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University of Maryland scientists compared four chemically diverse fungicides for their abiities to control dollar spot in creeping bentgrass as affected by simulated rain and mowing timing. Simulated rainfall imposed 30 minutes after fungicide application reduced dollar spot control from 33% up to 83% depending on the fungicide, but the incidence of dollar spot was reduced from 54% to 65% by AM mowing in all fungicide-treated plots over two years compared to mowing plots in the PM when the grass was dry.

Volume 10, Number 3
February 1, 2011

PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 450 projects at a cost of $31 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Simulated Rainfall and Mowing Impact Fungicide Performance When Targeting Dollar Spot in Creeping Bentgrass

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SUMMARY

In this two-year field study, four chemically diverse fungicides (i.e., chlorothalonil, Daconil Ultrex; boscalid, Emerald; iprodione, Chipco 26GT; and propiconazole, Banner MAXX) were evaluated for their ability to control dollar spot (*Sclerotinia homoeocarpa*) in creeping bentgrass (*Agrostis stolonifera*) as affected by simulated rain and mowing timing. Simulated rain (25 to 32 mm; 1.0 to 1.25 in.) was imposed about 30 minutes after fungicide application and was compared to rain-free plots. One set of plots was mowed in the AM with dew present and compared to plots that were mowed when the canopy was dry in the PM. Results include:

- The percent reduction in dollar spot control associated with simulated rain versus rain-free treatments in 2007 and 2008 was as follows: chlorothalonil 67 and 83%; propiconazole 42 and 79%; boscalid 48 and 70%; and iprodione 33 and 66%, respectively.
- All fungicides subjected to simulated rain provided effective dollar spot control for 7 or more days following the initial application in each year when disease pressure was low.
- The average percent reduction in dollar spot associated with AM mowing in all fungicide-treated plots over two years ranged from 54 to 65%.
- The reduction in dollar spot severity in AM-mowed plots improved the performance of all fungicides.

Numerous biological agents and cultural practices have shown some success in suppressing dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett). Fungicides, however, remain necessary to maintain acceptable levels of turf quality at most golf courses. The timing of fungicide applications on golf courses can be complicated by special events, heavy play, and weather. Applications are sometimes performed when rain is in the forecast or when unpredicted storm activity develops. Furthermore, golf course fairways are mowed several times weekly, and clippings often are removed. The effects of mowing just prior to and after the application of fungicides are unknown.

Most research to evaluate the effect of rainfall following fungicide application has been conducted on crops other than turf. Chlorothalonil has been the most commonly evaluated fungicide for rain safeness. Studies have shown that increasing the intensity of rainfall increased the amount of chlorothalonil displaced from plant foliage (5, 7). Carroll et al. (2) measured the residence time of three formulations of chlorothalonil on creeping bentgrass foliage after a simulated rainfall event. Flowable, water dispersible granule, and granular chlorothalonil formulations were evaluated, but they did not detect any wash-off differences among formulations for any residence time.

However, there were differences in the level of chlorothalonil displaced depending on length of the rain-free period after fungicide application. They found that 35% of chlorothalonil was displaced from creeping bentgrass foliage when turf was subjected to a rainfall event one hour

Sub-plots were further split into two sub-sub plots (1.5 m x 1.5 m; 5 ft x 5 ft) for the assignment of timing of mowing in the AM (right) or PM(left).

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USGA Turfgrass and Environmental Research Online 10(3):1-13.
TGIF Record Number: 175322

after the fungicide was applied. Simulated rain imposed 8, 24, and 72 hours after application resulted in 10 to 15% of the chlorothalonil being displaced.

Couch (3) conducted a post-application irrigation study on creeping bentgrass that was 60% blighted by *S. homoeocarpa* at the time of fungicide application. Although the study was not repeated, he found that effectiveness of contact fungicides was lost when subjected to irrigation prior to the time fungicides dried on leaves. The performance of penetrants varied and ranged from 50 to 100% effectiveness when subjected to irrigation before drying. All fungicides evaluated, however, provided effective dollar spot control when treated sites were irrigated soon after the chemical had dried on leaves.

The presence of canopy dew is known to increase disease severity in turfgrasses. Disease generally is promoted when leaf wetness duration is prolonged and by nutrients present in guttation fluids. Such nutrients, including amino acids, sugars, and other carbohydrates, can enhance pathogen growth and ability to penetrate tissue (4, 8, 10). Dew on the plant surface also assists the pathogen in adhering itself to the plant surface and in maintaining mycelia turgidity (9). The displacement of dew by mowing or poling in the morning has been shown to decrease the severity of dollar spot (6, 15).

To our knowledge, the effects of simulated or natural rainfall and mowing timing on the performance of fungicides used to target a turfgrass disease have not been studied. Therefore, our objectives in this field study were: (1) to determine the level of dollar spot control provided by four chemically diverse fungicides applied approximately 30 minutes prior to a simulated rain event, and (2) to determine if AM mowing to displace dew prior to fungicide application (and subsequently mowed in the AM) would affect fungicide performance compared to mowing a dry canopy in the PM.

The percent reduction in dollar spot control associated with simulated rain versus rain-free treatments in 2007 and 2008 was as follows: chlorothalonil 67 and 83%; propiconazole 42 and 79%; boscalid 48 and 70%; and iprodione 33 and 66%, respectively.

Material and Methods

This study was conducted in the field at the University of Maryland Paint Branch Turfgrass Research Facility in College Park, MD. Soil was a Keyport silt loam. A 50:50 (vol/vol) blend of 'Crenshaw' and 'Backspin' creeping bentgrass was established in September 2006 in eight, 3.1 m x 12.2 m independently irrigated main plots. Each main plot was outfitted with pop-up, matched precipitation spray irrigation heads. Since it has been shown that a turfgrass irrigation system can be employed to effectively simulate rainfall (1), the term simulated rain or rain will be used to describe these treatments. Prior to initiating the study in 2007 and 2008, the irrigation system was calibrated by placing 18 cans in each main plot and irrigation heads were adjusted as needed to ensure uniform water delivery. The amount of water delivered to each main plot ranged from 25 to 32 mm (1.0 to 1.25 in.) after 8 minutes.

