6Aug.	95.9	68.8	0.0025	26.4	16.2	0.1677	61.2	70.3	0.1124	28.8	16.2	0.1946
12 Aug.	114.5	92.6	0.0832	44.3	36.8	0.3444	85.8	94.0	0.3032	50.0	36.8	0.2088
14 Aug.	79.5	63.7	0.0601	27.6	30.5	0.2878	57.5	64.9	0.2346	32.0	30.5	0.8232
19 Aug.	119.9	92.3	0.0046	16.1	13.0	0.7592	75.8	95.6	0.0299	15.8	13.0	0.8367
29 Aug.	118.5	93.5	0.0586	43.0	44.5	0.4428	78.2	96.6	0.1275	49.0	44.5	0.7418

[z] Treatments were applied on 18 June; 2, 16 and 30 July; and 13 August, 2008.

Table. 4 'Crenshaw' creeping bentgrass color and area under the color curve (AUCC) as influenced by six N sources and chlorothalonil, 2008.

	Color ratings (0-10 scale; 10=best)										AUCC
Treatment[w]	25 June	3 July	9 July	15 July	30 July	6 Aug	12 Aug.	14 Aug.	19 Aug.	29 Aug.	(color x time)
Ammonium nitrate	8.9ab[z]	7.6bcd	8.2de	8.6bc	7.6de	8.5bcd	8.2bc	7.2e	8.1def	6.6d	520fg
Ammonium nitrate + chlorothalonil[x]	8.8ab	8.0bc	8.8abc	8.8abc	7.9cd	8.8ab	8.5b	8.0cd	8.6abc	8.2ab	547c
Ammonium sulfate	8.6b	7.4d	8.1e	8.5c	6.2ij	8.2def	8.2bc	5.4i	7.6g	7.0cd	491h
Ammonium sulfate + chlorothalonil[x]	8.6b	7.2d	8.1e	8.5c	5.9j	8.4cde	8.4bc	5.5hi	8.0efg	7.9bc	494h
Urea	9.0a	8.8a	8.9ab	8.5c	8.4b	8.5bcd	8.1c	8.1bcd	8.2cde	6.5d	542cd
Urea + chlorothalonil[x]	9.0a	9.0a	8.9ab	8.9ab	8.5b	8.8ab	8.5b	8.5b	8.8ab	8.2ab	566b
Potassium nitrate	8.9ab	8.0bc	8.4cde	8.8abc	7.1fg	8.0f	8.1c	6.5f	8.1def	6.9cd	515g
Potassium nitrate + chlorothalonil[x]	9.0a	8.1b	8.8abc	8.9ab	7.4ef	8.5bcd	8.5b	7.1e	8.5bcd	8.2ab	539cde
Calcium nitrate	8.9ab	7.6bcd	8.2de	8.6bc	6.6hi	8.1ef	8.4bc	5.9gh	7.8fg	6.8d	501h
Calcium nitrate + chlorothalonil[x]	8.8ab	7.5cd	8.5b-e	8.8abc	6.9gh	8.6bc	8.4bc	6.0g	8.1def	7.9bc	517g
20-20-20	8.9ab	8.9a	8.6a-d	8.6bc	7.9cd	8.2def	8.5b	7.8d	7.8fg	6.8d	533def
20-20-20 + chlorothalonil[x]	9.0a	8.8a	8.9ab	9.0a	8.2bc	9.0a	8.5b	8.5b	8.8ab	8.1ab	564b
Low rate chlorothalonil[x]	8.8ab	8.8a	8.5b-e	8.5c	8.2bc	8.5bcd	8.5b	8.4bc	8.5bcd	8.2ab	551c
High rate chlorothalonil[y]	8.9ab	9.0a	9.0a	8.9ab	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	583a
Untreated	8.8ab	8.1b	8.4cde	8.4c	8.3bc	8.1ef	8.1c	7.8d	7.9efg	6.2d	526efg

[w]Treatments were applied 18 June; 2, 16 and 30 July; and 13 August, 2008.

[x]The low rate of chlorothalonil was 1.6 kg a.i. ha^{-1} (1.0 fl oz/1000ft^2).

[y]The high rate of chlorothalonil was 6.4 kg a.i. ha^{-1} (4.0 fl oz/1000ft^2).

[z]Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test, $P \leq 0.05$.

Table 5. *Sclerotinia homoeocarpa* infection centers and area under the disease progress curve (AUDPC) as influenced by six nitrogen sources and chlorothalonil in 'Providence' creeping bentgrass between 23 June and 21 August, 2009.

	Infection centers (no. $plot^{-1}$)								AUDPC
Treatment[w]	23 June	29 June	7 July	17 July	23 July	3 Aug.	14 Aug.	21 Aug.	(disease x time)
Ammonium nitrate	5.2abc[z]	11.0a	14.0ab	11.0abc	53.5a	65.5abc	52.8ab	46.8a-e	2120ab
Ammonium nitrate + chlorothalonil[x]	2.0bcd	0.8b	0.0d	0.0d	16.5c	62.8abc	56.2ab	62.5a	1567de
Ammonium sulfate	4.0a-d	7.8a	13.2ab	8.5bc	41.0a	58.8bcd	43.2b	23.5fg	1720bcd
Ammonium sulfate + chlorothalonil[x]	5.0abc	2.0b	2.0c	0.0d	18.5c	54.2cd	55.2ab	48.2a-d	1467de
Urea	3.0a-d	11.0a	10.2b	9.5abc	48.2a	69.2ab	46.8b	26.5efg	1940bc
Urea + chlorothalonil[x]	1.8bcd	0.2b	0.0d	0.5d	12.2cd	54.2cd	47.0b	43.2a-f	1286ef
Potassium nitrate	4.5a-d	9.2a	13.0ab	8.2bc	48.5a	65.8abc	48.8ab	33.2c-g	1952bc
Potassium nitrate + chlorothalonil[x]	5.0abc	0.5b	0.2d	0.0d	15.0c	51.2d	53.8ab	38.5b-f	1330ef
Calcium nitrate	6.2ab	10.5a	15.2ab	6.5c	43.5a	60.0a-d	60.8ab	27.5d-g	1954bc
Calcium nitrate + chlorothalonil[x]	4.8abc	1.8b	1.0cd	0.2d	26.0b	66.0ab	58.5ab	51.2abc	1690cd
20-20-20	5.8ab	13.2a	19.5a	14.5ab	51.5a	69.2ab	49.0ab	35.2c-f	2165ab
20-20-20+chlorothalonil[x]	3.2a-d	1.8b	0.2d	0.0d	14.2cd	63.2abc	47.8b	48.2a-d	1440de
Low rate chlorothalonil[x]	1.0cd	0.2b	0.0d	0.0d	8.2d	38.5e	43.5b	58.2ab	1094f
High rate chlorothalonil[y]	0.5d	0.0b	0.0d	0.0d	0.0e	1.8f	0.5c	12.2g	68g
Untreated	7.5a	14.4a	15.9ab	15.4a	54.1a	75.4a	69.5a	44.4a-f	2460a

[w]Treatments were applied 28 May; 11 and 25 June; 9 and 23 July; and 5 August, 2009.

[x]The low rate of chlorothalonil was applied at 3.2 kg a.i. ha^{-1} (2.0 fl $oz/1000ft^2$).

[y]The high rate of chlorothalonil was applied at 6.4 kg a.i. ha^{-1} (4.0 fl $oz/1000ft^2$).

[z] Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test, $P \leq 0.05$.

Table 6. Pre-planned orthogonal contrasts among nitrogen sources and the low chlorothalonil rate (3.2 kg a.i./ha) treatments and their effect on the number of *S. homoeocarpa* infection centers in 'Providence' creeping bentgrass, 2009.

	No N vs. all N sources			All N sources + chlorothalonil vs. chlorothalonil only			Ammonium sulfate vs. all other N sources			Ammonium sulfate + chlorothalonil vs. chlorothalonil only		
Date[z]	No N	All N	P-value	All N sources + chlorothalonil	Chlorothalonil only	P-value	Ammonium sulfate	All other N sources	P-value	Ammonium sulfate + chlorothalonil	Chlorothalonil only	P-value
AUDPC	2460	1975	0.0049	1463	1094	0.0037	1720	2026	0.0495	1467	1094	0.0226
23 Jun	7.8	4.8	0.0670	3.6	1.0	0.1279	4.0	5.0	0.3156	5.0	1.0	0.0778
29 Jun	14.4	10.4	0.0266	1.2	0.2	0.6442	7.8	11.0	0.0556	2.0	0.2	0.5013
7 Jul	15.9	14.2	0.2120	0.6	0.0	0.7790	13.2	14.4	0.2929	2.0	0.0	0.4635
17 Jul	15.4	9.7	0.0006	0.1	0.0	0.9395	8.5	10.0	0.1935	0.0	0.0	1.0000
23 Jul	54.1	47.7	0.0458	17.1	8.2	0.0219	41.0	49.0	0.0192	18.5	8.2	0.0410
3 Aug	75.4	64.8	0.0498	58.6	38.5	<.0001	58.8	66.0	0.1336	54.2	38.5	0.0066
14 Aug	69.5	50.2	0.0190	53.1	43.5	0.2075	43.2	51.6	0.1832	55.2	43.5	0.2373
21 Aug	44.4	32.1	0.0786	48.7	58.2	0.3004	23.5	33.8	0.1185	48.2	58.2	0.4081

[z] Treatments were applied 28 May; 11 and 25 June; 9 and 23 July; and 5 August, 2009.

Table. 7 'Providence' creeping bentgrass color and area under the color curve (AUCC) as influenced by six N sources and chlorothalonil , 2009.

Treatment[x]	Color ratings (0-10 scale; 10=best)											AUCC
	28 May	15 June	23 June	29 June	7 July	10 July	17 July	25 July	7 Aug.	14 Aug.	21 Aug.	(color x time)
Ammonium nitrate	8.4abc[z]	8.2bcd	7.9de	8.1cd	8.1ab	8.1bc	8.0bc	8.1bc	6.4ef	6.2j	6.9fgh	657e
Ammonium nitrate + chlorothalonil[x]	8.1bc	8.5abc	8.4abc	8.5abc	8.1ab	8.2abc	8.4ab	8.4abc	7.2c	7.5de	8.0bcd	691c
Ammonium sulfate	6.9d	6.4f	7.9de	6.2f	8.0b	6.1e	6.8f	6.0g	6.2f	6.9gh	7.1fg	567i
Ammonium sulfate + chlorothalonil[x]	6.4d	6.6f	7.8e	6.4f	8.0b	6.2e	6.9ef	6.0g	6.4ef	7.0fg	7.2ef	570i
Urea	8.4abc	8.0de	8.4abc	8.2bcd	8.0b	8.1bc	7.9c	8.1bc	6.9cd	7.5de	7.9cd	674d
Urea+ chlorothalonil[x]	8.2abc	8.6ab	8.6ab	8.5abc	8.4a	8.4abc	8.4ab	8.2bc	7.9b	8.1c	8.2bc	708b
Potassium nitrate	8.1bc	7.6e	8.1cde	7.9de	8.0b	7.4d	6.6f	7.0de	6.0f	6.4ij	6.6h	616h
Potassium nitrate + chlorothalonil[x]	8.2abc	8.1cd	8.2bce	8.1cd	8.0b	7.4d	7.4d	7.2d	7.2c	7.6d	7.6de	659e
Calcium nitrate	8.0c	8.1cd	8.1cde	7.6de	8.0b	7.9cd	6.9ef	6.8ef	6.2f	6.6hi	6.8gh	626gh
Calcium nitrate + chlorothalonil[x]	8.4abc	7.6e	8.4abc	8.1cd	8.1ab	7.9cd	7.4d	6.4fg	6.8de	6.8gh	6.9fgh	635fg
20-20-20	8.5abc	7.9de	8.2bcd	8.2bcd	8.0b	8.4abc	8.4ab	8.0c	6.8de	7.2ef	7.1fg	670de
20-20-20 + chlorothalonil[x]	8.5abc	8.5abc	8.4abc	8.5abc	8.0b	8.5ab	8.5a	8.1bc	7.8b	8.1c	8.2bc	704bc
Low rate chlorothalonil[x]	8.6ab	8.5abc	8.6ab	8.6ab	8.0b	8.4abc	8.2abc	8.5ab	8.1b	8.5b	8.4ab	716b
High rate chlorothalonil[y]	8.8a	8.8a	8.8a	8.9a	8.1ab	8.8a	8.5a	8.8a	9.1a	8.9a	8.8a	744a
Untreated	8.2bc	8.1cde	7.8e	8.1cd	8.0b	7.4d	7.2de	7.2d	6.8cde	6.9fgh	7.0fgh	641f

[w]Treatments were applied 28 May; 11 and 25 June; 9 and 23 July; and 5 August, 2009.

[x]The low rate of chlorothalonil was 3.2 kg a.i. ha^{-1} (2.0 fl oz/1000ft^2).

[y]The high rate of chlorothalonil was 6.4 kg a.i. ha^{-1} (4.0 fl oz/1000ft^2).

[z]Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test, $P \leq 0.05$.

Table 8. Analysis of variance of area under the disease progress curve (AUDPC) data from 2010. The AUDPC values were based on the number of *S. homoeocarpa* infection centers plot^{-1}.

		'Crenshaw'	'Providence'
Source of Variation[y]	df	*P* > F	*P* > F
Nitrogen (N) source	2	0.4093	0.1017
Fungicide	2	<0.0001	<0.0001
N source x fungicide	4	0.2544	0.5688
Contrast[z]			
Ammonium sulfate vs. no N	1	0.1903	0.7202
Urea vs. no N	1	0.1785	0.1506
Ammonium sulfate + iprodione vs. iprodione alone	1	0.0061	0.1838
Urea +iprodione vs. iprodione alone	1	0.0643	0.1502
Ammonium sulfate + triticonazole vs. triticonazole alone	1	0.1248	0.1988
Urea + triticonazole vs. triticonazole alone	1	0.8483	0.3305

[y]Main effect values of the factorial analysis.

[z] Pre-planned orthogonal contrasts of N source and fungicide.

Table 9. *Sclerotinia homoeocarpa* infection centers as influenced by two nitrogen sources and two fungicides in 'Crenshaw' creeping bentgrass between 24 May and 30 July, 2010.

