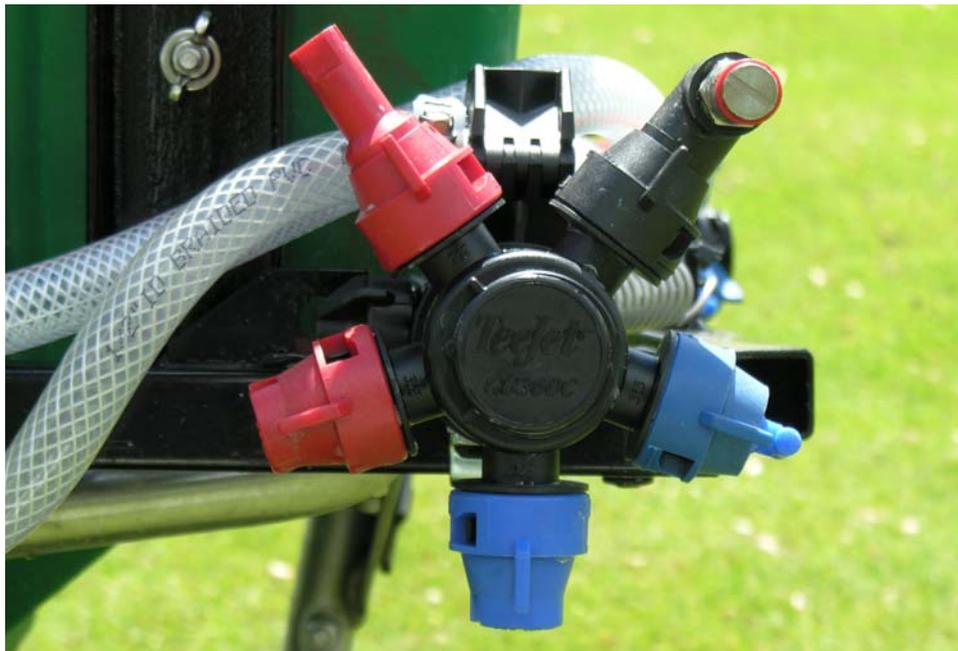


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This research consisted of four identical field studies conducted in two locations in Connecticut and Pennsylvania in 2005. The purpose of this study was to examine the impact of nozzle type and fungicide mode of activity on fungicide performance for dollar spot control in creeping bentgrass. The specific objectives were: 1) to evaluate fungicide efficacy when delivered through five different nozzle types, and 2) to elucidate any interactions among nozzle type and fungicide mode of activity.

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 400 projects at a cost of \$30 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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Dollar Spot Severity as Influenced by Fungicide Mode of Activity and Spray Nozzle

John E. Kaminski and Michael A. Fidanza

SUMMARY

This research consisted of four identical field studies conducted in two locations in Connecticut and Pennsylvania in 2005. The purpose of this study was to examine the impact of nozzle-type and fungicide mode of activity on fungicide performance for dollar spot control in creeping bentgrass. The specific objectives were: 1) to evaluate fungicide efficacy when delivered through five different nozzle types, and 2) to elucidate any interactions among nozzle type and fungicide mode of activity.

- Regardless of nozzle type evaluated in this study, all fungicides reduced dollar spot compared to the untreated control.
- The 1/4TTJ04 nozzle produced the largest water droplet size and provided highly variable and often times poor control of dollar spot regardless of fungicide mode of activity.
- In years where dollar spot pressure is low, the impact of nozzle type on disease control may not be observed. During periods of high dollar spot pressure, however, the impact of nozzle likely plays a larger role in the suppression of the disease.

Dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) continues to be one of the most chronic and problematic diseases of golf course turf in the United States. Due to the severity and destructive nature of dollar spot in high-value turf, fungicides are considered a key component in most management strategies or programs (5, 8).