In a 2006 pilot study, few differences in dollar spot control were detected among the same fungicides and rates assessed in the current study using about 6.5 mm (0.25 in.) of simulated rain 60 minutes after fungicide application. In the current study, the amount of simulated rain was increased and duration between fungicide application and simulated rainfall was reduced. Four main plots received approximately 25 to 32 mm of water in an 8-minute period within 30 to 40 minutes of fungicide application, as described below. Otherwise, plots were not irrigated for several days or until there were visual signs of wilt.

In 2007 and 2008, the following fungicides and rates were assessed: chlorothalonil (tetrachloroisophthalonitrile; Daconil Ultrex 87.5 DG; Syngenta Crop Protection, Inc., Greensboro, NC.) applied at 3.2 oz product/ 1000 ft^2 = 8.1 kg a.i. ha^{-1}; propiconazole [(1-(2-(2',4'-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl-methyl)-1H-1,2,4-triazole; Banner MAXX 1.3 ME; Syngenta Crop Protection, Inc., Greensboro, NC] applied at 1.0 fl. oz product /1000 ft^2= 0.5 kg a.i. ha^{-1} ; iprodione [3-(3,5-dichlorophenyl)-N-(1-methylethyl)-2, 4-dioxo-1-imidazolidinecarboxamide; Chipco 26GT 2SC; Bayer Environmental Sciences, Research Triangle Park, NC] applied at 4.0 fl. oz product /1000 ft^2 = 3.1 kg a.i. ha^{-1} ; and boscalid [3-pyridinecarboxamide, 2-chloro-N-(4'-chloro(1,1'-biphenyl)-2-yl]; Emerald 70WG; BASF Corporation, Research Triangle Park, NC] applied at 0.13 oz product/ 1000 ft^2 = 0.28 kg a.i. ha^{-1}. To minimize the influence of fungicide effects and inoculum levels from the previous year, the simulated rainfall main plots and mowing treatments were reversed in the second year, and fungicide treatments were re-randomized.

In both years, main plots for the simulated rain treatments were split into 1.5 m x 3.1 m (5 ft x 10 ft) sub-plots within which the four fungicide treatments and one untreated control were applied randomly. Sub-plots were further split into two sub-sub plots (1.5 m x 1.5 m; 5 ft x 5 ft) for the assignment of timing of mowing in the AM or PM. One set of sub-sub plots was mowed and clippings removed prior to each fungicide application at about 0700 hours when the canopy was wet. These AM plots always were mowed in the morning throughout the study (i.e., AM-mowed). The other sub-sub plots were mowed the day following each fungicide application after the canopy was dry and always were mowed thereafter when dry in the PM (i.e., PM-mowed typically after 1200 hours). Plots were mowed three times a week to a height of about 12 mm (0.47 in.) and clippings were removed. All fungicides were applied in 468 liters of water ha^{-1} (i.e., 50 GPA) using a CO_2-pressurized backpack sprayer (262 kPa; 35 psi) equipped with an 8004E Tee Jet flat fan nozzle.

All fungicides initially were applied between 0730 and 0800 hours on July 3, 2007 and August 7, 2008 when dollar spot was active, but disease pressure was low and averaged less than 5 *S. homoeocarpa* infection centers (ICs) per sub-sub plot. It required less than 10 minutes to apply all treatments so that simulated rain was imposed about 30 to 40 minutes after the last and first treatments were applied, respectively. Since the canopy remained moist in AM-mowed plots by the time the last treatment was applied, it is not likely that any chemical had fully dried on foliage for any one treatment prior to being subjected to simulated rain.

Dollar spot was assessed by counting the number of *S. homoeocarpa* infection centers per plot. A reapplication threshold of 20 infection centers was chosen to ensure that creeping bentgrass did not sustain severe damage and more rapid recovery would occur after fungicide reapplication. A fungicide was reapplied when the average number of infection centers exceeded 20 in two of four replicates of a fungicide within a simulated or rain-free treatment in 2007. When the threshold was reached, which occurred first in simulated rain plots, all simulated and rain-free plots within each fungicide treatment were retreated. Respraying of the plots was limited to that fungicide treatment where the infection center threshold was reached.

In 2008, a chemical was not reapplied until all four replicates of each fungicide within a rain treatment had exceeded the 20-infection center threshold. It should be noted that the thresholds were not intended to mimic accepted levels of dollar spot for golf courses. Thresholds were used in this study as a guideline for the reapplication of fungicides and as a point of reference for the discussion of results. Application dates are shown in the figures.

It is not unusual for dollar spot symptoms to subside following an early summer epidemic in May and June in Maryland, and turf can recover partially or fully prior to a late summer epidemic. Sustained and severe dollar spot epidemics, however, are common in mid-to-late summer in Maryland (11). To avoid fluctuations in dollar spot activity, the study area was kept dollar spot-free during early summer epidemics in both years. Hence, treatments were not imposed until July 3, 2007 and August 7, 2008, when sustained and severe dollar spot pressure was most likely.

Treatments were arranged in a randomized complete block split-split plot design with four replications. A description of the statistical analyses can be found in Pigati et al. (12). Two statistical tests were heavily relied upon and are referred to as Area Under the Disease Progress Curve (AUDPC) and orthogonal pre-planned comparisons. The AUDPC allowed us to combine data where appropriate to describe the amount of disease present in a treatment over the season with a single number. The larger the number, the more disease was present. It is a powerful test that simplifies and makes clear the most important statistical difference among treatments. We also used planned comparison, which also allowed us to combine data over time where appropriate for comparing rain versus no rain and AM versus PM test parameters.

	AUDPC					
	2007			2008		
Fungicide	**Rain[x]**	**Rain-free[y]**	**P-level**	**Rain**	**Rain-free**	**P-level**
Chlorothalonil	726	237	0.002	1,123	196	0.002
Propiconazole	658	382	0.059	528	112	0.057
Boscalid	364	191	0.225	321	96	0.255
Iprodione	428	288	0.324	363	123	0.228
Average	544	274	0.037	536	153	0.081

[x]Plots were subjected to simulated rain (25 to 32 mm) within about 30 minutes of fungicide application.