	Infection centers plot^{-1}									AUDPC
Treatment[w]	24 May	4 June	11 June	18 June	24 June	30 June	9 July	23 July	30 July	(disease x time)
Urea 46-0-0	28.0a	43.3a	60.3a	77.5a	75.0a	90.3a	74.5a	77.5a	94.3a	4596a
Ammonium sulfate	28.0a	41.8ab	62.5a	75.0a	90.0a	89.8a	85.5a	64.0b	82.3b	4611a
Iprodione[x]	3.0c	5.3e	1.3e	7.0d	1.8e	0.5d	1.8d	4.5e	3.0e	210c
Triticonazole[y]	12.3b	26.5c	19.8c	36.3b	31.3c	36.8b	32.0bc	29.5c	34.5c	1941b
Urea + iprodione	4.5c	15.8d	2.5de	13.5c	3.0e	1.0cd	1.0d	1.5e	1.5e	330c
Urea + triticonazole	15.0b	30.5bc	24.3bc	43.3b	35.8bc	39.0b	26.3c	19.5d	21.8d	1898b
Ammonium sulfate + iprodione	5.0c	16.0d	4.5c	12.3c	9.5d	2.3c	1.8d	3.0e	1.3e	413c
Ammonium sulfate + triticonazole	22.5a	36.0ab	29.8b	42.5b	41.8b	43.5b	41.0b	24.3cd	23.5cd	2317b
Untreated	27.9a	41.5ab	63.6a	79.8a	84.4a	104.1a	84.6a	77.0a	95.3a	4893a

[w]Fungicides were applied on 19 May; 2, 16 and 30 June; and 14 July, 2010. N sources were applied 26 May; 9 and 23 June; and 7 and 21 July, 2010.

[x]The rate of iprodione was 1.5 kg a.i. ha^{-1}.

[y]The rate of triticonazole was 0.3 kg a.i. ha^{-1}.

[z]Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test, $P \leq 0.05$.

Table 10. Pre-planned orthogonal contrasts among nitrogen sources and two fungicide treatments and their effect on the number of *S. homoeocarpa* infection centers in 'Crenshaw' creeping bentgrass, 2010.

	Ammonium sulfate vs. No N			**Urea vs. No N**			**Ammonium sulfate + iprodione vs. iprodione**			**Urea + iprodione vs. iprodione**			**Ammonium sulfate + triticonazole vs. triticonazole**			**Urea + triticonazole vs. triticonazole**		
Date	Ammonium sulfate	No N	P-value	Urea	No N	P-value	Ammonium sulfate + iprodione	Iprodione	P-value	Urea + iprodione	Iprodione	P-value	Ammonium sulfate + triticonazole	Triticonazole	P-value	Urea + triticonazole	Triticonazole	P-value
AUDPC	4611	4893	0.1903	4596	4893	0.1785	412	210	0.0061	330	210	0.0643	2317	1941	0.1248	1898	1941	0.4242
24 May	28.0	27.9	0.9770	28.0	27.9	0.9770	5.0	3.0	0.2073	4.5	3.0	0.3348	22.5	12.2	0.0142	15.0	12.2	0.4370
4 June	41.8	41.5	0.9736	43.3	41.5	0.8168	16.0	5.2	0.0038	15.8	5.2	0.0044	36.0	26.5	0.0182	30.5	26.5	0.2563
11 June	62.5	63.6	0.4568	60.3	63.6	0.3727	4.5	1.2	0.0179	2.5	1.2	0.2950	29.8	19.8	0.0368	24.2	19.8	0.2991
18 June	75.0	79.8	0.2377	77.5	79.8	0.3662	12.2	7.0	0.1060	13.5	7.0	0.0532	42.5	36.2	0.1857	43.2	36.2	0.1430
24 June	90.0	84.4	0.5119	75.0	84.4	0.1422	9.5	1.8	0.0005	3.0	1.8	0.4105	41.8	31.2	0.0280	35.8	31.2	0.2915
30 June	89.8	104.1	0.0498	90.3	104.1	0.0551	2.2	0.5	0.0257	1.0	0.5	0.4656	43.5	36.8	0.1818	39.0	36.8	0.6411
9 July	85.5	84.6	0.8725	74.5	84.6	0.0442	1.8	1.8	1.0000	1.0	1.8	0.1040	41.0	32.0	0.1123	26.2	32.0	0.1450
23 July	64.0	77.0	<.0001	77.5	77.0	0.8035	3.0	4.5	0.1517	1.5	4.5	0.0285	24.2	29.5	0.1219	19.5	29.5	0.0208
30 July	82.2	95.2	0.0022	94.3	95.2	0.3891	1.2	3.0	0.0293	1.5	3.0	0.0482	23.5	34.5	0.0311	21.8	34.5	0.0179

[z] Fungicides were applied on 19 May; 2, 16 and 30 June and 14 July, 2010. N sources were applied 26 May; 9 and 23 June; and 7 and 21 July, 2010.

Table 11. *Sclerotinia homoeocarpa* infection centers as influenced by two nitrogen sources and two fungicides in 'Providence' creeping bentgrass between 28 May and 28 July, 2010.

	Infection centers plot^{-1}								AUDPC
Treatment[w]	28 May	4 June	14 June	24 June	1 July	9 July	23 July	28 July	(disease x time)
Urea 46-0-0	12.8a[z]	26.5a	43.5abc	57.5ab	67.8a	66.5a	75.3a	100.8a	3400a
Ammonium sulfate 21-0-0	12.0a	30.5a	51.0ab	70.8a	78.8a	77.5a	97.0a	120.0a	4077a
Iprodione[x]	9.8a	5.8c	15.3d	17.5c	10.3c	10.5c	9.8d	25.8d	734c
Triticonazole[y]	14.3a	22.8a	31.5bc	38.8b	31.0b	34.5b	43.0bc	59.0bc	2056b
Urea + iprodione	9.3a	5.0c	13.3d	14.0c	6.5c	5.3d	9.5d	22.0d	578c
Urea + triticonazole	11.5a	18.8ab	29.3c	39.3b	25.8b	35.5b	38.5c	57.0c	1918b
Ammonium sulfate + iprodione	13.3a	8.3bc	13.3d	14.3c	5.5c	3.3d	9.3d	25.8d	599c
Ammonium sulfate + triticonazole	13.5a	25.3a	39.3abc	46.3b	36.0b	42.0b	53.3b	77.0b	2478b
Untreated	10.8a	23.3a	52.0a	71.4a	86.8a	76.1a	83.6a	104.9a	3907a

[w]Fungicides were applied on 26 May; 9 and 23 June; and 7 and 21 July, 2010. N sources were applied on 2, 16 and 30 June; and 14 July, 2010.

[x]The rate of iprodione was 1.5 kg a.i. ha^{-1}.

[y]The rate of triticonazole was 0.3 kg a.i. ha^{-1}.

[z]Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test, $P \leq 0.05$.

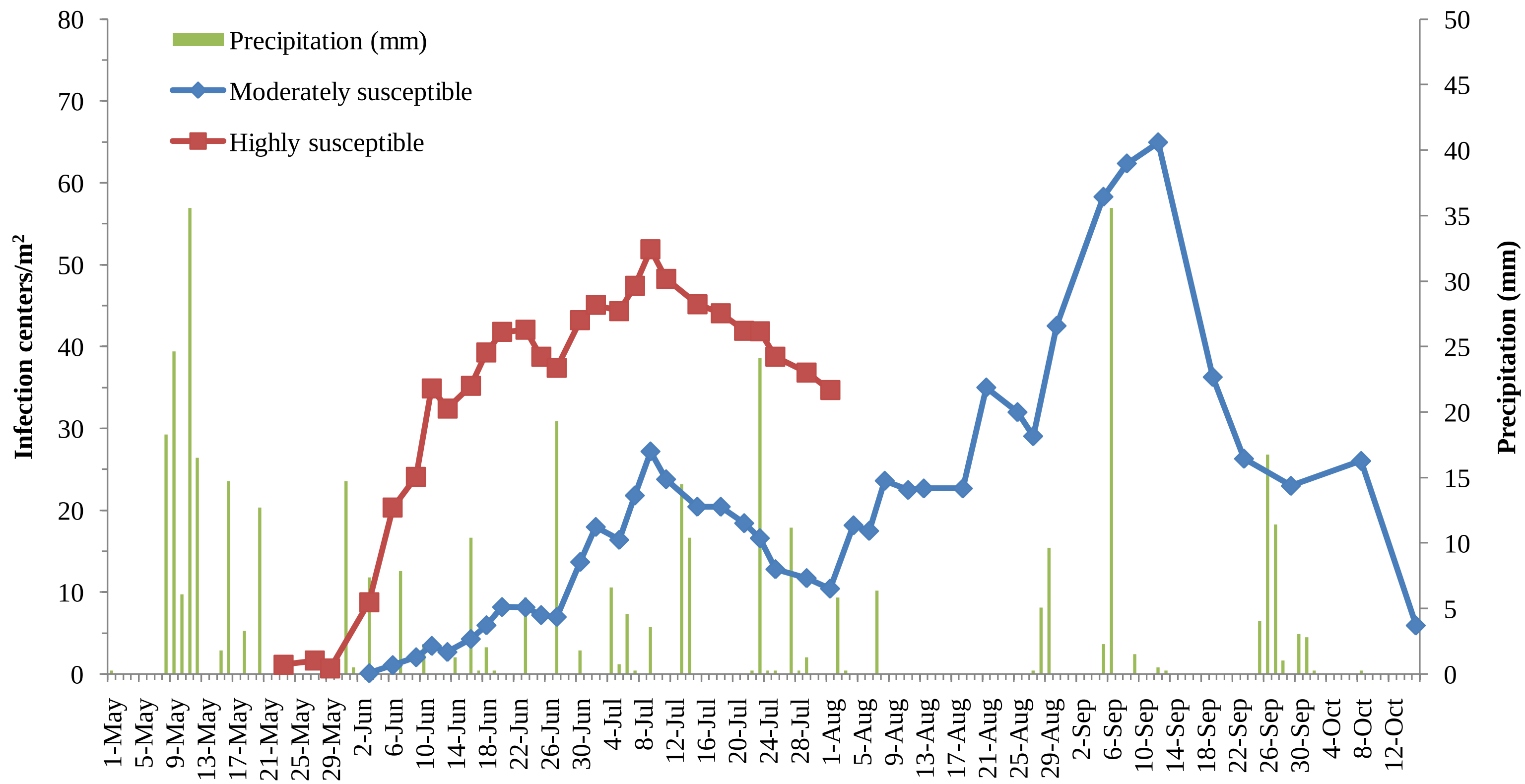
Table 12. Pre-planned orthogonal contrasts among nitrogen sources and two fungicide treatments and their effect on the number of *S. homoeocarpa* infection centers in a ‘Providence’ creeping bentgrass green, 2010.

	Ammonium sulfate vs. No N			**Urea vs. No N**			**Ammonium sulfate + iprodione vs. iprodione**			**Urea + iprodione vs. iprodione**			**Ammonium sulfate + triticonazole vs. triticonazole**			**Urea + triticonazole vs. triticonazole**		
Date	Ammonium sulfate	No N	P-value	Urea	No N	P-value	Ammonium sulfate + iprodione	Iprodione	P-value	Urea + iprodione	Iprodione	P-value	Ammonium sulfate + triticonazole	Triticonazole	P-value	Urea + triticonazole	Triticonazole	P-value
AUDPC	4077	3907	0.7202	3400	3907	0.1506	599	734	0.1838	578	734	0.1502	2478	2056	0.1988	1918	2056	0.3305
28 May	12.0	10.8	0.7647	12.8	10.8	0.6334	13.2	9.8	0.4076	9.2	9.8	0.4520	13.5	14.2	0.4343	11.5	14.2	0.2738
4 June	30.5	23.2	0.3712	26.5	23.2	0.6830	8.2	5.8	0.2963	5.0	5.8	0.3735	25.2	22.8	0.7194	18.8	22.8	0.2838
14 June	51.0	52.0	0.4674	43.5	52.0	0.2460	13.2	15.2	0.2864	13.2	15.2	0.2864	39.2	31.5	0.1879	29.2	31.5	0.3444
24 June	70.8	71.4	0.4755	57.5	71.4	0.0971	14.2	17.5	0.2972	14.0	17.5	0.2834	46.2	38.8	0.4421	39.2	38.8	0.9584
1 July	78.8	86.8	0.2188	67.8	86.8	0.0429	5.5	10.2	0.0630	6.5	10.2	0.1079	36.0	31.0	0.4810	25.8	31.0	0.2300
9 July	77.5	76.1	0.8644	66.5	76.1	0.1249	3.2	10.5	0.0012	5.2	10.5	0.0073	42.0	34.5	0.3637	35.5	34.5	0.9013
23 July	97.0	83.6	0.2375	75.3	83.6	0.2243	9.2	9.8	0.4305	9.5	9.8	0.4651	53.2	43.0	0.0982	38.5	43.0	0.2195
28 July	120.0	104.9	0.2873	100.8	104.9	0.3824	25.8	25.8	1.0000	22.0	25.8	0.1364	77.0	59.0	0.0659	57.0	59.0	0.4107