Studies have reported on the efficacy of fungicides when applied at varying water volumes or through different nozzle types. Couch (4) showed that contact fungicides were most effective at a lower water volume (e.g., 407 L ha⁻¹, 43.5 gal acre⁻¹) and systemic-type fungicides more effective at higher water volume (e.g., 814 L ha⁻¹, 87 gal acre⁻¹). Improved suppression of dollar

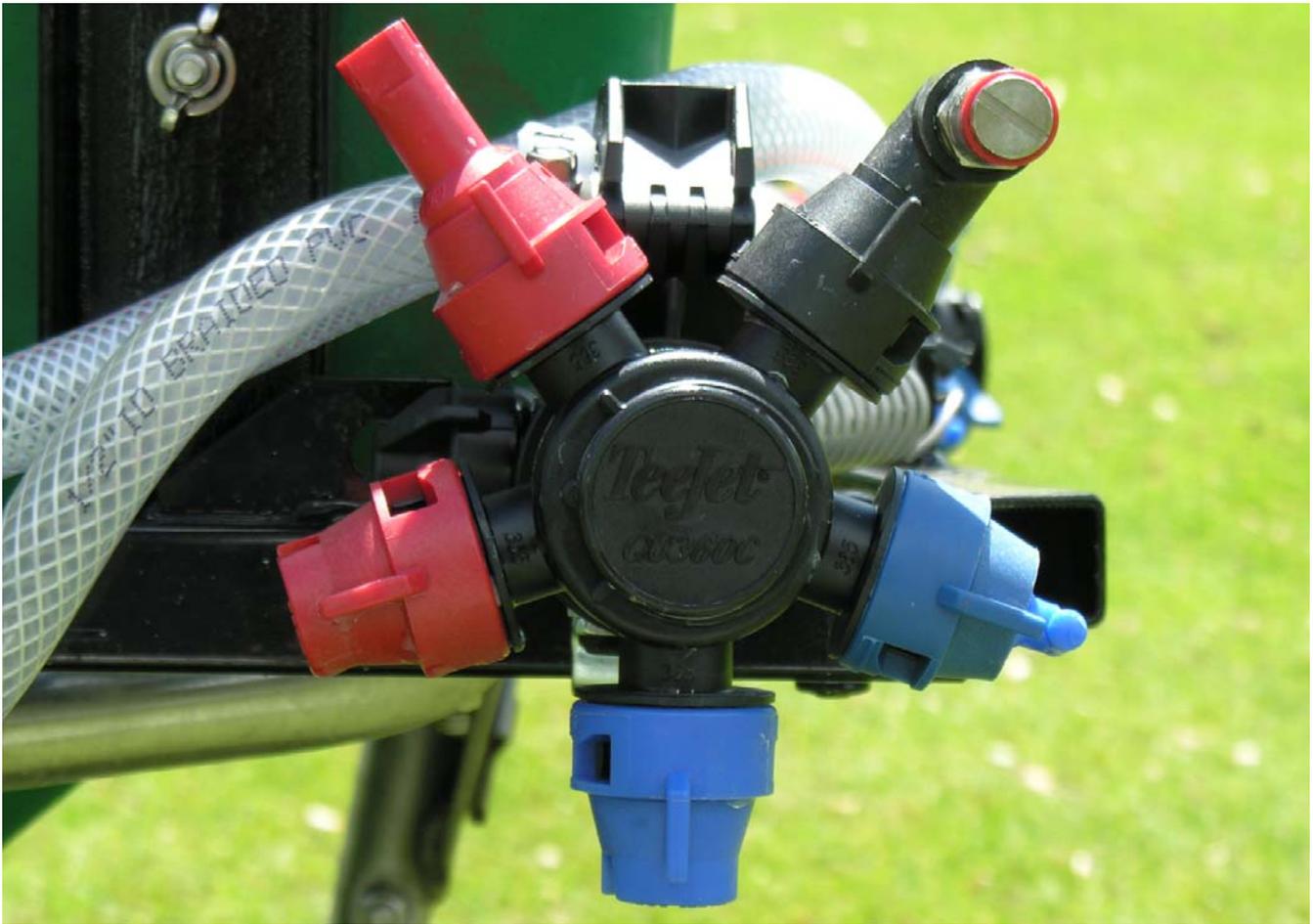
spot in creeping bentgrass from nozzles that produce smaller droplet sizes have also been recently reported with the use of contact fungicides (7, 12, 16). However, turfgrass managers often apply tank-mixes of fungicides with varying modes of activity (e.g., contact or systemic type categorized as acropetal or localized penetrant, etc.) in lower water volumes in the interest of saving labor expenses and time (2).