[y]Plots were not subjected to simulated rain or irrigated within 24 hours of fungicide application.

Table 1. Area under the disease progress curve (AUDPC) and probability of significance for four fungicides targeting *S. homoeocarpa* in creeping bentgrass and subjected to simulated or rain-free treatment in 2007 and 2008.

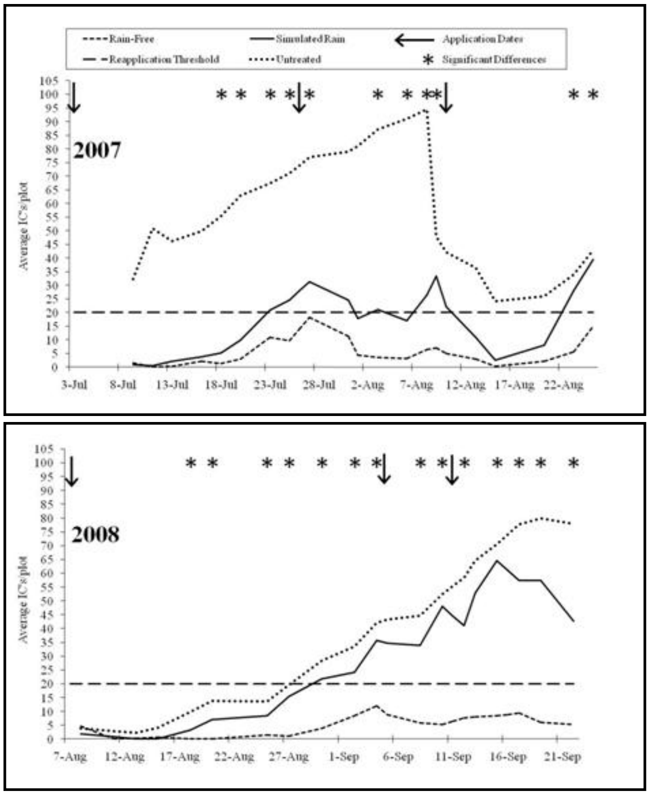

Figure 1. *Sclerotinia homoeocarpa* infection centers in plots treated with chlorothalonil and subjected to simulated rain versus rain-free plots in 2007 and 2008. Pre-planned orthogonal contrasts on dates marked by different symbols are significantly different based on Fisher's protected least significant difference test at P≤ 0.05.

Results

Simulated Rain

Dollar spot developed faster and was more severe in 2007 than 2008. When averaged over fungicide treatments, there was more dollar spot in simulated rain versus rain-free plots in 2007 and 2008 as measured by AUDPC (Table 1). On individual rating dates, there was one rating date in 2007 and 11 dates in 2008 when there was a significant rain x chemical interaction, thus only pre-planned contrasts will be discussed. Dollar spot resurgence (i.e., a rapid increase in blighting) occurred in all fungicide-treated plots by late August in 2007, but none occurred in 2008.

There was a greater amount of dollar spot in chlorothalonil-treated plots subjected to rain versus rain-free in both 2007 and 2008 (Table 1). Significantly more infection centers developed in chlorothalonil-treated plots subjected to rain compared to rain-free plots on 11 of 18 rating dates in both years (Figure 1). Chlorothalonil-treated plots subjected to rain had dollar spot levels that exceeded the reapplication threshold 3 times during the season, whereas, rain-free plots had dollar spot levels below the threshold on all dates in both years. Chlorothalonil-treated plots subject to rain first exceeded the threshold 20 days after the initial application on July 23, 2007. Blighting increased for 24 hours before the number of infection centers dropped below the threshold and remained suppressed for about 6 days.

The threshold was again exceeded on August 3, 2007 in rain-treated plots only. Dollar spot levels fell sharply in rain plots following the third chlorothalonil application to very low levels by August 15, but increased rapidly thereafter and exceeded the threshold on August 23, 2007. Once the threshold was exceeded in 2008, plots subjected to rain after subsequent chlorothalonil applica-

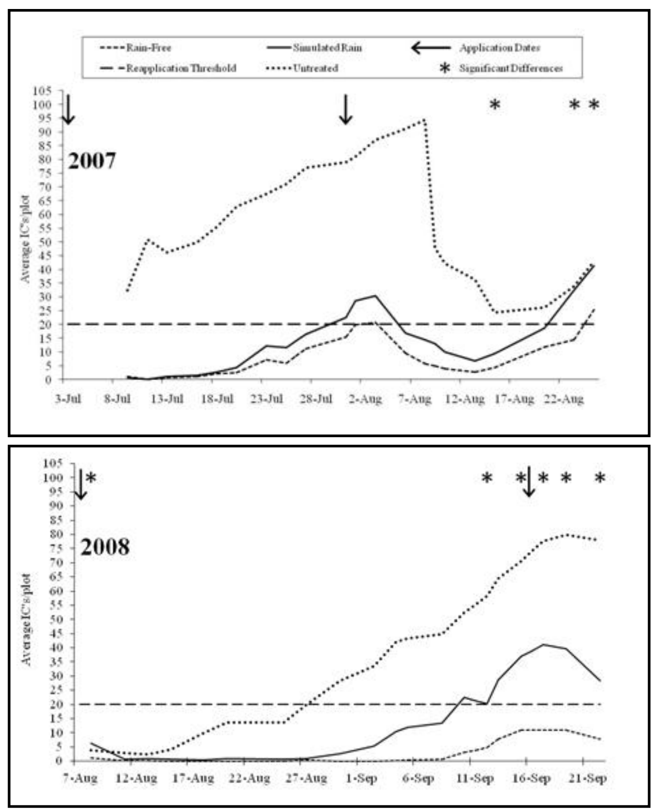

Figure 2. *Sclerotinia homoeocarpa* infection centers in plots treated with propiconazole and subjected to simulated rain versus rain-free plots in 2007 and 2008. Pre-planned orthogonal contrasts on dates marked by different symbols are significantly different based on Fisher's protected least significant difference test at P≤ 0.05.