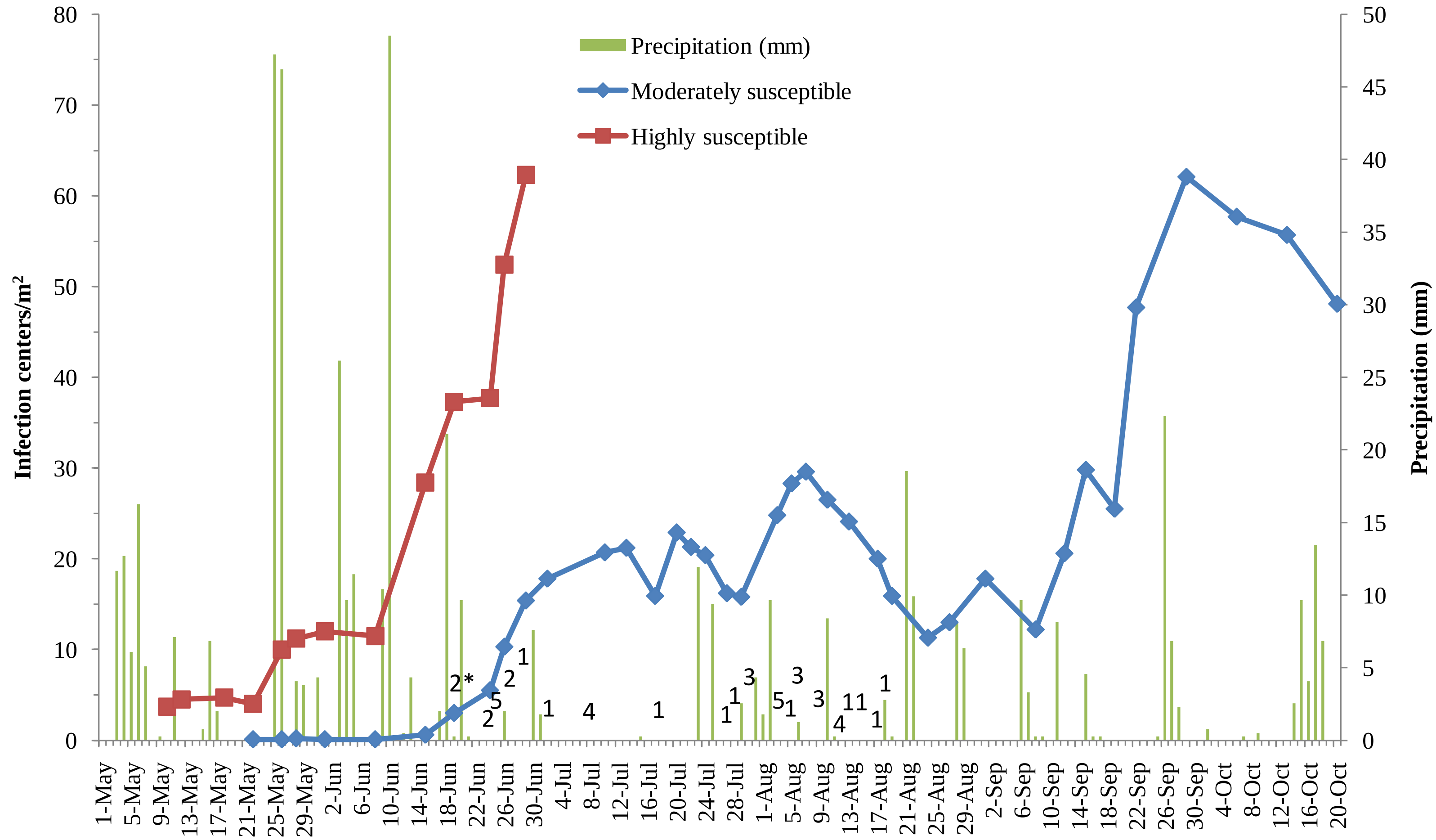
[z] Fungicides were applied on 26 May; 9 and 23 June; and 7 and 21 July, 2010. N sources were applied on 2, 16, and 30 June; and 14 July, 2010.

Appendix I

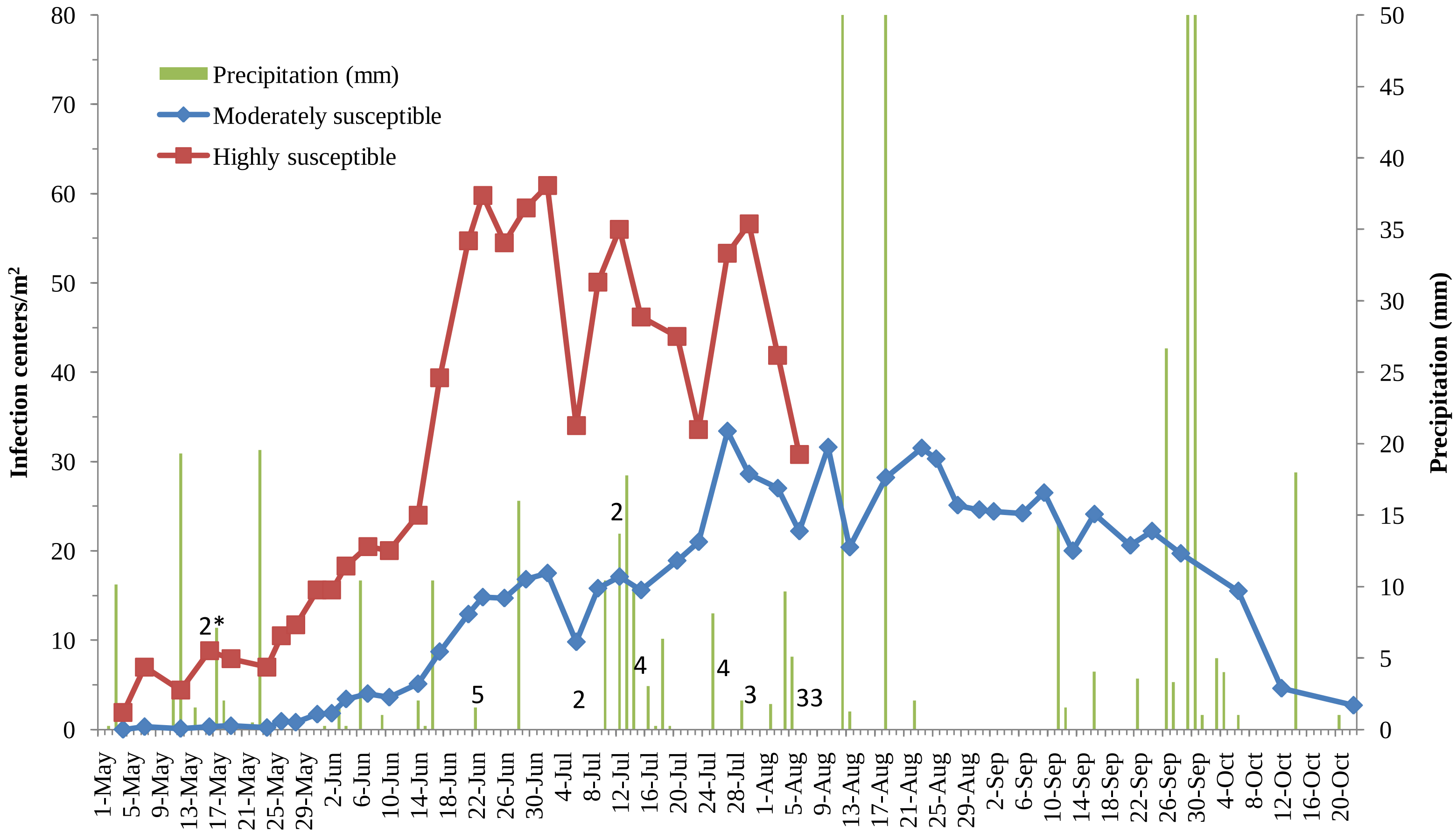
Appendix I. Figure 1. Daily precipitation (mm) between 1 May and 15 October, 2008.



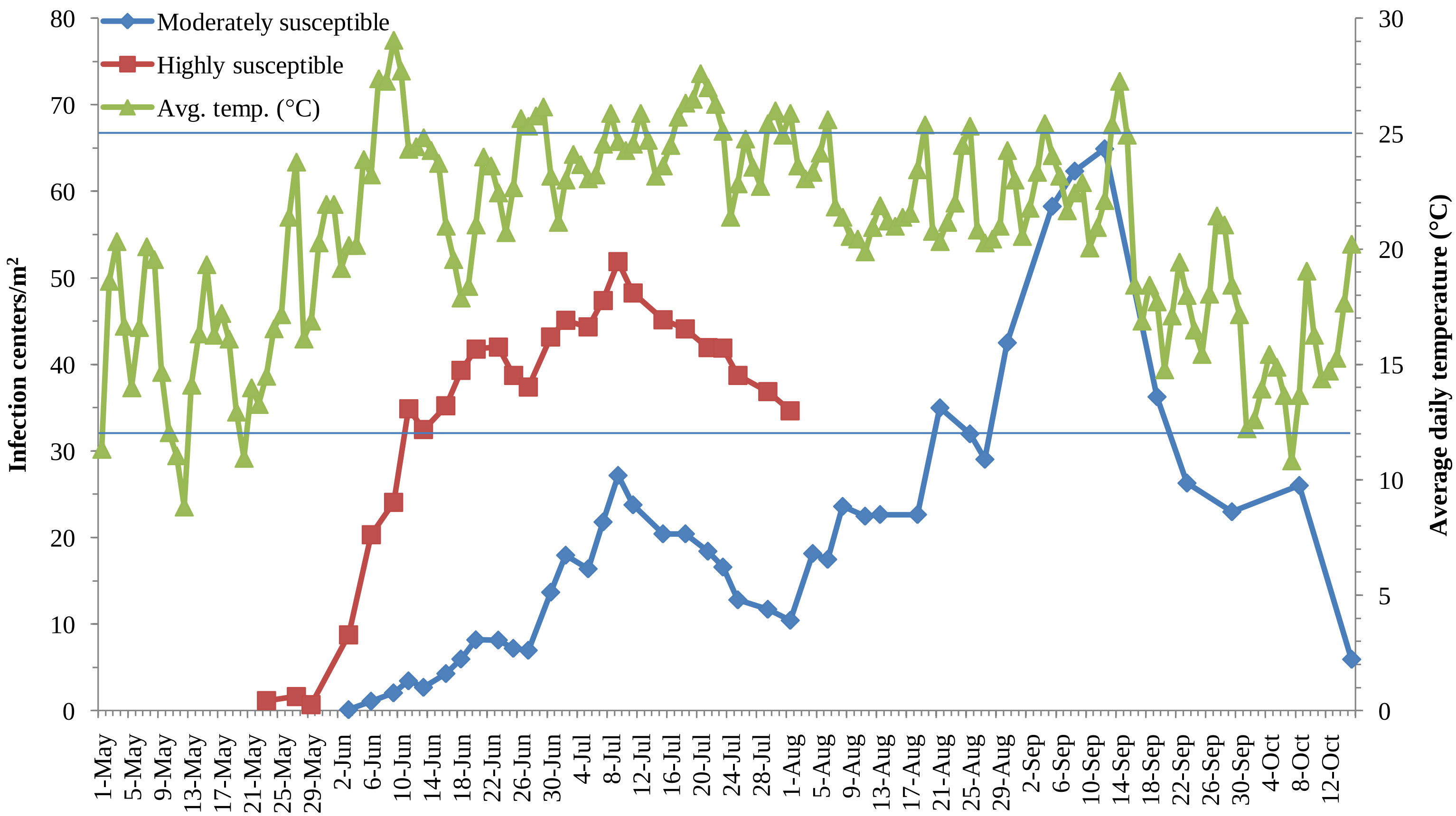
Appendix I. Figure 2. Daily precipitation (mm) between 1 May and 20 October, 2009. * Aerial mycelium evaluated on a 1 to 5 scale where 1= sparse amounts of mycelium and 5= copious amounts of mycelium.



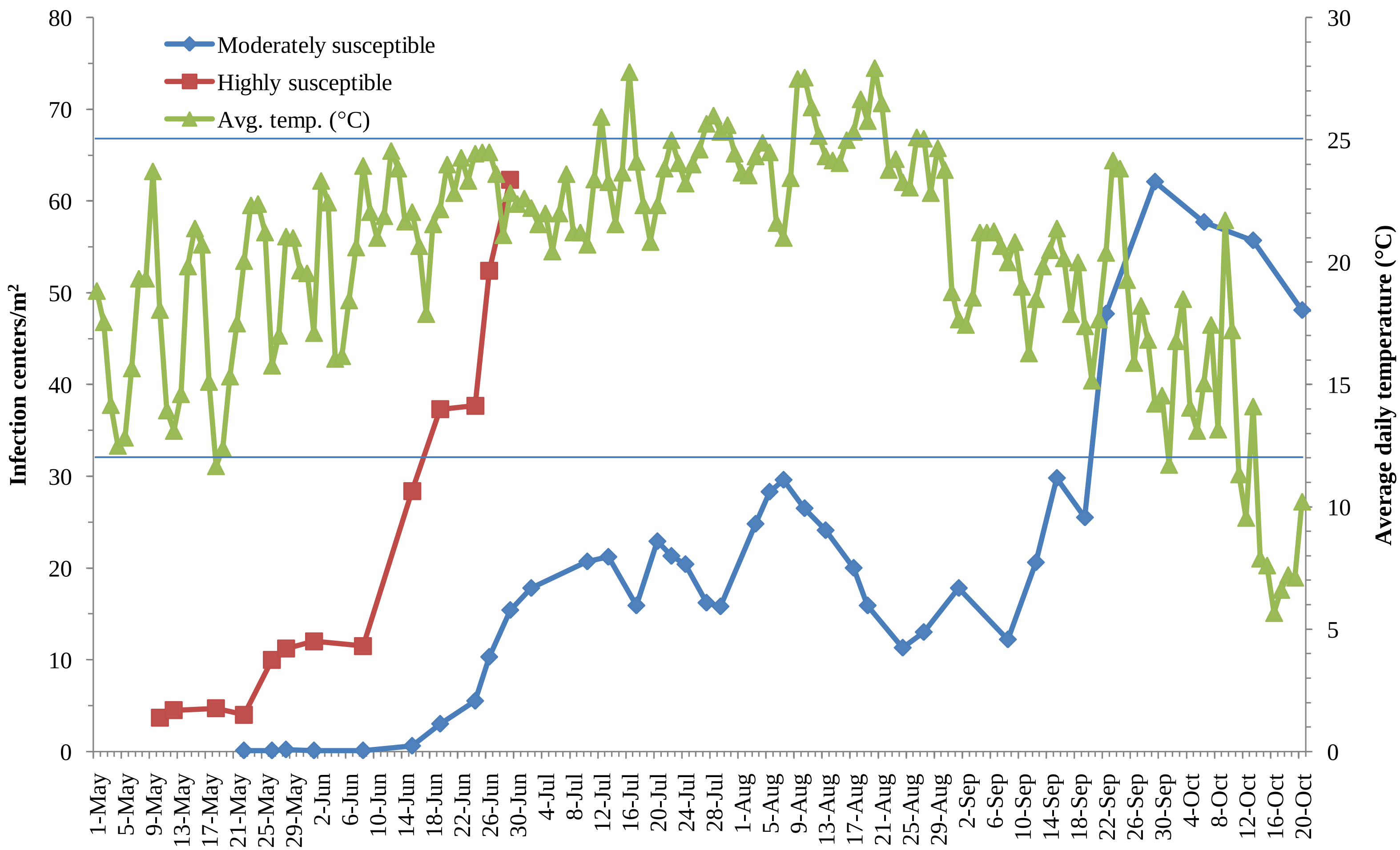
Appendix I. Figure 3. Daily precipitation (mm) between 1 May and 22 October, 2010. * Aerial mycelium evaluated on a 1 to 5 scale where 1= sparse amounts of mycelium and 5= copious amounts of mycelium.