Fungicide programs are commonly recommended to manage diseases in turf maintained as golf course greens, tees, and fairways (1), and optimum fungicide delivery has become a critical factor to ensure a successful disease control outcome (2, 4, 12, 15). In recent years, many turfgrass practitioners have reported a reduction in efficacy and length of control associated with fungicides used to manage dollar spot (9, 15). Possible reasons for this reduction include variation in product application rates and timings, differences in application techniques and procedures, and resistance issues attributed to continuous use of the same fungicide product or fungicide biochemical mode of action (6, 10, 18).



This research consisted of four identical field studies conducted in two locations in Connecticut and Pennsylvania in 2005.

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Fungicide treatments were applied using one of five flat-fan nozzle types designed to distribute varying water droplet sizes. The nozzles were selected to produce droplet sizes that were classified as extremely coarse, very coarse, coarse, medium, and fine.

Several types of nozzles are available in the crop protection market, and these nozzles produce a range of water droplet sizes (13, 17). Many of these nozzles were recently introduced into the green industry and specialty crop markets (9, 10). Hence, the overall purpose of this study was to examine the impact of nozzle type and fungicide mode of activity on fungicide performance for dollar spot control in creeping bentgrass. The specific objectives were: 1) to evaluate fungicide efficacy when delivered through five different nozzle types, and 2) to elucidate any interactions among nozzle type and fungicide mode of activity.

Materials and Methods

This research consisted of four identical field studies conducted in two locations in

Connecticut and Pennsylvania in 2005. In Connecticut, field studies were conducted on golf course fairways at The Country Club of Farmington (Farmington, CT) and Stanley Golf Club (New Britain, CT). The Stanley Golf Club site consisted of a mixed stand of creeping bentgrass (unknown cultivar) and annual bluegrass maintained at a height of 1.9 cm (0.75 inch). Soil was a Ludlow (coarse-loamy, mixed, semiactive, mesic Aquic Dystrudepts) silt loam with a pH of 5.7 and 9.2% organic matter.

The Country Club of Farmington site was predominantly 'Penncross' creeping bentgrass with < 10% annual bluegrass grown on a Rippowan (coarse loamy, mixed, superactive, nonacid, mesic Fluvaquentic Endoaquepts) fine sandy loam with a pH of 5.3 and 3.4% organic matter and mowed to a height of 1.3 cm (0.5 inch). Plots measured 1.5 m x 4.5 m and were arranged



Treatments in Connecticut were applied with a CO₂ pressurized (275 kPa) backpack sprayer and in Pennsylvania with a Gregson-Clark Spreader Mate (above). Both application mechanisms were outfitted with a spray boom containing 4 nozzles spaced 48 cm on center and calibrated to deliver water at 407 L ha⁻¹.

as a 3 x 5 factorial design with three (The Country Club of Farmington) or four (Stanley Golf Club) replications.

In Pennsylvania, two field studies were conducted on a golf course fairway (Royal Oaks Golf Course; Lebanon, PA) and a driving range (Bellewood Golf Club; North Coventry, PA) maintained as a fairway. The Royal Oaks Golf Course and Bellewood Golf Club site consisted of a monostand of creeping bentgrass established to cultivars 'Princeville' and 'PennTrio', respectively. Soil at Royal Oaks Golf Course was a Clarksburg (fine-loamy, mixed, active, mesic Typic Fragiudalfs) clay loam with a pH of 6.8 and 4.0% organic matter. At the Bellewood Golf Club site, soil was a Readington (fine-loamy, mixed, semi-active, mesic Typic Fragiudalfs) silt loam with a

pH of 6.6 and 2.0% organic matter. Both sites were mowed to a height of 1.1 cm (0.43 inch) with a reel mower, and plots measured 1.5 x 3 m with 3 replications arranged similar to studies in Connecticut.