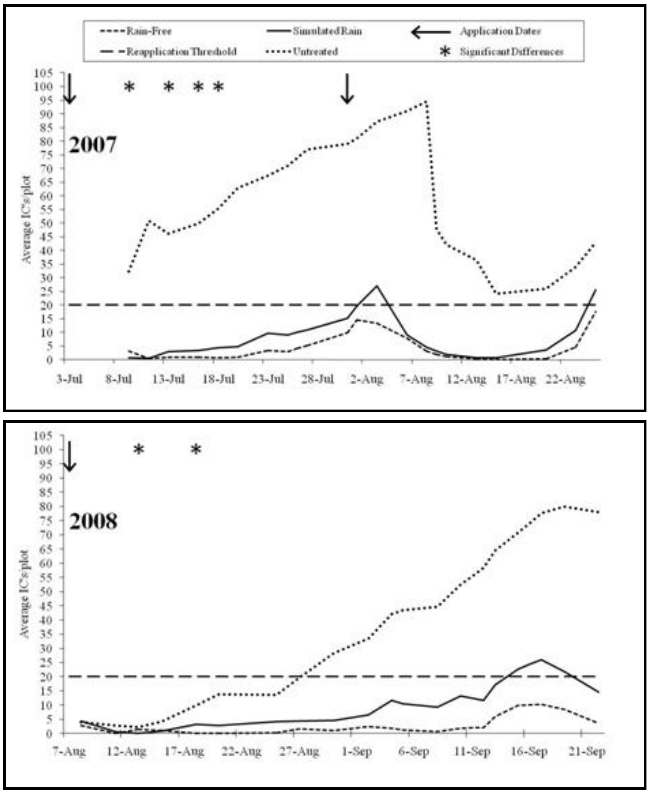

Figure 3. *Sclerotinia homoeocarpa* infection centers in plots treated with boscalid and subjected to simulated rain versus rain-free plots in 2007 and 2008. Pre-planned orthogonal contrasts on dates marked by different symbols are significantly different based on Fisher's protected least significant difference test at P≤ 0.05.

tions had dollar spot levels that remained above the threshold.

There was more dollar spot in rain versus rain-free propiconazole-treated plots in 2007 and 2008 (Table 1). Significantly more infection centers developed in rain versus rain-free propiconazole-treated plots on 3 assessment dates in 2007 and on 5 assessment dates in 2008 (Figure 2). Propiconazole-treated plots subjected to rain had dollar spot levels that exceeded the reapplication threshold twice in 2007 and once in 2008. Following the second propiconazole application in 2007, blight ratings continued to increase for 3 days before declining below the threshold. On August 23 and 25, 2007, dollar spot levels exceeded the threshold in rain and rain-free plots, respectively. In 2008, dollar spot rose to the threshold on September 10 in the rain plots and remained above the threshold for the remainder of the study. Rain-free plots only exceeded the threshold at the end of the season in 2007. However, rain-free plots treated with propiconazole did not exceed the threshold on any date in 2008.

Although a similar pattern of greater dollar spot levels in rain versus rain-free plots were observed for boscalid and iprodione, the AUDPC data were not significantly different for either fungicide in both years (Table 1). There were significantly more infection centers in rain versus rain-free plots on several dates early in the season for boscalid (Figure 3) and on a few late dates for iprodione (Figure 4) in both years, but the differences were small. The reapplication threshold was exceeded on two to three dates in 2007 and 2008 for both fungicides in plots subjected to rain. The threshold was not exceeded in rain-free plots treated with boscalid (2007 and 2008) or iprodione (2008). Rain-free plots treated with iprodione only exceeded the threshold in late August 2007, about 21 days since the fungicide was last applied.

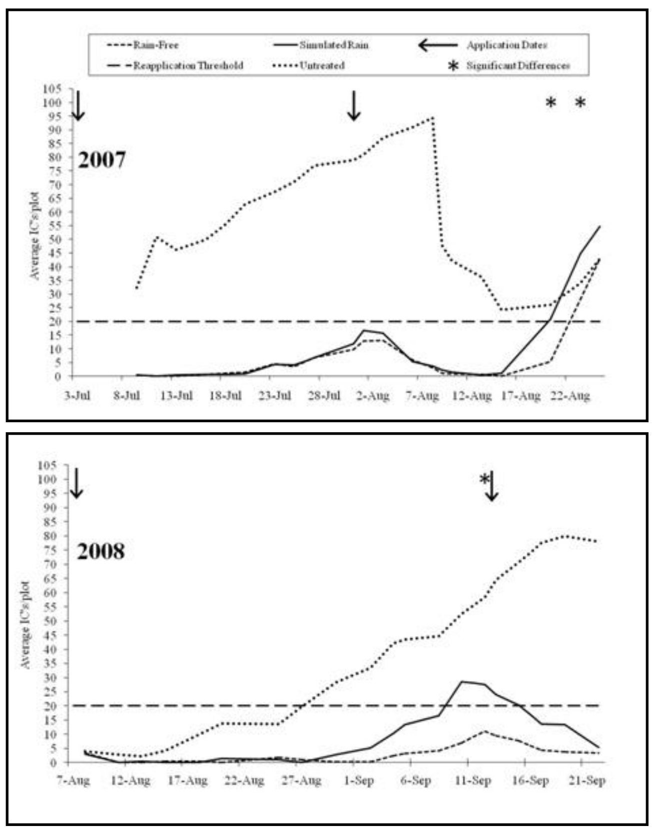

Figure 4. *Sclerotinia homoeocarpa* infection centers in plots treated with iprodione and subjected to simulated rain versus rain-free plots in 2007 and 2008. Pre-planned orthogonal contrasts on dates marked by different symbols are significantly different based on Fisher's protected least significant difference test at P≤ 0.05.