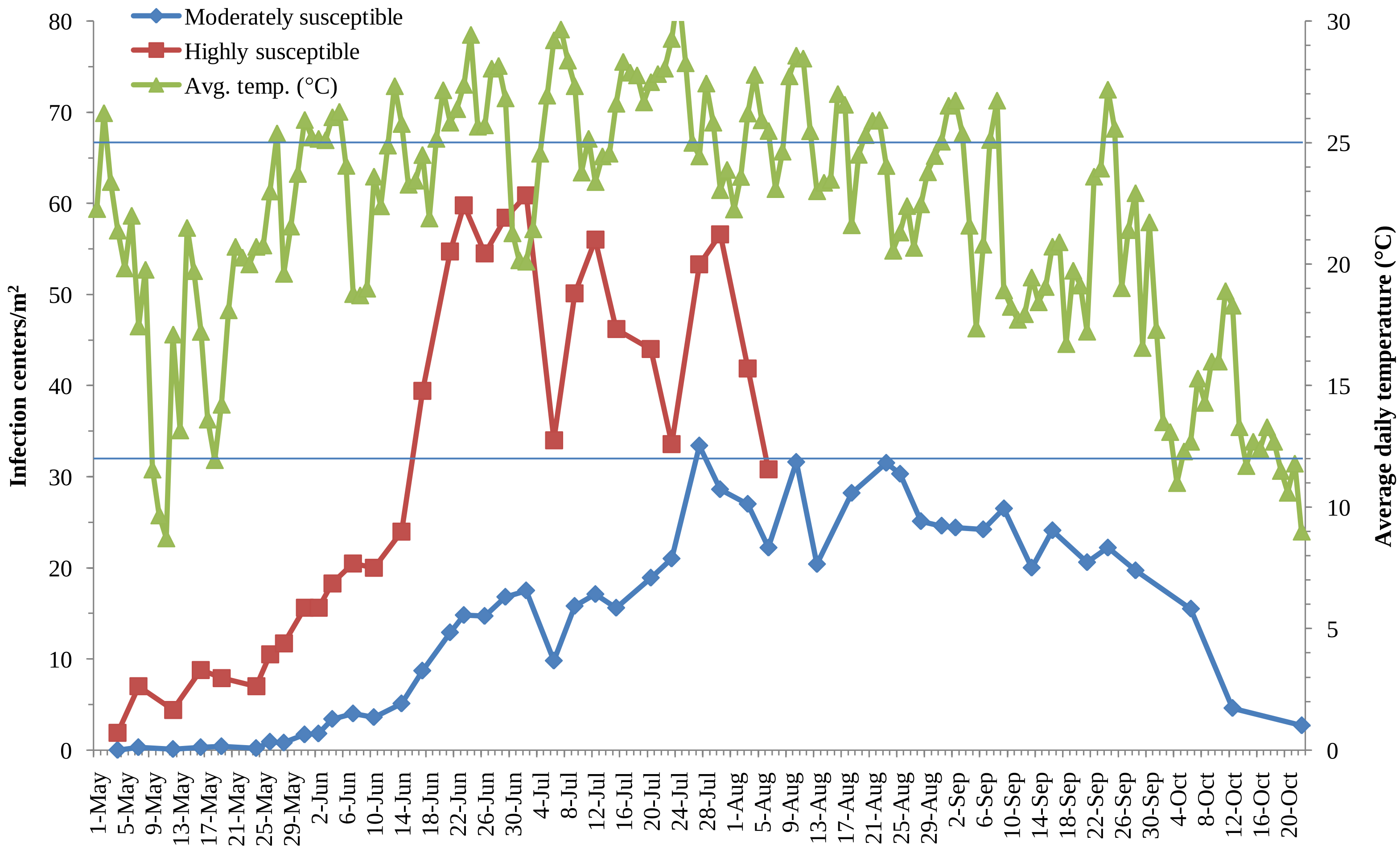
Appendix I. Figure 4. Average daily air temperatures (°C) between 1 May and 15 October, 2008.



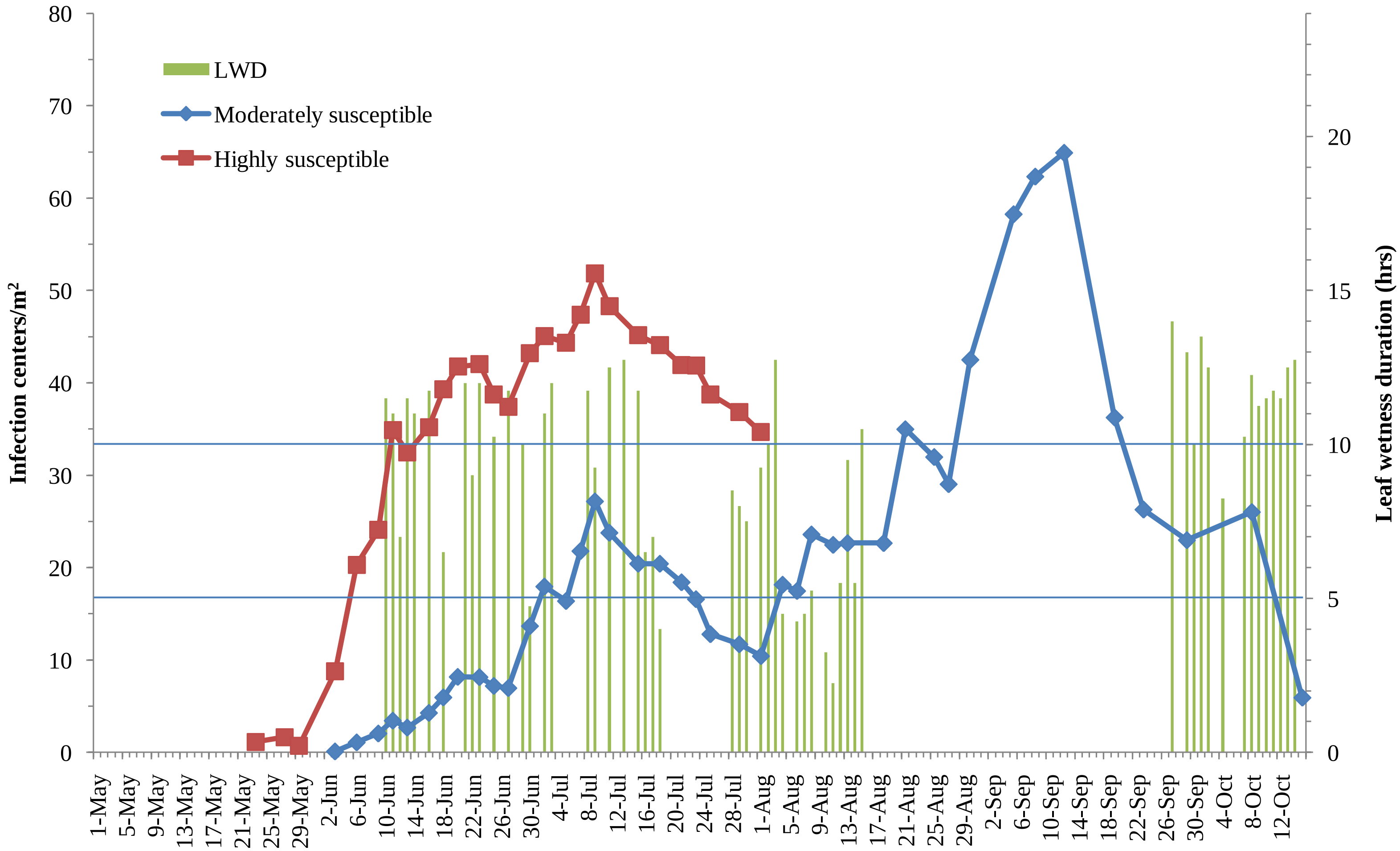
Appendix I. Figure 5. Average daily air temperatures (°C) between 1 May and 20 October, 2009.



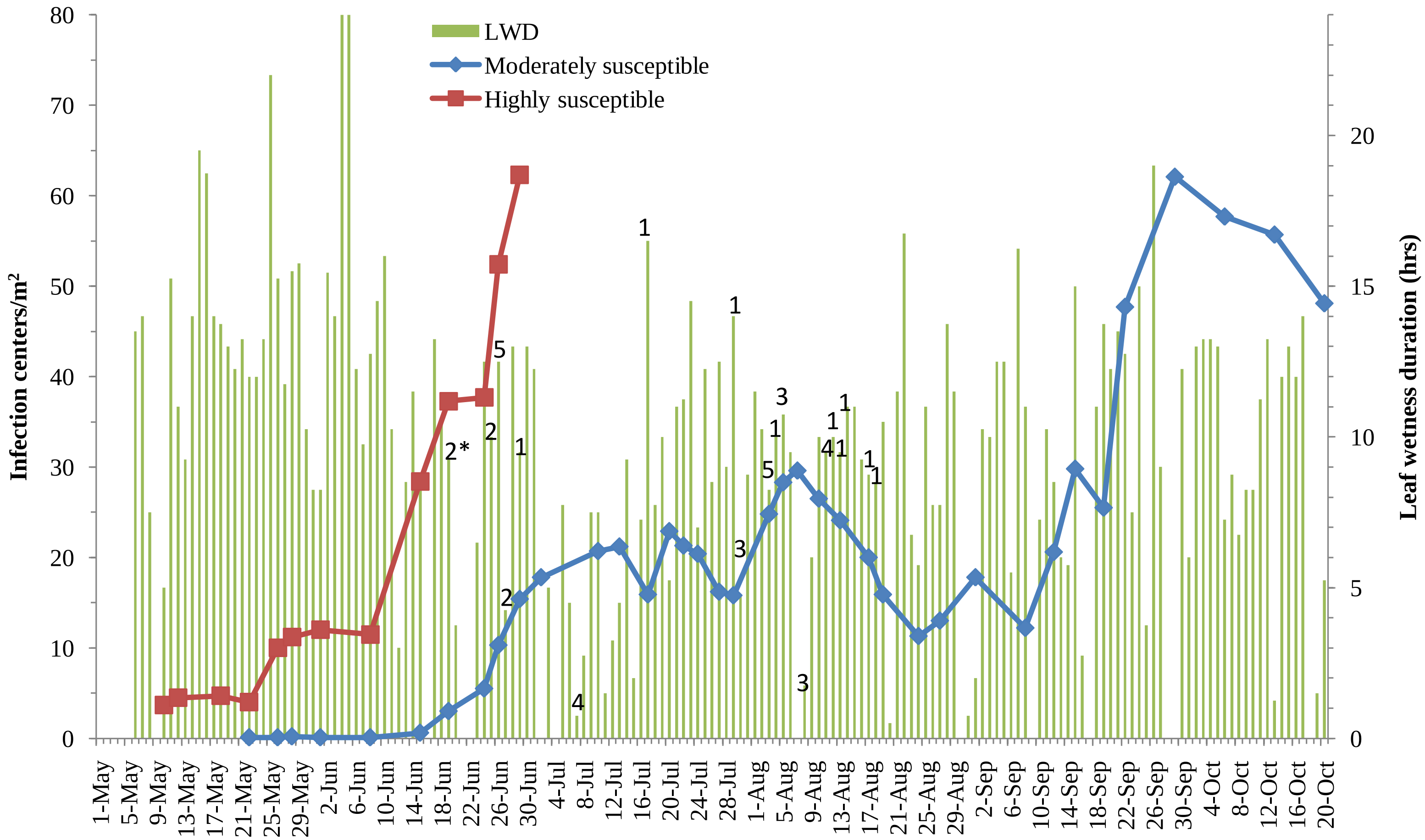
Appendix I. Figure 6. Average daily air temperatures (°C) between 1 May and 22 October, 2010.