At all four locations, fungicide treatments were applied using one of five flat-fan nozzle types designed to distribute varying water droplet sizes. The nozzles were selected to produce droplet sizes that were classified as extremely coarse ($\geq 450 \mu\text{m}$ diam.; TurfJet 1/4TTJ04), very coarse (375 to 450 μm diam.; Air Induction TeeJet AI11004), coarse (250 to 375 μm diam.; TurboTeeJet TT11003), medium (175 to 250 μm diam.; XR TeeJet XR11004), and fine (100 to 175 μm diam.; XR TeeJet XR11003) (11). All nozzles were used to apply fungicides with an acropetal

Treatment ^W	Dollar Spot (no.) ^V			
	June 10	June 24	July 1	July 19
<i>Fungicide</i>				
Chlorothalonil	9 a ^X	4 a	13 b	148 a
Propiconazole	14 a	6 a	18 a	147 a
Chlorothalonil + Propiconazole	1 b	0 b	1 c	94 b
<i>Nozzle (droplet size)^Y</i>				
TTJ1104 (EC)	13 a	7 a	24 a	148
AI11004 (VC)	3 b	1 b	3 c	120
TT11003 (C)	13 a	6 a	11 b	140
XR11004 (M)	6 b	3 b	9 bc	122
XR11003 (F)	5 b	2 b	5 c	117
<i>Untreated^X</i>	57	54	145	329
Probability				
Fungicide	*** z	***	***	***
Nozzle	***	**	***	NS
Fungicide x Nozzle	NS	NS	NS	NS
^V Dollar spot was rated by counting the number of infection centers per plot (4 m ²). ^W Treatments were applied on May 27 and June 10 and 24. ^X Means for each main factor and within each column followed by the same letter are not significantly different (P=0.05) according to Fisher's protected least significant difference				

Table 1. Dollar spot (*Sclerotinia homoeocarpa*) infection centers as influenced by chlorothalonil, propiconazole, and a tank-mix applied using five different nozzles at Stanley Golf Club 2005.

penetrant mode of activity (propiconazole, Banner MAXX), a contact mode of activity (chlorothalonil, Daconil), and a tank-mix of the two fungicides. Chlorothalonil (4.56 kg ai ha⁻¹) and propiconazole (0.236 kg ai ha⁻¹) were applied at the low recommended label use rate for the preventive control of dollar spot.

Treatments in Connecticut were applied with a CO₂ pressurized (275 kPa) backpack sprayer and in Pennsylvania with a Gregson-Clark Spreader Mate (Gregson-Clark, Le Roy, NY). Both application mechanisms were outfitted with a spray boom containing 4 nozzles spaced 48 cm on center and calibrated to deliver water at 407 L ha⁻¹, which is a standard volume used for golf

course fairways (7). To account for variation in output from each nozzle, walking speed was adjusted to 3.2 or 4.5 km h⁻¹ using a metronome. All treatments were applied on approximately 14-day intervals, and all application dates are foot-noted in the data tables.

To assess dollar spot incidence, the numbers of dollar spot infection centers per plot were counted throughout the study. To reduce the impact of an edge effect, a 25.4-cm (10-inch) border was excluded from each plot during the rating. A threshold of up to 10 infection centers per plot was considered an acceptable amount of dollar spot activity for fairway turf in these studies.