	AUDPC					
	2007			2008		
Fungicide	AM[x]	PM[y]	P-level	AM	PM	P-level
Chlorothalonil	253	711	0.003	325	995	< 0.001
Propiconazole	349	691	0.022	201	439	0.132
Boscalid	154	401	0.089	81	336	0.109
Iprodione	272	444	0.227	113	373	0.101
Average	257	561	0.022	180	510	0.025

[x]Plots were mowed prior to each fungicide application in the morning to remove dew; thereafter, plots always were mowed in the morning in the presence of dew.

[y]Plots were mowed in the afternoon 24 hours following each fungicide application; thereafter, plots always were mowed in the afternoon when the canopy was dry.

Table 2. Area under the disease progress curve (AUDPC) and probability of significance for four fungicides targeting *S. homoeocarpa* and applied to creeping bentgrass subjected to AM and PM mowing in 2007 and 2008.

AM versus PM mowing

Less dollar spot developed in AM- versus PM-mowed plots (Table 2). Chlorothalonil performance was most greatly impacted by mowing ($P = 0.003$ in 2007 and $P < 0.001$ in 2008). Propiconazole and boscalid also performed better with AM mowing, especially in 2007 when disease pressure was greater ($P= 0.022$ and $P=0.089$, respectively). Differences between mowing timings were first observed for chlorothalonil-treated plots on July 18, 2007 and on August 20, 2008. Dollar spot levels were greater in PM- versus AM-mowed plots on most rating dates thereafter (Figure 5). Dollar spot levels generally remained below the threshold on most dates in AM-mowed plots, but exceeded the threshold in PM-mowed plots three times in 2007 and once in 2008. There was a greater tendency to remain near or above the threshold in PM-mowed plots once the threshold was exceeded.

Propiconazole also performed better in AM- versus PM-mowed plots (Table 2). The only date prior to the second application when significantly fewer infection centers were observed in AM- versus PM-mowed plots was July 20, 2007 (Figure 6). Following propiconazole reapplication in 2007, there were fewer infection centers in AM- versus PM-mowed plots on most rating dates. There were no mowing differences among individual rating dates in 2008.

Dollar spot levels generally were lower in AM- versus PM-mowed plots treated with boscalid (Figure 7). However, due to variation and somewhat better disease suppression the P-levels for differences in AUDPC ranged from $P = 0.089$ to 0.109 during the study period. The numbers of infection centers were significantly higher in boscalid-treated plots subjected to PM versus AM mowing on 7 of 19 rating dates in 2007, and on 3 of 18 rating dates in 2008 (Figure 7).

There were no significant AUDPC or individual rating date differences for the mowing timings in iprodione-treated plots in 2007 (Table 2 and Figure 8). There was less dollar spot ($P = 0.101$) in AM- than PM-mowed plots treated with iprodione in 2008. Dollar spot levels were greater in PM- versus AM-mowed plots on only September 8, 10, and 12, 2008.

Discussion

The objective of the study was not to compare the level of dollar spot control among fungicides, but to compare their individual performance as influenced by simulated rain and mowing timing. Both rain and mowing timing affected

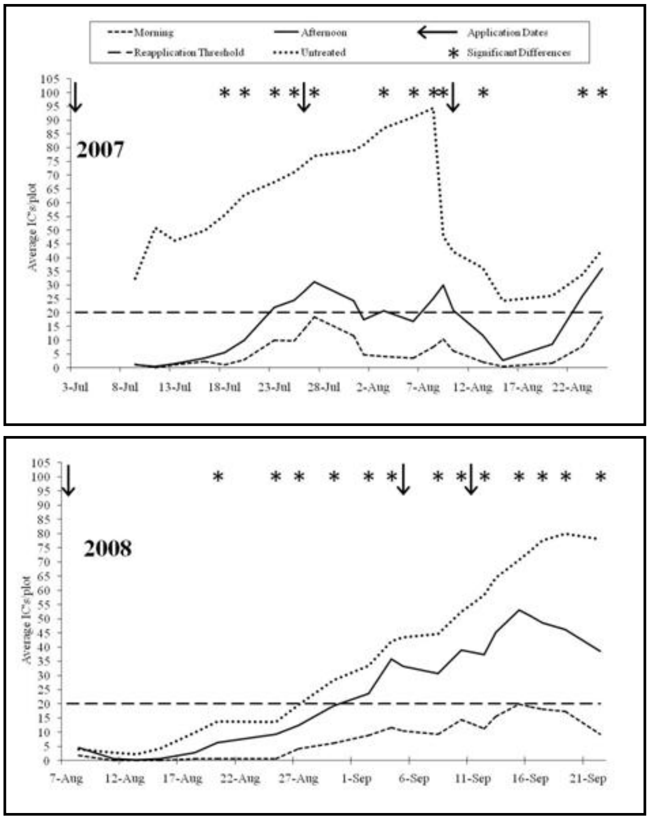

Figure 5. *Sclerotinia homoeocarpa* infection centers in plots treated with chlorothalonil and subjected to AM versus PM mowing in 2007 and 2008. Pre-planned orthogonal contrasts on dates marked by different symbols are significantly different based on Fisher's protected least significant difference test at P≤ 0.05.

Chlorothalonil is a contact protectant (i.e., active ingredient remains on plant surfaces), whereas, the other fungicides are penetrants (i.e., some active ingredient translocates into the plant). Penetrants are protected by virtue of some active ingredient being taken up into tissue, whereas, the active ingredient of a contact fungicide is likely to be diminished more rapidly on plant surfaces by environmental forces. As expected, the contact protectant (i.e., chlorothalonil) required more frequent application since its residual effectiveness was shorter-lived than the penetrants evaluated.

A measure of the influence of rain may be to compare the percentage or number of days each fungicide provided a level of dollar spot control that was above or below the threshold. A reapplication threshold was employed to determine potential differences among treatments, but was not intended to represent disease levels that would fungicide performance. There were differences in disease levels and fungicide performance between years. There was less effective dollar spot control in rain-free plots in 2007 than in 2008. Dollar spot increased in intensity more rapidly after the first application in 2007 than occurred in 2008. Furthermore, dollar spot resurgence was associated with all fungicides in 2007, but none in 2008. Resurgence is defined as a rapid and severe recurrence of a disease in turfs previously treated with fungicides compared to sites that had not been treated, but the mechanism is unknown (14). Finally, it should be noted that the cultivars grown (i.e., blend of 'Backspin' and 'Crenshaw') are extremely susceptible to dollar spot, which was a factor that may have impacted the results.