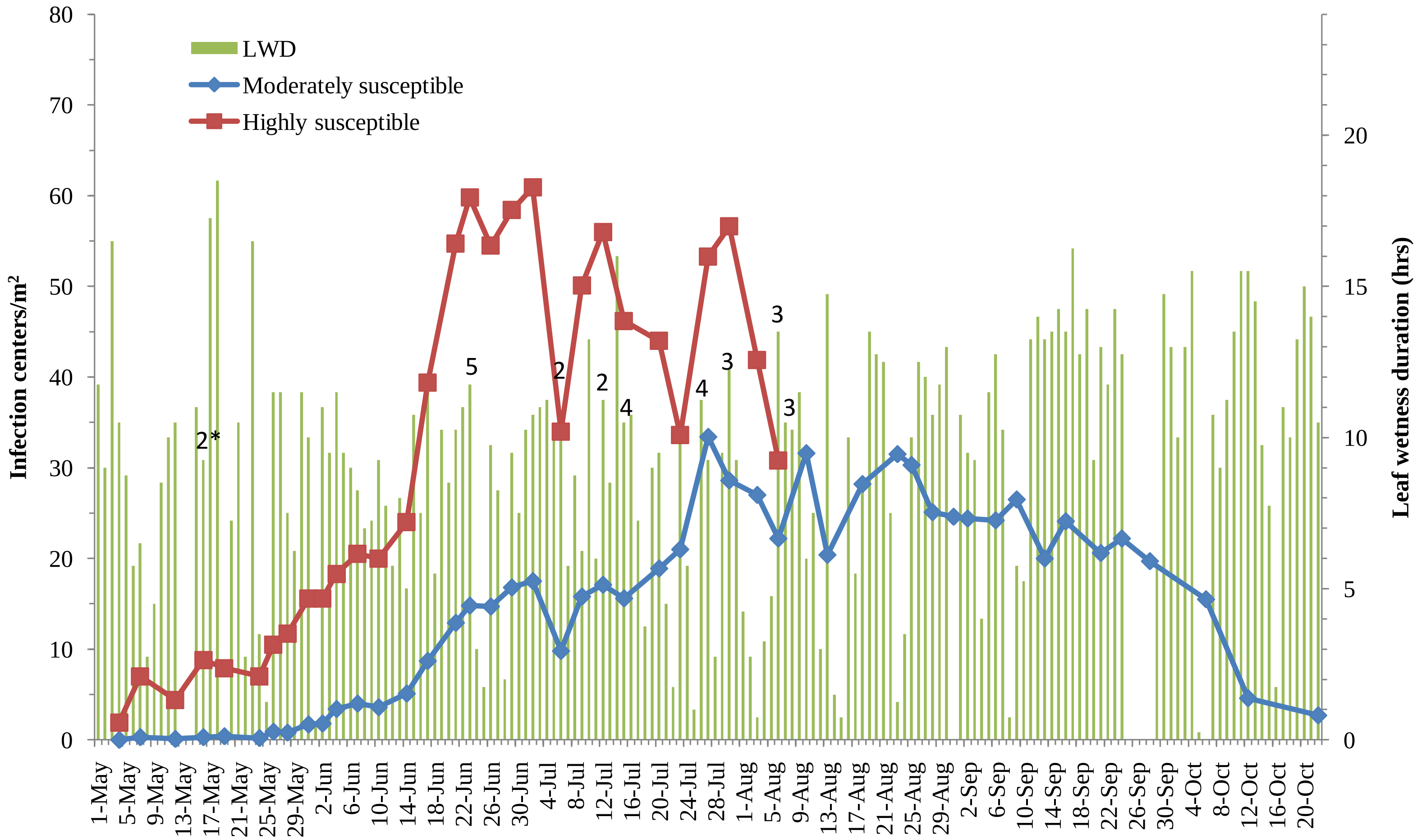
Appendix I. Figure 7. Hours of leaf wetness duration (LWD) between 1 May and 15 October, 2008.



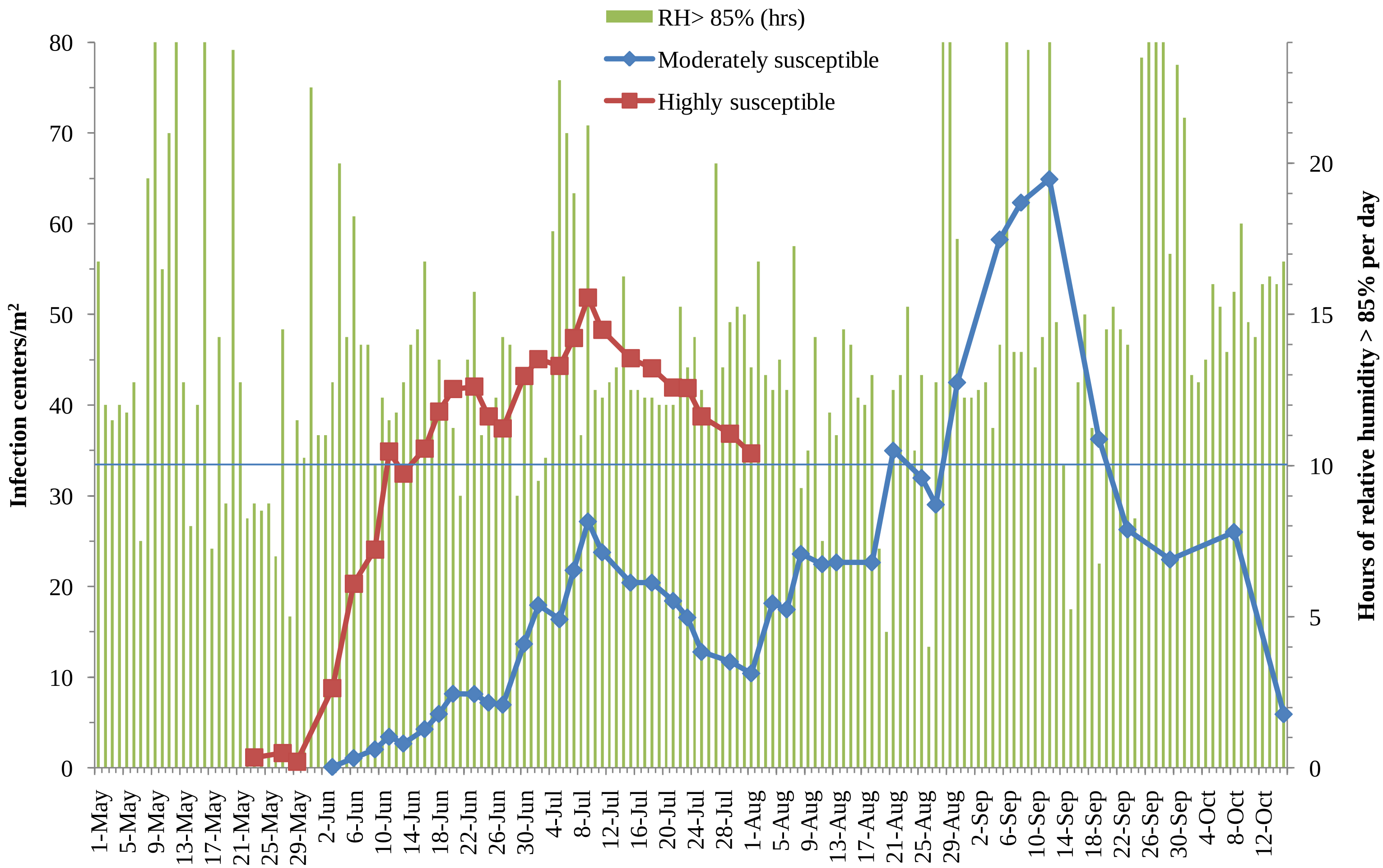
Appendix I. Figure 8. Hours of leaf wetness duration (LWD) between 1 May and 20 October, 2009. * Aerial mycelium evaluated on a 1 to 5 scale where 1= sparse amounts of mycelium and 5= copious amounts of mycelium.



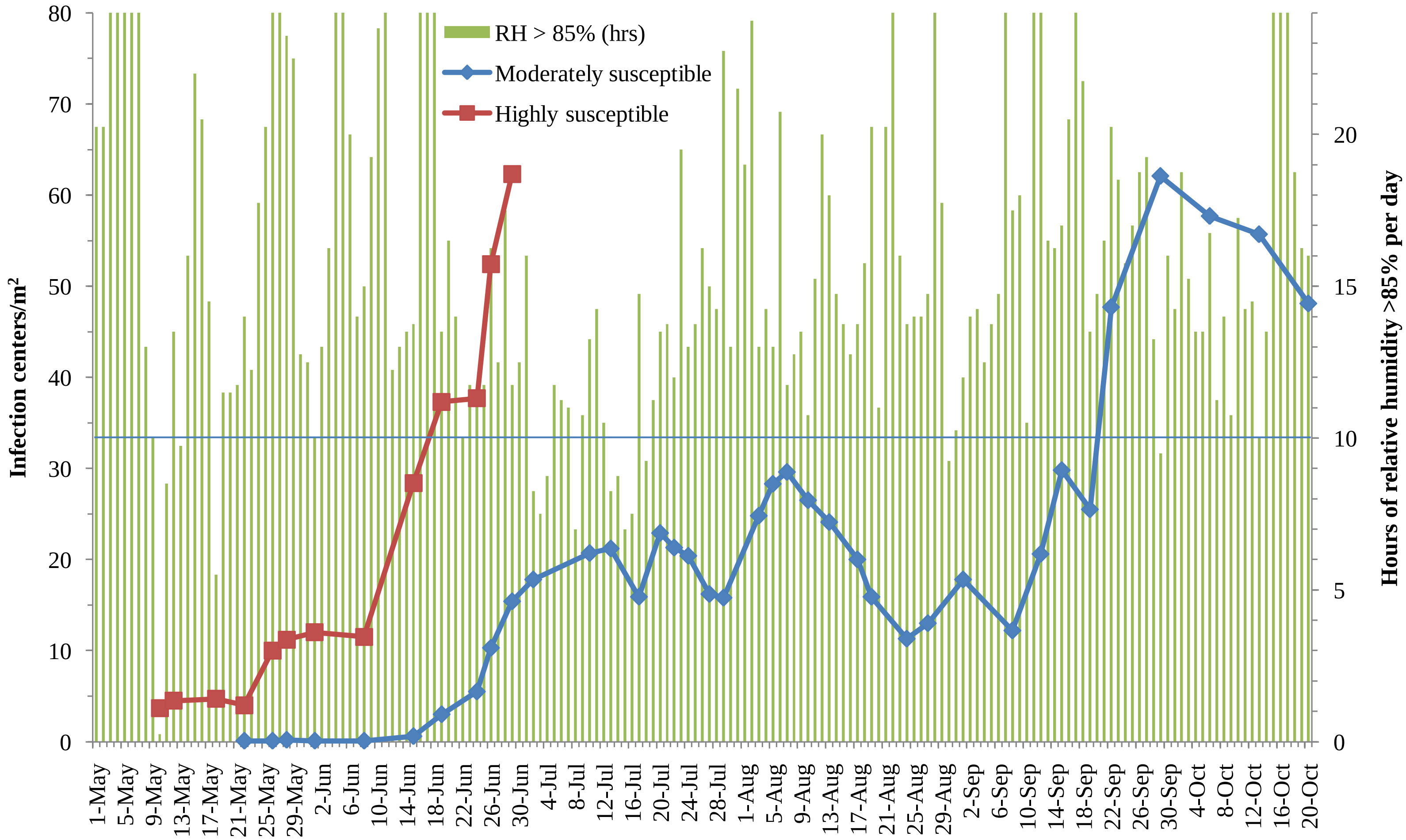
Appendix I. Figure 9. Hours of leaf wetness duration (LWD) between 1 May and 22 October, 2010. * Aerial mycelium evaluated on a 1 to 5 scale where 1= sparse amounts of mycelium and 5= copious amounts of mycelium.



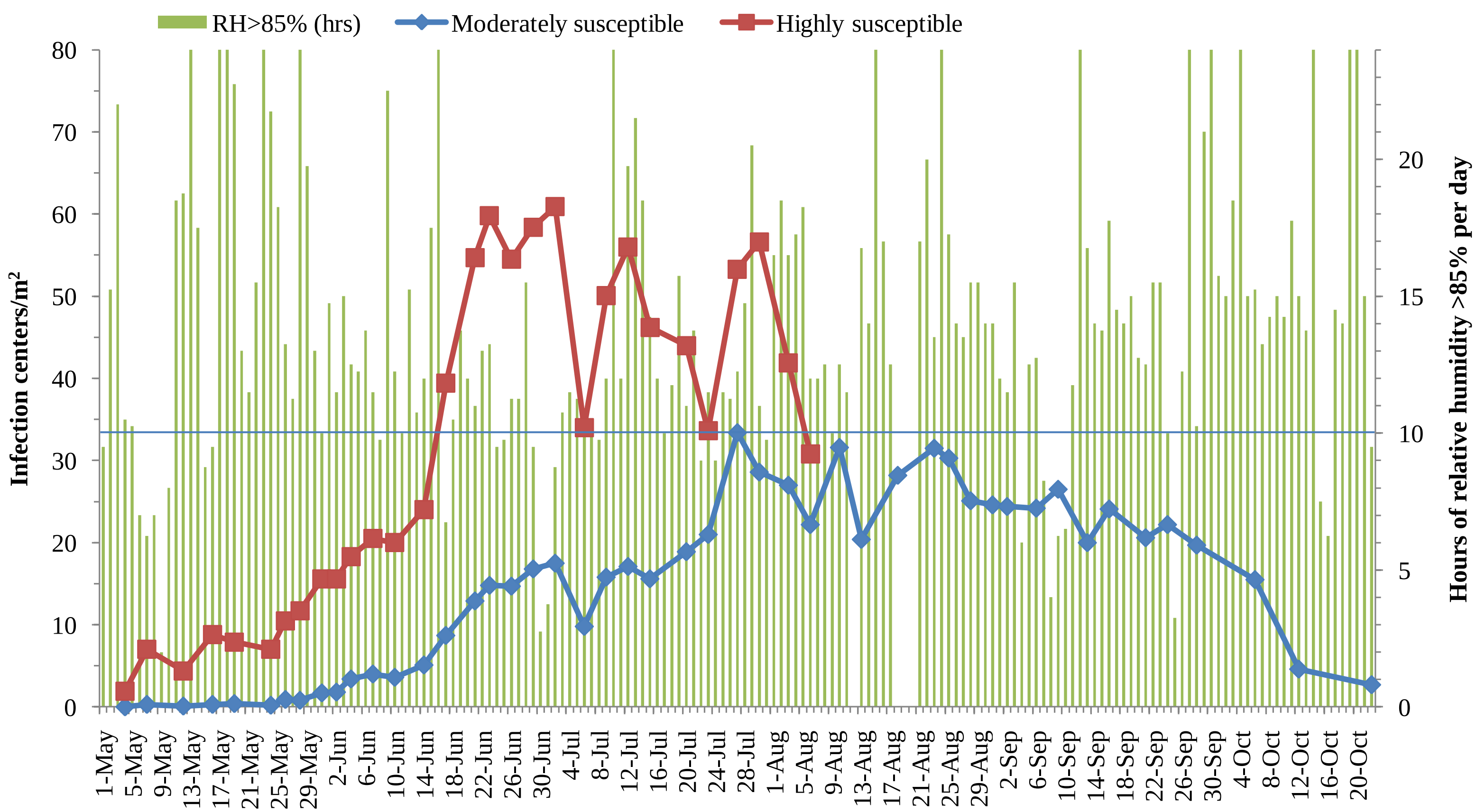
Appendix I. Figure 10. Hours of average relative humidity (RH) greater than 85% per day between 1 May and 15 October, 2008.