To assess the overall impact of disease development throughout the study, the area under

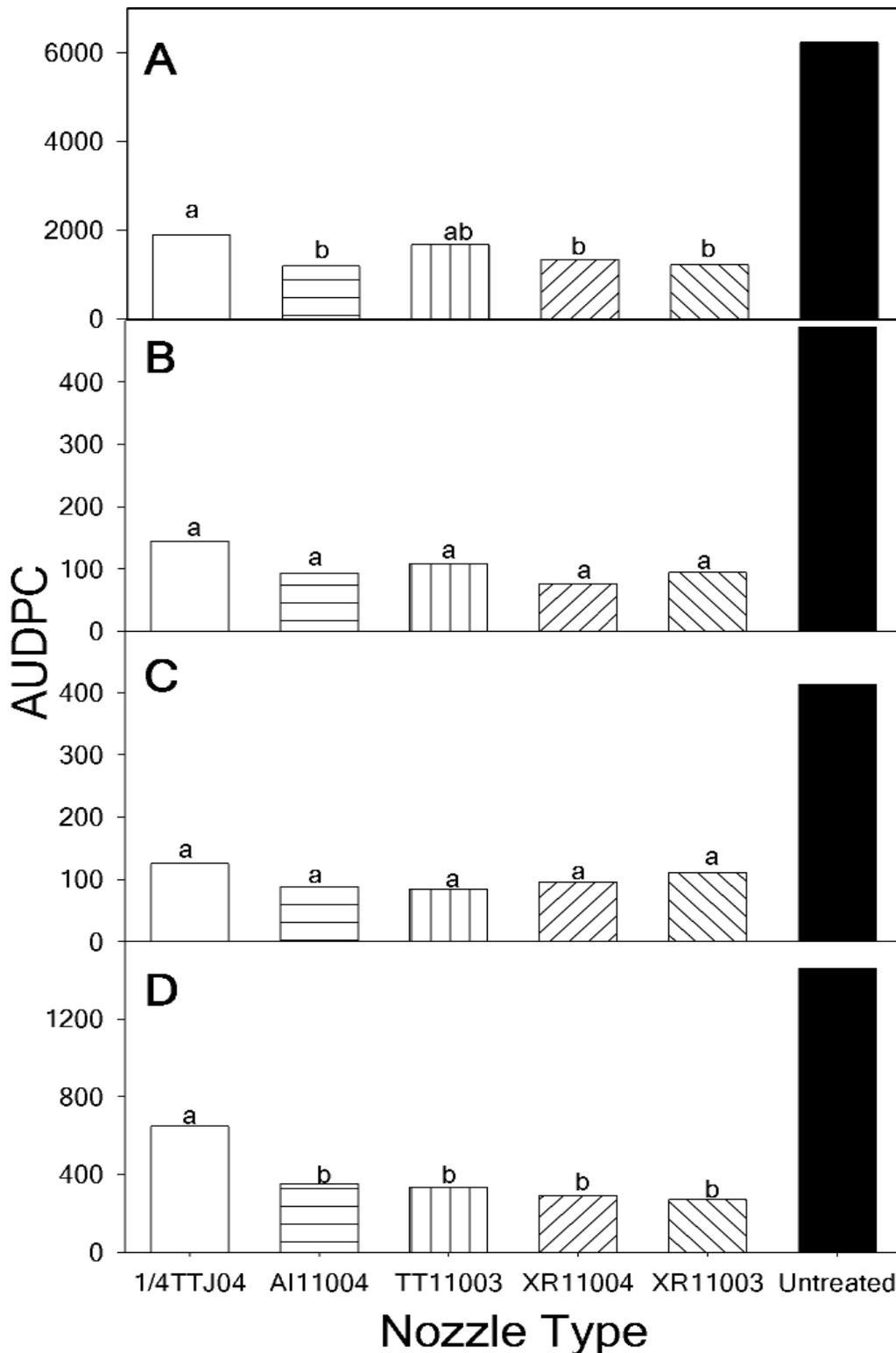


Figure 1. Area under the disease progress curve (AUDPC) for dollar spot infection centers at four locations as influenced by nozzle type (TurfJet 1/4TTJ04, extremely coarse water droplet, $\geq 450 \mu\text{m}$ diam.; Air Induction TeeJet AI11004, very coarse 375 - 450 μm diam.; TurboTeeJet TT11003, coarse 250 - 375 μm diam.; XRteeJet XR11004, medium 175 - 250 μm diam.; XR11003, fine 100 - 175 μm diam.) from Stanley Golf Club (A), Country Club of Farmington (B), Bellewood Golf Club (C), and Royal Oaks Golf Course (D). Means followed by the same letter are not different according to Fisher's protected least significant difference test at $P=0.05$. Dollar spot levels in untreated plots are shown for comparison purposes, but are not included in the statistical analysis.