Plots subjected to rain and PM mowing sustained far more dollar spot injury than rain-free and AM-mowed plots in both 2007 and 2008.

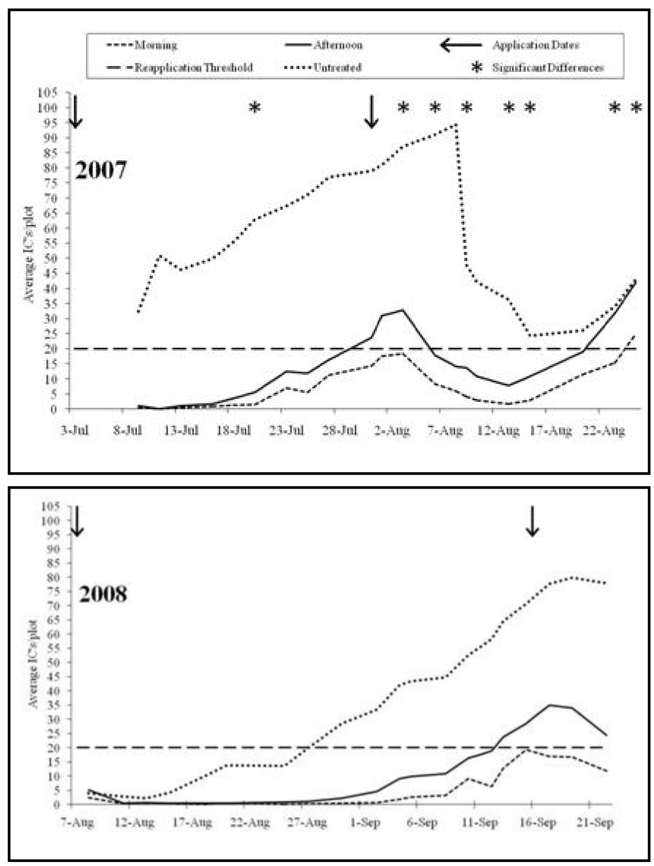

Figure 6. *Sclerotinia homoeocarpa* infection centers in plots treated with propiconazole and subjected to AM versus PM mowing in 2007 and 2008. Pre-planned orthogonal contrasts on dates marked by different symbols are significantly different based on Fisher's protected least significant difference test at P≤ 0.05.

This research has shown that while rain within about 30 minutes of fungicide treatment diminished the level of dollar spot control over the long term it does not render them ineffective. This was especially true following the initial application of all fungicides in both years when disease pressure was low.

be considered acceptable by golf course superintendents. The ranges in the percentage of days when *S. homoeocarpa* infection centers were below the threshold for each fungicide subjected to rain versus rain-free were as follows: chlorothalonil 55 to 66% versus 100% of days; propiconazole 80 to 83% versus 98 to 100% of days; boscalid 89 to 100% versus 100% of days; and iprodione 82 to 94% versus 96 to 100% of days in 2007 and 2008, respectively. All fungicides applied to rain-free plots generally provided a level of dollar spot control that was below the threshold.

Another measure of the influence of rain may be to examine the percent difference in infection centers between rain and rain-free treatments. The greater the percentage, the less rain-safe a fungicide would be. The ranges in the percentage of dollar spot reduction in rain versus rain-free plots for each fungicide treatment averaged over all rating dates in both years were as follows: chlorothalonil = 67 to 83% (two year average = 75%); propiconazole = 42 to 79% (average = 60%); boscalid = 48 to 70% (average = 59%); and iprodione = 33 to 66% (average = 50%). Clearly, chlorothalonil was most negatively impacted by simulated rain.

The larger AUDPC values and more numerous dates when propiconazole-treated plots subjected to rain were above the threshold following the second application in each year compared to the other penetrants indicated that propicona-

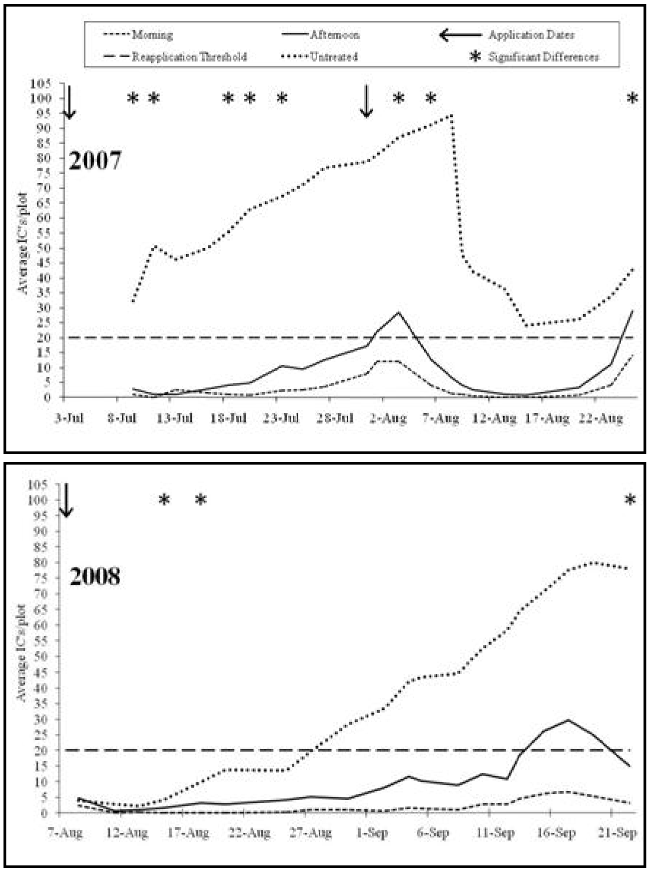

Figure 7. *Sclerotinia homoeocarpa* infection centers in plots treated with boscalid and subjected to AM versus PM mowing in 2007 and 2008. Pre-planned orthogonal contrasts on dates marked by different symbols are significantly different based on Fisher's protected least significant difference test at P≤ 0.05.

zole provided an intermediate level of rain safeness. Boscalid and iprodione generally were the most rain-safe fungicides evaluated. It should be noted, however, that *S. homoeocarpa* isolates from the study site were shown to be less sensitive to propiconazole than base-line isolates in Petri dish tests. Isolates from boscalid and iprodione-treated plots were equal in sensitivity to base-line isolates. Hence, the reduced sensitivity of the pathogen population to propiconazole in the study site may have influenced these results.