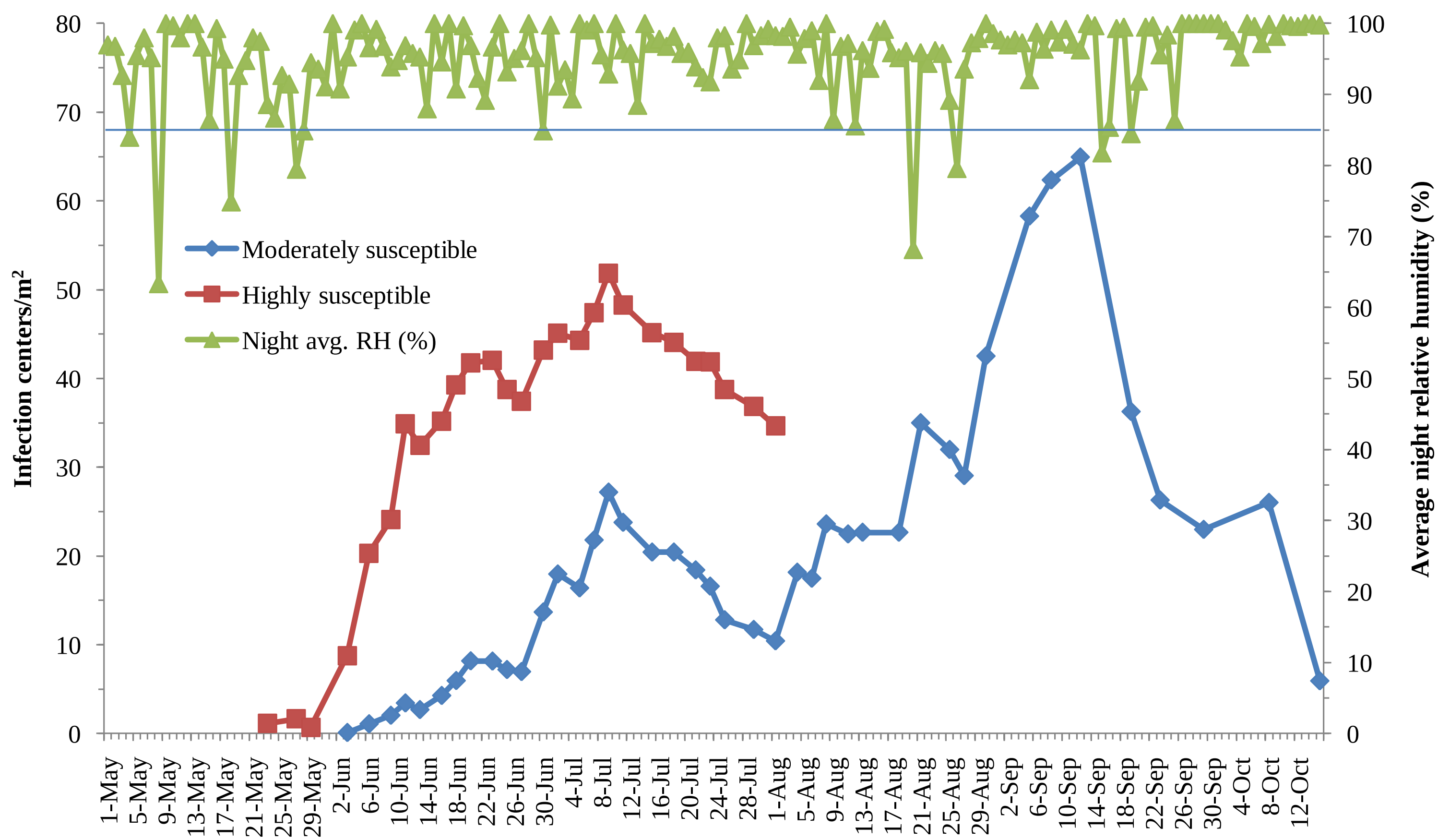
Appendix I. Figure 11. Hours of average relative humidity (RH) greater than 85% per day between 1 May and 20 October, 2009.



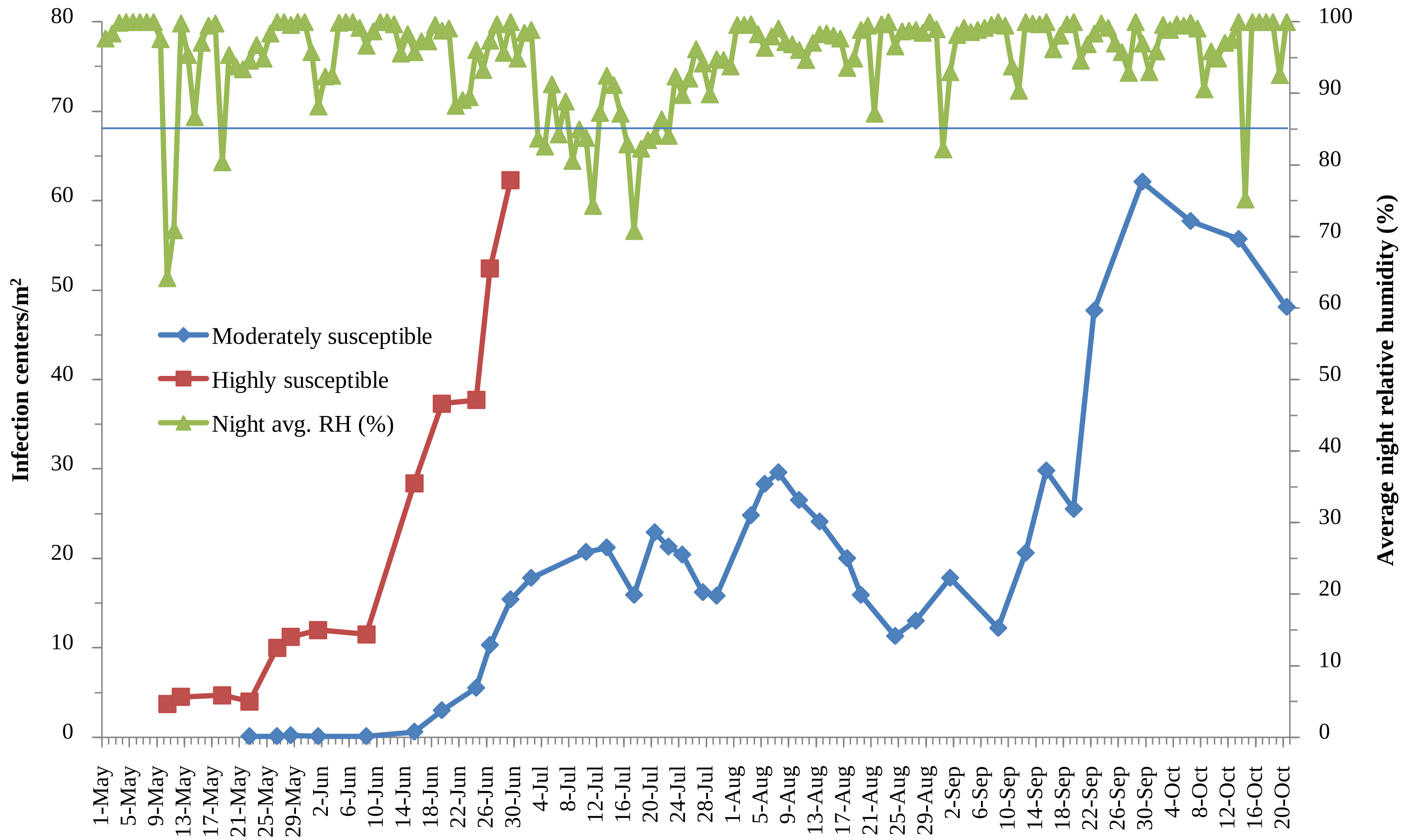
Appendix I. Figure 12. Hours of average relative humidity (RH) greater than 85% per day between 1 May and 22 October, 2010.



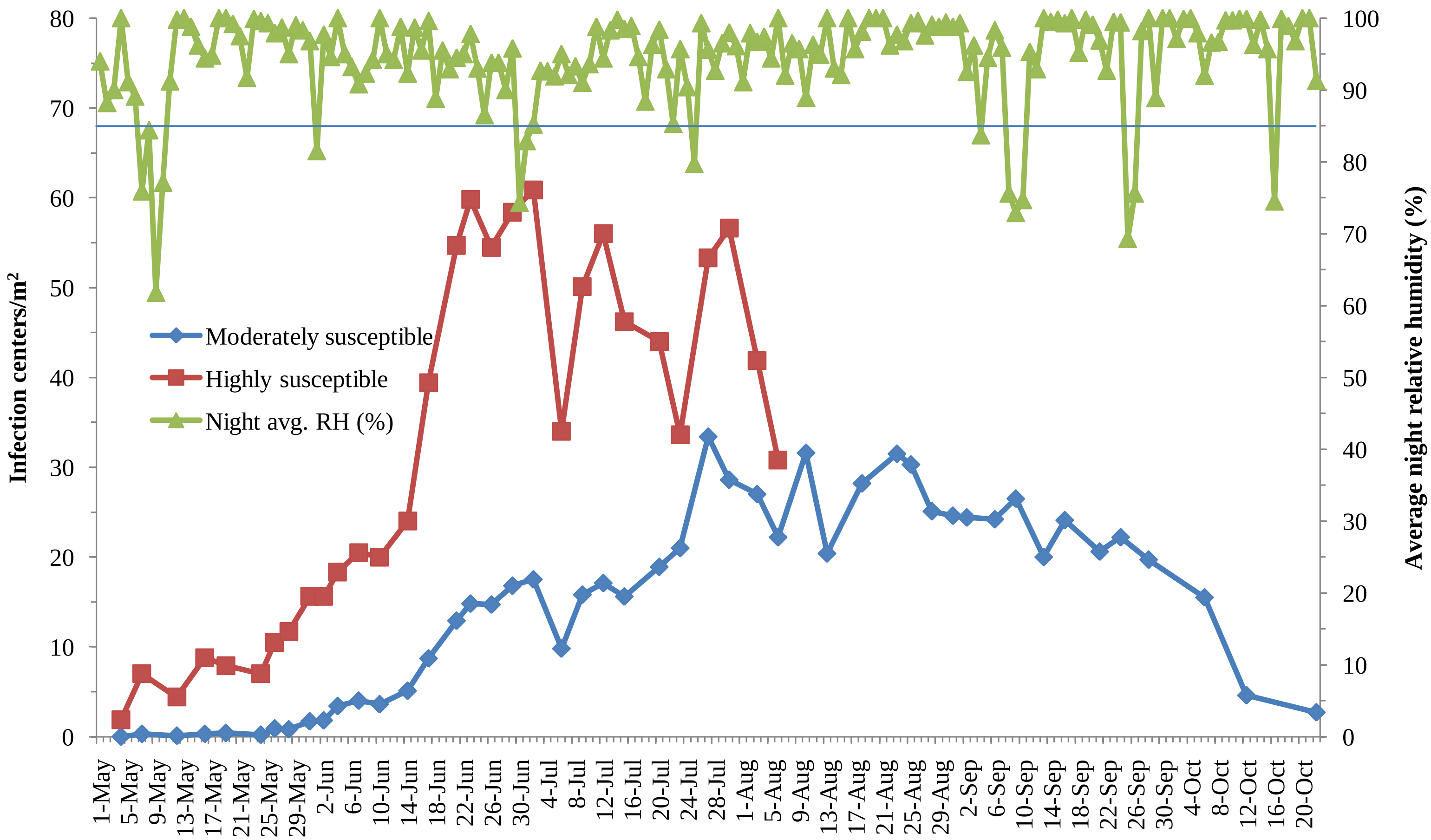
Appendix I. Figure 13. Average night (1800 to 0559 hrs) relative humidity (RH) between 1 May and 15 October, 2008.



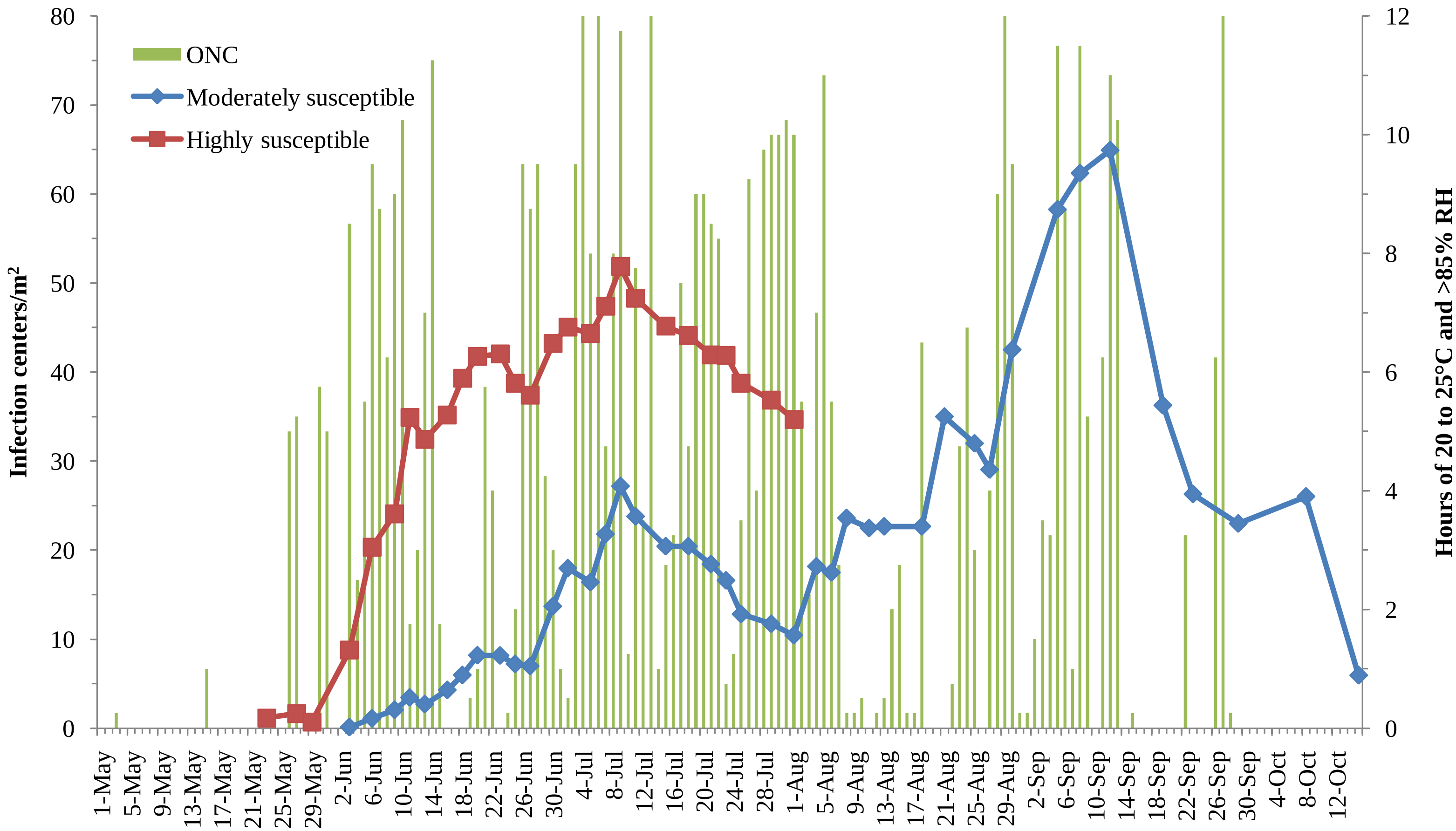
Appendix I. Figure 14. Average night (1800 to 0559 hrs) relative humidity (RH) between 1 May and 20 October, 2009.