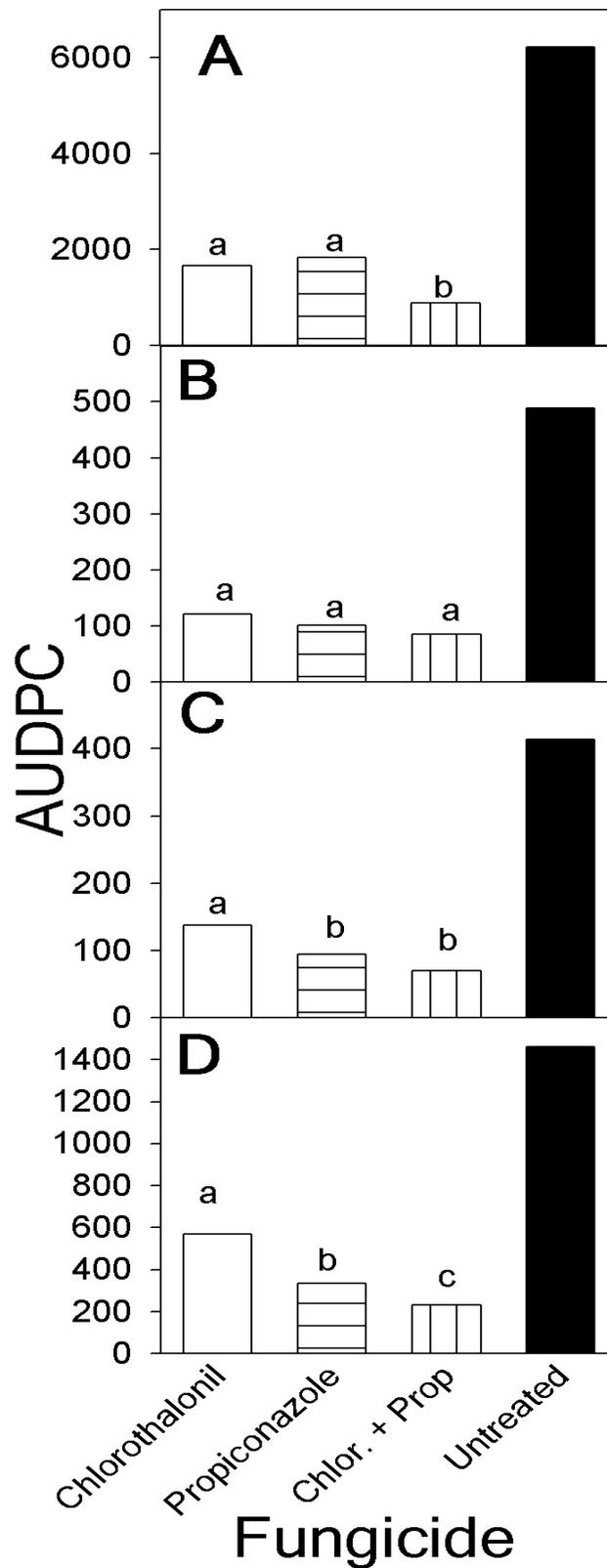


Figure 2. Area under the disease progress curve (AUDPC) for dollar spot infection centers at four locations as influenced by fungicides. Fungicides included chlorothalonil (4.56 kg ai ha⁻¹), propiconazole (0.236 kg ai ha⁻¹) and a tank-mix of the two. Data were pooled across five nozzle types. Data represent seasonal dollar spot infection center ratings from Stanley Golf Club (A), Country Club of Farmington (B), Bellewood Golf Club (C), and Royal Oaks Golf Course (D). Means followed by the same letter are not different according to Fisher's protected least significant difference test at P=0.05. Dollar spot levels in untreated plots are shown for comparison purposes, but are not included in the statistical analysis.

the disease progress curve (AUDPC) was determined (3). Data were subjected to analysis of variance and means were separated using the Fisher's protected least significant difference test (P=0.05). In addition to treatment effects, treatments were further subjected to pre-planned single degree-of-freedom orthogonal contrasts (14).