Most previous studies involving chlorothalonil and other contact fungicides generally demonstrated that a high intensity rainfall removed more fungicide from plant surfaces than a low intensity rainfall (2, 7). Average AUDPC data from the current study showed that simulated rain reduced the ability of the fungicides to control dollar spot. In this study, plots were subjected to a simulated rain event, which delivered water at a rate of approximately 19 to 24 cm h^{-1} (7.5 to 9.5 in. h^{-1}) for 8 minutes. A rainfall event of this intensity, having duration of 5 minutes, has a return frequency of 25 to 100 years. However, it is not unusual in Maryland for a rain event lasting several hours to deliver 25 mm (1.0 inch) or more water. Despite the high level of simulated rain, chlorothalonil provided at least 7 days of effective control following the initial application in both years when disease pressure was generally low but intensifying.

In a one-application study that was not repeated, Couch (3) observed that the effects of chlorothalonil and iprodione were rendered ineffective in controlling dollar spot curatively when irrigating turf prior to the fungicide drying on

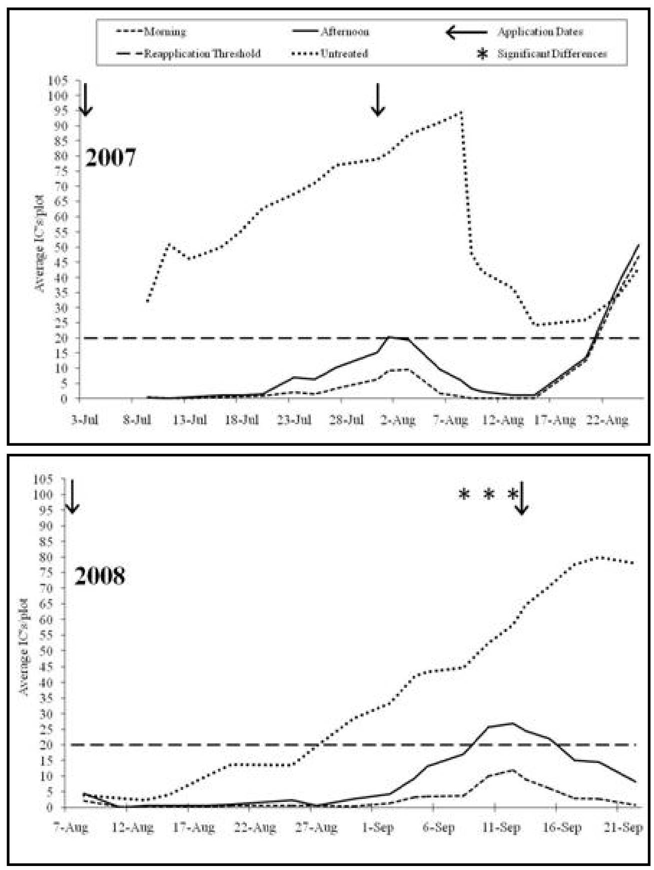

Figure 8. *Sclerotinia homoeocarpa* infection centers in plots treated with iprodione and subjected to AM versus PM mowing in 2007 and 2008. Pre-planned orthogonal contrasts on dates marked by different symbols are significantly different based on Fisher's protected least significant difference test at P≤ 0.05.

foliage. Couch (3) also reported that two penetrants in the same chemical group as propiconazole (i.e., fenarimol and triadimefon) provided about 50 to 100% control when plots were irrigated before the chemicals had time to dry on surfaces. The three penetrants evaluated in this study provided a minimum of 10 days of effective control in rain plots following the initial application. About 35% of chlorothalonil can be displaced from creeping bentgrass foliage by rain within 1 hour of application (2).

Thus, it is likely that the generally poor performance of chlorothalonil, compared to rain-free plots, was due to its displacement from leaf surfaces by rain. It is speculated that significant amounts of boscalid, iprodione, and propiconazole entered plant foliage directly or possibly from between sheaths within 30 minutes of application, but before the spray suspension could dry on the canopy. It also is likely that some of these fungicides were absorbed by roots. Since formulation can impact fungicide performance, these findings only may apply to the formulations evaluated (13).

Mowing in the AM versus PM had a large impact on decreasing disease pressure in both years. There were 54% (2007) and 65% (2008) fewer infection centers in plots subjected to AM versus PM mowing when data were averaged over all fungicides and rating dates in each year. The average percent of dollar spot reduction in AM versus PM mowed plots for each fungicide in 2007 and 2008 was as follows: chlorothalonil = 64% and 67%; propiconazole = 50% and 54%; boscalid = 62% and 76%; iprodione = 39% and 70%, respectively. Untreated control data were not included in the analyses for fungicide treatments, However, there was a 26% ($P = 0.088$) and 23% ($P = 0.134$) reduction in dollar spot (i.e., AUDPC) in AM- versus PM-mowed control plots in 2007 and 2008, respectively (data not shown). Except for iprodione in late August 2007, there were no dates in either year when plots subjected to AM mowing were above the threshold for any fungicide. Hence, the lower levels of dollar spot attributed to AM mowing improved the performance of all fungicides.