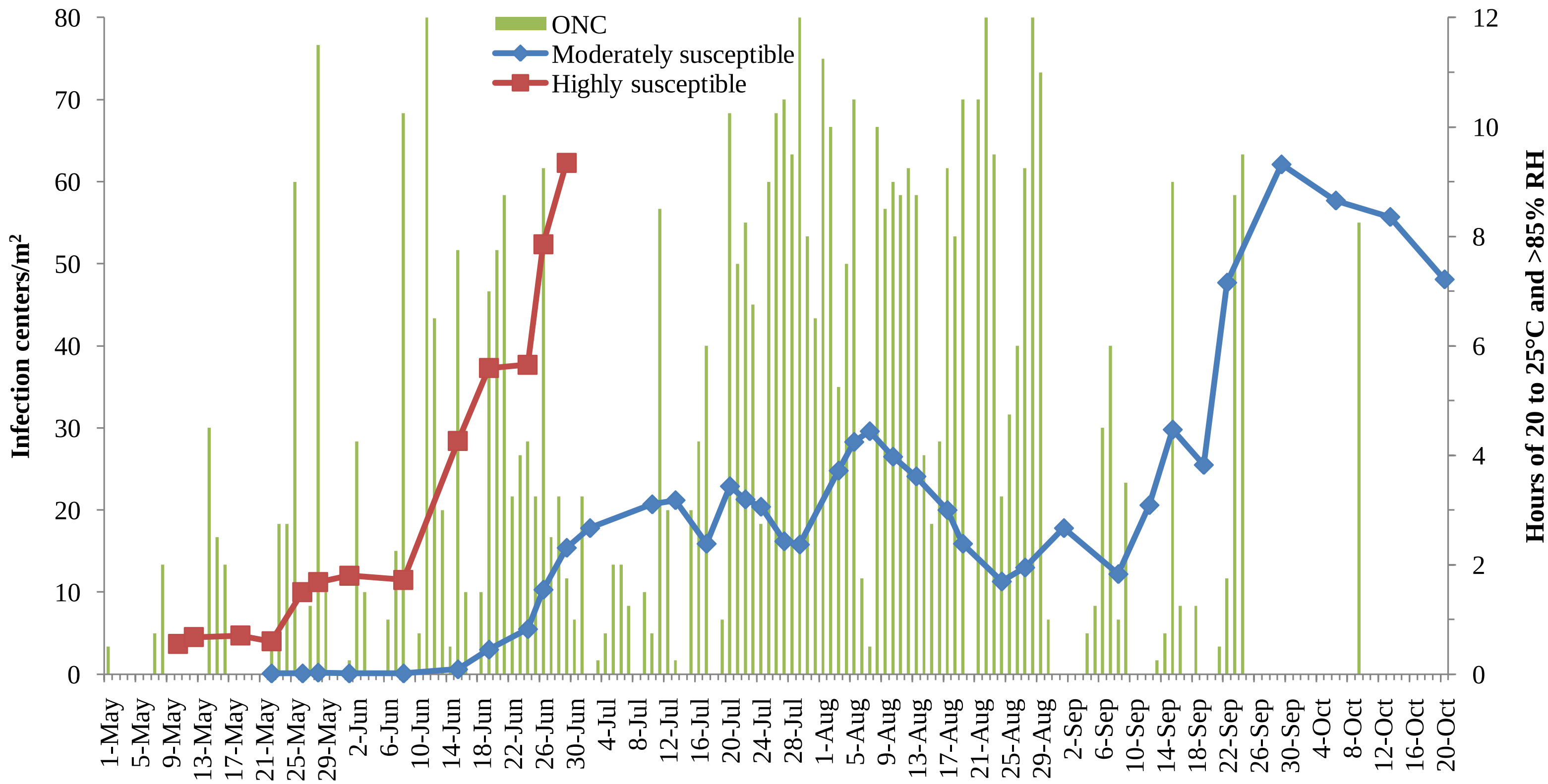
Appendix I. Figure15. Average night (1800 to 0559 hrs) relative humidity (RH) between 1 May and 22 October, 2010.



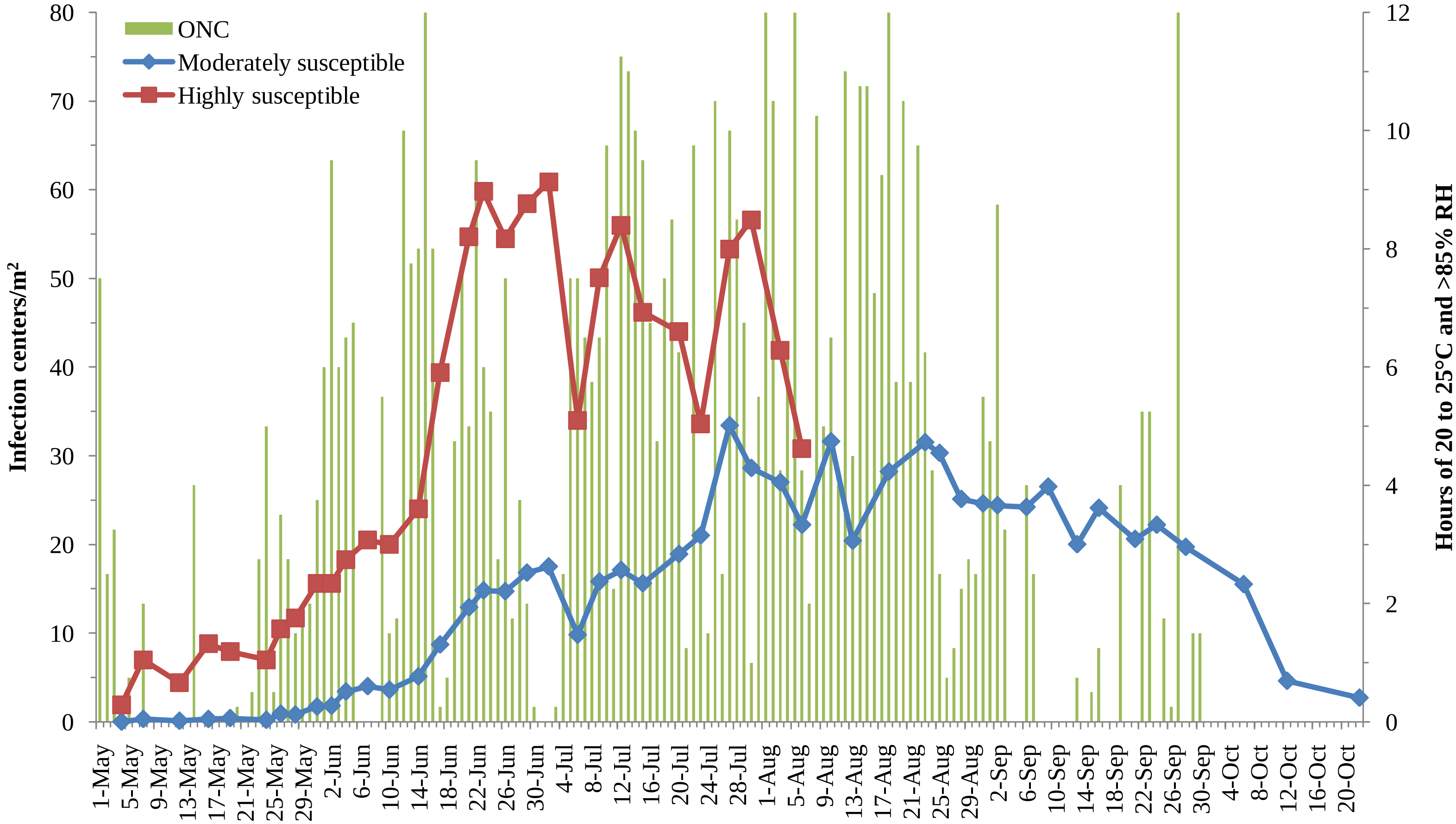
Appendix I. Figure 16. Optimum night conditions (ONC) as defined by hours of average night (1800 to 0559 hrs) temperature between 20 and 25°C and average relative humidity >85% between 1 May and 15 October, 2008.



Appendix I. Figure 17. Optimum night conditions (ONC) as defined by hours of average night (1800 to 0559 hrs) temperature between 20 and 25°C and average relative humidity >85% between 1 May and 20 October, 2009.



Appendix I. Figure 18. Optimum night conditions (ONC) as defined by hours of average night (1800 to 0559 hrs) temperature between 20 and 25°C and average relative humidity >85% between 1 May and 22 October, 2010.



Appendix II

Table 1. 'Crenshaw' creeping bentgrass quality and area under the quality curve (AUQC) as influenced by six N sources and chlorothalonil, 2008.

	Quality ratings (0-10 scale; 10=best)										AUQC
Treatment[x]	25 June	3 July	9 July	15 July	30 July	6 Aug.	12 Aug.	14 Aug.	9 Aug.	29 Aug.	(quality x time)
Ammonium nitrate	8.8ab[z]	7.5de	6.9bcd	6.8de	4.9f	4.9d	4.2c	4.6efg	4.2cd	4.5d	372ef
Ammonium nitrate + chlorothalonil[x]	8.8ab	8.0b-e	8.6a	8.5ab	6.9cd	7.5bc	6.4b	6.9c	8.2ab	6.4bc	500bcd
Ammonium sulfate	8.4b	7.9b-e	7.1bcd	7.4cd	4.9f	5.5d	4.9c	4.2g	5.0c	4.9d	394ef
Ammonium sulfate + chlorothalonil[x]	8.6ab	7.4e	8.4a	8.3abc	5.5ef	7.1c	6.2b	5.4de	8.0ab	6.0c	464d
Urea	8.9a	7.9b-e	7.4bc	6.9de	5.4ef	5.0d	4.5c	4.9d-g	4.0cd	4.8d	388ef
Urea + chlorothalonil[x]	8.6ab	8.6ab	8.6a	8.6ab	7.4bc	8.0bc	6.2b	7.2bc	8.1ab	7.0b	517b
Potassium nitrate	8.9a	7.6cde	7.5b	7.0de	5.4ef	5.2d	4.6c	4.6efg	4.5cd	4.5d	392ef
Potassium nitrate + chlorothalonil[x]	9.0a	8.2a-e	8.9a	9.0a	6.8cd	7.9bc	6.4b	6.8c	7.8b	6.8bc	508bc
Calcium nitrate	9.0a	7.6cde	6.6cd	6.8de	5.2ef	5.0d	4.8c	4.2g	4.5cd	4.6d	381ef
Calcium nitrate + chlorothalonil[x]	8.8ab	7.6cde	8.4a	8.4abc	6.2de	7.1c	6.0b	5.6d	7.5b	6.1c	472cd
20-20-20	8.8ab	8.4a-d	6.9bcd	7.6bcd	5.6ef	5.4d	4.8c	5.2def	4.5cd	4.5d	405e
20-20-20 + chlorothalonil[x]	9.0a	8.5abc	8.8a	8.6ab	8.0ab	8.2ab	6.5b	8.0b	8.1ab	6.4bc	527b
Low rate chlorothalonil[x]	8.6ab	8.6ab	8.5a	8.6ab	7.8bc	7.9bc	6.5b	7.1bc	8.2ab	6.2bc	517b
High rate chlorothalonil[y]	8.9a	9.0a	8.8a	9.0a	9.0a	9.0a	9.2a	9.0a	9.0a	8.9a	583a
Untreated	8.7ab	7.5de	6.4d	6.2e	4.9f	4.6d	3.9c	4.4fg	3.6d	4.2d	354f

[w]Treatments were applied 18 June; 2, 16 and 30 July; and 13 August, 2008.

[x]The low rate of chlorothalonil was 1.6 kg a.i. ha^{-1} (1.0 fl oz/1000ft^2).

[y]The high rate of chlorothalonil was 6.4 kg a.i. ha^{-1} (4.0 fl oz/1000ft^2).

[z]Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test,
$P \leq 0.05$.

Table 2. 'Providence' creeping bentgrass quality and area under the quality curve (AUQC) as influenced by six N sources and chlorothalonil , 2009.