Williams et al. (15) reported that displacement of dew by mowing at 0700 hours (7 AM) on fairway-height creeping bentgrass reduced the number of *S. homoeocarpa* infection centers 37 to 78% on selected rating dates compared to plots mowed at 1400 hours (2 PM). Ellram et al. (6) found that plots that had dew displaced at 0400 hours (4 AM) had about 40% less dollar spot compared to plots subject to dew removal at 1000 hours (10 AM) and about 15% less disease when dew was displaced at 2200 hours (10 PM). Results of the current study confirm the beneficial effect of AM mowing on reducing dollar spot severity in fungicide-treated turf.

Our observations indicate that another important factor in reducing dollar spot severity was the physical disruption of foliar *S. homoeocarpa* mycelium by mowing. Mowing in the morning not only would reduce leaf wetness duration, but it physically disrupted and/or removed or otherwise displaced foliar mycelium. Furthermore, mycelium in infected tissue also would have been removed by collecting clippings. This could explain why Ellram et al. (6) found that mowing to displace dew was more effective than the squeegee in reducing dollar spot severity. It should be noted, however, that Williams et al. (1996) found little effect of collecting versus returning clippings on dollar spot injury.

Conclusions

In conclusion, this research has shown that while rain within about 30 minutes of fungicide treatment diminished the level of dollar spot control over the long term, it does not render them ineffective. This was especially true following the initial application of all fungicides in both years when disease pressure was low but increasing. Subsequent applications of chlorothalonil generally were not effective in reducing dollar spot below the threshold when subjected to rain. When subjected to rain, boscalid, iprodione, and propiconazole provided effective control for 10 or more days following the initial application and were more effective in subsequent applications when disease pressure was higher compared to chlorothlonil.

The results of this study have shown that if rain is forecast and it is deemed necessary to apply a fungicide targeting dollar spot, boscalid and iprodione would be the preferred products. Chlorothalonil use should be avoided if rain is likely, but propiconazole would be preferred to chlorothalonil. Data showed that under low dollar spot pressure, fungicides do no need to be reapplied immediately following a rain event occurring within about 30 minutes of treatment. However, under high dollar spot pressure, rain within 30 minutes can diminish performance to below acceptable limits for golf course superintendents. Finally, this study showed that AM mowing can greatly reduce dollar spot severity and thus improve fungicide performance.

Acknowledgements

We thank Michael Agnew, Ph.D., Senior Field Technical Manager, Syngenta Crop Protection, Inc.; Eastern Shore Association of Golf Course Superintendents; Mid-Atlantic Association of Golf Course Superintendents, and the USGA's Turfgrass and Environmental Research Program for their interest in and financial support of this project. We are grateful to Michael Newnam, Bayer Environmental Services, and Gilberto Olaya, Ph.D., Syngenta Crop Protection for testing isolates of *Sclerotinia homoeocarpa* from the study site for sensitivity to the fungicides evaluated.

Literature Cited

1. Bell, G., and K. Koh. 2008. A comparison of rainfall simulation and turfgrass irrigation for their effects on nutrient runoff from bermudagrass. *Agron. Abstr*. C-05-649-9. (TGIF Record 145181)

2. Carroll, M. J., R. L. Hill, E. Pfeil, and J. M. Krouse. 2001. Effect of residence time on washoff of chlorothalonil from turf foliage. *Int. Turfgrass Soc. Res. J.* 9:1-5. (TGIF Record 74179)

3. Couch, H. B. 1985. Effect of post-spray rainfall or irrigation on the effectiveness of fungicides. *Golf Course Management* 53(2):50-58. (TGIF Record 7804)

4. Curtis, L. C. 1944. The exudation of glutamine from lawn grasses. *Plant Physiology* 19:1-5. (TGIF Record 171448)

5. Elliott, V. J., and H. W. Spurr, Jr. 1993. Temporal dynamics of chlorothalonil residues on peanut foliage and the influence of weather factors and plant growth. *Plant Dis.* 77:455-460.

6. Ellram, A., B. Horgan, and B. Hulke. 2007. Mowing strategies and dew removal to minimize dollar spot on creeping bentgrass. *Crop Sci.* 47:2129-2136. (TGIF Record 128769)

7. Fife, J. P., and S. E. Nokes. 2002. Evaluation of the effect of rainfall intensity and duration on the persistence of chlorothalonil on processing tomato foliage. *Crop Protection* 21:733-740.

8. Goatley, J. L., and R. W. Lewis. 1966. Composition of guttation fluid from rye, wheat, and barley seedlings. *Plant Physiology* 41:373-375.

9. Jackson, N., and F. L. Howard. 1966. Fungi as agents of turfgrass disease. *J. Sports Turf Res. Institute* 42:9-16. (TGIF Record 75103)

10. Marion, D. F. 1974. Leaf surface fluid composition of velvet bentgrass as affected by nitrogen fertility and its relationship to inoculum viability of *Gloeocercospora sorghi* and severity of copper spot disease. Ph.D. Diss. Univ. of Rhode Island, Kingston RI. (TGIF Record 171608)

11. McDonald, S. J., P. H. Dernoeden, and C. A. Bigelow. 2006. Dollar spot and gray leaf spot severity as influenced by irrigation, chlorothalonil, paclobutrazol, and a wetting agent.

Crop Sci. 46:2675-2684. (TGIF Record 119223)

12. Pigati, R. L., P. H. Dernoeden, A. P. Grybauskas, and B. Momen. 2010. Stimulated rainfall and mowing impact fungicide performance when targeting dollar spot in creeping bentgrass. *Plant Dis.* 94:596-603. (TGIF Record 162561)

13. Shepard, D., M. Agnew, M. Fidanza, J. Kaminski, and L. Dant. 2006. Selecting nozzles for fungicide spray applications. *Golf Course Management* 74(6):83-88. (TGIF Record 111793)

14. Smiley, R. W., P. H. Dernoeden, and B. B. Clarke. 2005. Compendium of turfgrass diseases. 3rd ed. American Phytopathological Society, St. Paul, MN. (TGIF Record 105934)

15. Williams, D. W., A. J. Powell, Jr., P. Vincelli, and C. T. Dougherty. 1996. Dollar spot on bentgrass influenced by displacement of leaf surface moisture, nitrogen, and clipping removal. *Crop Sci.* 36:1304-1309. (TGIF Record 31042)