	Quality ratings (0-10 scale; 10=best)										AUQC
Treatment[x]	28 May	15 June	23 June	29 June	7 July	17 July	25 July	7 Aug.	14 Aug.	21 Aug.	(qual. x time)
Ammonium nitrate	8.1abc[z]	8.2bc	7.8def	7.4d	6.1c	5.2e	5.6def	5.1cde	5.4bc	5.5bcd	550fg
Ammonium nitrate + chlorothalonil[x]	8.4a	8.2bc	8.5ab	8.5abc	8.1ab	6.5bcd	6.5bc	5.4bc	5.6bc	5.2cd	607cd
Ammonium sulfate	6.5d	8.1c	7.8def	5.9h	6.1c	5.1e	4.9g	4.6e	4.4d	6.0b	505h
Ammonium sulfate + chlorothalonil[x]	6.8d	8.4abc	8.0cde	6.2gh	8.1ab	6.0d	6.1cd	5.5bc	4.5d	5.2cd	560f
Urea	8.1abc	8.2bc	7.9de	7.1de	6.2c	5.0e	5.8de	5.2cd	5.4bc	5.8bc	551fg
Urea + chlorothalonil[x]	8.2ab	8.4abc	8.1bcd	8.6ab	8.5a	6.9bc	6.8b	5.6bc	5.4bc	5.5bcd	617bc
Potassium nitrate	7.8bc	8.5abc	7.9de	6.8ef	6.4c	5.0e	5.2efg	5.1cde	5.4bc	5.5bcd	543g
Potassium nitrate + chlorothalonil[x]	7.6c	8.4abc	7.6ef	8.1c	8.1ab	6.4cd	8.5bc	5.6bc	5.2c	5.4cd	592de
Calcium nitrate	7.6c	8.1c	7.4fg	7.0de	6.2c	5.2e	5.1fg	5.5bc	5.5bc	5.6bcd	540g
Calcium nitrate + chlorothalonil[x]	8.1abc	8.1c	7.6ef	8.1c	7.9b	6.1d	6.4bc	5.2cd	5.2c	5.2cd	584e
20-20-20	7.9abc	8.5abc	7.1g	6.8ef	6.1c	5.1e	5.1fg	5.4bc	5.8b	5.6bcd	542g
20-20-20 + chlorothalonil[x]	8.4a	8.4abc	8.0cde	8.4bc	8.2ab	6.4cd	6.9b	5.1cde	5.6bc	5.2cd	606cd
Low rate chlorothalonil[x]	8.4a	8.6ab	8.4abc	8.6ab	8.1ab	7.0b	6.9b	5.9b	5.5bc	5.5bcd	625b
High rate chlorothalonil[y]	8.2ab	8.8a	8.6a	8.9a	8.5a	7.6a	8.2a	8.1a	8.1a	6.8a	696a
Untreated	7.9abc	8.2c	7.4fg	6.4fg	5.9c	5.2e	5.1fg	4.8de	4.6d	5.1d	521h

[w]Treatments were applied 28 May; 11 and 25 June; 9 and 23 July; and 5 August, 2009.

[x]The low rate of chlorothalonil was 3.2 kg a.i. ha^{-1} (2.0 fl oz/1000ft^2).

[y]The high rate of chlorothalonil was 6.4 kg a.i. ha^{-1} (4.0 fl oz/1000ft^2).

[z]Means in a column followed by the same letter are not significantly different according to Fisher's least significant difference test, $P \leq 0.05$.

Literature Cited

Anonymous. 2010. Daconil Weather Stik® fungicide label. EPA Reg. No. 50534-209-100. Syngenta Crop Protection, Greensboro, NC.

Baldwin, N. A., and A. J. Newell. 1992. Field production of fertile apothecia by *Sclerotinia homoeocarpa* in *Festuca* turf. Journal of the Sports Turfgrass Research Institute 68:73-76.

Bennett, F.T. 1937. Dollar spot disease on turf and its causal organism *Sclerotinia homoeocarpa* n. sp. Annals of Applied Biology 24:236-257.

Brosnan, J.T., G.K. Breeden, and M.T. Elmore. 2010. Early and late postemergence control of dallisgrass in tall fescue. Online. Applied Turfgrass Science doi: 10.1094/ATS-2010-0312-02-RS.

Burpee, L. L., and L. G. Goulty. 1986. Evaluation of two dollar spot forecasting systems for creeping bentgrass. Canadian Journal of Plant Science 66:345-351.

Campbell, C. L., and Madden, L.V. 1990. Introduction to Plant Disease Epidemiology. John Wiley & Sons, New York, NY.

Carroll, M.J., R.L. Hill, E. Pfeil, and J.M. Krouse. 2001. Effect of resident time on washoff of chlorothalonil from turf foliage. Int. Turfgrass Soc. Res. J. 9:1-5.

Carrow, R.N., D.V. Waddington and P.E. Rieke. 2001. Turfgrass Soil Fertility and Chemical Problems : Assessment and Management. John Wiley & Sons, Inc. Hoboken, NJ.

Couch, H. B., and J. R. Bloom. 1960. The influence of environment on diseases of Turfgrasses. II. Effect of nutrition, pH and soil moisture on *Sclerotinia* dollar spot. Phytopathology 50:761-763.

Couch, H.B. 1995. Diseases of Turfgrasses. 3rd ed. Krieger Publishing, Malabar, FL.

Davis, J.G. and P.H. Dernoeden. 2002. Dollar spot severity, tissue nitrogen, and soil microbial activity in bentgrass as influenced by nitrogen source. Crop Science 42:480-488.

Dernoeden, P.H. 1987. Management of take-all patch of creeping bentgrass with nitrogen, sulfur and phenyl mercury acetate. Plant Dis. 71:226-229.

Dernoeden, P.H. 2002. Creeping Bentgrass Management: Summer Stresses, Weeds and Selected Maladies. John Wiley & Sons, Inc., Hoboken, NJ.

Dernoeden, P.H., J.N. Crayhay, and D.B. Davis. 1991. Spring dead spot and bermudagrass quality as influenced by nitrogen source and potassium. Crop Sci. 31: 1674-1680.

Ellram, A., B. Horgan, and B. Hulke. 2007. Mowing strategies and dew removal to minimize dollar spot on creeping bentgrass. Crop Science 47:2129-2137.

Endo, R.M. 1963. Influence of temperature on rate of growth of five fungal pathogens of turfgrass and on rate of disease spread. Phytopathology 53:857-861.

Endo, R.M. 1966. Control of dollar spot of turfgrass by nitrogen and its probable basis. Phytopathology 56:877 (Abstr.).

Fenstermacher, J.M. 1980. Certain features of dollar spot disease and its causal organism, *Sclerotinia homoeocarpa.* Advances in Turfgrass Pathology. B.G. Joyner and P.O Larsen, eds. Harcourt Brace Jevanovich, Duluth, MN.

Fidanza, M. A., Dernoeden, P. H. and Grybauskas, A. P. 1996 Development and field validation of a brown patch warning model for perennial ryegrass turf. Phytopathology 86:385-390.

Gomez, K.A. and A.A. Gomez. 1984. Statistical Procedures for Agricultural Research. John Wiley & Sons, New York, NY.

Hall, R. 1984. Relationship between weather factors and dollar spot of creeping bentgrass. Canadian Journal of Plant Science 64:167-174.

Hill, W.J., J.R. Heckman, B.B. Clarke, and J.A. Murphy. 1999. Take-all patch suppression in creeping bentgrass with manganese and copper. HortScience 34: 891-892.

Jackson, N. 1974. Proceedings of the Second International Turfgrass Research Conference. p. 353-357.

Kaminski, J.E., and P.H. Dernoeden. 2005. Nitrogen source impact on dead spot (*Ophiosphaerella agrostis*) recovery in creeping bentgrass. International Turfgrass Society Research Journal 10:214-223.

Kaminski, J.E. and P.H. Dernoeden. 2006. Dead spot severity, pseudothecia development, and overwintering of *Ophiosphaerella agrostis* in creeping bentgrass. Phytopathology 96: 248-254.

Kaminski, J. E., Dernoeden, P. H. and Fidanza, M. A. 2007. Environmental monitoring and exploratory development of a predictive model for dead spot of creeping bentgrass. Plant Disease. 91:565-573.

Landschoot, P.J. and A.S. McNitt. 1997. Effect of nitrogen fertilizers on suppression of dollar spot disease of *Agrostis stolonifera* L. International Turfgrass Society Research Journal 8: 905-911.

Liu, L.X., Hsiang. T., Carey, K., and J.L Eggens. 1995. Microbial populations and suppression of dollar spot disease in creeping bentgrass with inorganic and organic amendments. Plant Disease 79:144-147.

Malca, I., and R.M. Endo. 1965. Identification of galactose in cultures of *Sclerotinia homoeocarpa* [sic] as the factor toxic to bentgrass. Phytopathology 55:775-780.

McDonald, S.J., P.H. Dernoeden, and C.A. Bigelow. 2006a. Dollar spot and gray leaf spot severity as influenced by irrigation, chlorothalonil, paclobutrazol, and a wetting agent. Crop Science 46:2675-2684.

McDonald, S.J., P.H. Dernoeden and C.A. Bigelow. 2006b. Dollar spot control in creeping bentgrass as influenced by fungicide spray volume and application timing. Online. Applied Turfgrass Science doi: 10.1094-2006-0531-01-RS.

Mills, G. and J. D. Rothwell. 1982. Predicting diseases – the hygrothermograph. Greenmaster 8:14-15.

Monteith, John Jr., 1927. Can you identify brown patch? The National Greenkeeper. June. 1 (6): 7-11, 31.

Monteith, John Jr. 1928. Some diseases of turf grasses. The National Greenkeeper. May. 2 (5) :5-9.

Monteith, J., and A. S. Dahl. 1932. Turfgrass Diseases and Their Control. Bulletin of the United States Golf Association 12:85-186.

Nelson, E.B. and C.M. Craft. 1992. Suppression of dollar spot on creeping bentgrass and annual bluegrass turf with compost-amended topdressing. Plant Disease 76: 954-958.

Pigati, R.L., Dernoeden, P.H., Grybauskas, A.P., and Momen, B. 2010. Simulated rainfall and mowing impact fungicide performance when targeting dollar spot in creeping bentgrass. Plant Dis. 94:596-603.

Powell, J.F., and J.M. Vargas. 1999. Taxonomic clarification of the dollar spot pathogen: *Sclerotinia homoeocarpa* Bennett. Phytopathology 89:S61.

Powell, J.F. and J.M. Vargas. 2001. Vegetative compatibility and seasonal variation among isolates of *Sclerotinia homoeocarpa.* Plant Dis. 85: 377-381.

Powell, J.F. and J.M. Vargas. 2007. Taxonomic clarification of the dollar spot pathogen: *Sclerotinia homoeocarpa.* Phytopathology 97: S134-S135.

Ritchie J.T., D.S. NeSmith (1991) Temperature and crop development. p.5-29. In: Modeling Plant and Soil Systems. J Hanks, JT Ritchie (eds.) ASA, Madison, WI.

SAS Institute Inc., 2004. SAS Online Doc. Version 9.2, SAS Institute, Cary, North Carolina.

Smiley, R. W., P. H. Dernoeden, and B. B. Clarke. 2005. Compendium of Turfgrass Diseases. 3rd ed. American Phytopathological Society, St. Paul, MN, 98 p.

Smith, J.D., N. Jackson, and A.R. Woolhouse. 1989. Fungal Diseases of Amenity Turf Grasses. E. & F.N. Spon, NY.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics : A Biometrical Approach. 2nd ed. McGraw-Hill, Inc. , New York, NY.

United States Golf Association Green Section Staff. 1993. USGA recommendations for a method of putting green construction. USGA Green Section Record 31: 1-3.

United States Environmental Protection Agency. 1999. Reregistation eligibility decision (RED) chlorothalonil. Office of Prevention, Pesticides and Toxic Substances, Washington DC.

Vargas, J. M., Jr. 2005. Management of Turfgrass Diseases. 3rd ed. John Wiley & Sons, Hoboken, NJ.

Walsh, Brenda. 2000. Ph.D. Dissertation: Epidemiology and Disease Forecasting System for Dollar Spot Caused by *Sclerotinia homoeocarpa* F.T. Bennett. University of Guelph (Canada).

Williams, D. W.; Powell, A. J. Jr.; Vincelli, P.; Dougherty, C. T. 1996. Dollar spot on bentgrass influenced by displacement of leaf surface moisture, nitrogen, and clipping removal. Crop Science. September/October. 36(5): p. 1304-1309.

CHRIS RYAN

1800 Light St. #1R, Baltimore, MD 21230 | (765) 430-8633 | cryan@umd.edu

EDUCATION

University of Maryland, College Park, MD
M.S. in Plant Science **2011 (Expected)**
Thesis: "Seasonal Development and Epidemiology of Dollar Spot in Maryland and Nitrogen Effects on Fungicide Performance in Creeping Bentgrass"

Purdue University, West Lafayette, IN
B.S. in Agronomy **2008**
Area of Concentration: Turfgrass Science

AWARDS

Joe Cravens Memorial Scholarship, Purdue University **2007**
Olive K. Smith Scholarship, Purdue University **2006**
Luther V. & Huldah J. Rice Scholarship, Purdue University **2006**

TEACHING EXPERIENCE

University of Maryland, College Park, MD
Teaching Assistant- to Professor Scott Glenn in "Introductory Crop Science" **2008**
Assisted with laboratory instruction, grading quizzes and exams.

RELATED EXPERIENCE

University of Maryland, College Park, MD
Graduate Research Assistant **2008 – Present**
Assist with the design and implementation of research experiments. Collect, analyze and report data. Maintain research areas by scouting for diseases, weeds and insects, as well as irrigation needs and other environmental stresses.

United States Golf Association
Green Section Intern **August 2010**
Accompanied Mid-Atlantic Agronomist on Turf Advisory Service visits. Observed the diagnosis of various golf course issues and resulting recommendations.

Chevy Chase Club, Chevy Chase, MD
Golf Course Maintenance Intern **Summer 2006 and 2007**
Crew management, fertilizer and pesticide calibration and application, mower and aerifier operation, water management.

Birck Boilermaker Golf Complex, West Lafayette, IN
Golf Course Maintenance **May 2003 – Oct. 2005**
General maintenance, mower operation.

PUBLICATIONS AND PAPERS

Dernoeden, P.H. and C.P. Ryan. 2009. Evaluation of cytokinian-plant extract, iron and nitrogen products for their effects on creeping bentgrass summer quality. MTC Turf News 1(4):4, 6, 7.

Ryan, C.P. and P.H. Dernoeden. 2010. Do spoon feeding N or I-Mol improve the ability of Daconil to control dollar spot? MTC Turf News 2(3):4-5.

Dernoeden, P.H and C.P. Ryan. 2011. Smooth crabgrass management with corn gluten, nitrogen and herbicides. Proc. N.E. Weed Sci. Soc. 65:78-79.

Dernoeden, P.H and C.P. Ryan. 2011. Field paspalum control in tall fescue. Proc. N.E. Weed Sci. Soc. 65:84-85.

MEMBERSHIPS

Maryland Turfgrass Council