Results and Discussion

Connecticut - Stanley Golf Club

Disease pressure at Stanley Golf Club was considered severe. Over the entire study, infection centers within the untreated control plots ranged from 54 to 329 (Table 1). The main effect of fungicide was significant on all rating dates, and plots treated with chlorothalonil + propiconazole exhibited the least dollar spot compared to each fungicide applied alone. The tank-mix combination provided near complete suppression (≤ 1 infection center) of dollar spot between June 10 and July 1. When plots were rated on July 19 (~ 4 weeks after treatment), the tank-mix combination continued to provide suppression of dollar spot compared to each individual fungicide, but no treatments were considered acceptable.

The greatest level of dollar spot suppression was achieved in plots receiving fungicides applied with AI11004, XR11004, or XR 11003 nozzles. Turfgrass within plots receiving fungicides applied with the 1/4TTJ04 nozzles had the greatest number of infection centers throughout the study. Compared to the untreated control plots, all nozzles and fungicides resulted in an 83% to 98% reduction in dollar spot during the treatment period. Under the high seasonal pressure observed at Stanley Golf Club, AUDPC values indicated that the tank-mix combination applied from XR11004, XR11003, or AI11004 nozzles provided the greatest suppression of dollar spot (Figures 1 and 2).

Connecticut - Country Club of Farmington

Dollar spot was low throughout the study period and a total of 26 infection centers were

observed in the untreated plots when disease activity peaked on July 19 (25 DAT) (Table 2). Compared across all fungicide-treated plots, differences in dollar spot suppression among nozzle types were only significant at the time of peak disease activity. On July 19, plots receiving fungicides applied with either XR nozzle provided the greatest suppression of dollar spot.

Fungicides applied with the AI11004 nozzle, however, provided acceptable levels of dollar spot control and were not different from the XR nozzles. Among nozzle types, the poorest level of disease suppression (17 infection centers) was observed when fungicides were applied with the 1/4TTJ04 nozzles. Compared to the untreated control plots, dollar spot was suppressed by 69% to 88% when fungicides were applied with the extended range or air induction nozzles. Under the low disease pressure observed at The Country Club of Farmington, no fungicide x nozzle interactions or main effects were significant for seasonal AUDPC dollar spot values (Figures 1 and 2).

Pennsylvania - Bellewood Golf Club

Disease pressure was low throughout the duration of this study, with the untreated control plots averaging a total of 1 to 25 infection centers (Table 3). Differences in dollar spot suppression were only observed among fungicides on August 24 (19 DAT). At this time, plots treated with propiconazole or chlorothalonil + propiconazole provided a greater level of disease suppression when compared to chlorothalonil alone. However, all fungicides applied through all nozzle types were providing acceptable dollar spot suppression. Plots treated with propiconazole alone or tank-mixed with chlorothalonil resulted in the fewest dollar spot infection centers over the course of the season as indicated by AUDPC values (Figures 1 and 2).

Pennsylvania - Royal Oaks Golf Course

At the Royal Oaks Golf Course site, disease pressure was moderate and ranged from 9 to

Treatment ^w	Dollar Spot (no.) ^v		
	June 24	July 19	July 26
<i>Fungicide</i>			
Chlorothalonil	2	14	3
Propiconazole	2	8	3
Chlorothalonil + Propiconazole	1	5	2
<i>Nozzle (droplet size)^y</i>			
TTJ1104 (EC)	2	17 a ^x	5
AI11004 (VC)	2	8 ab	1
TT11003 (C)	2	11 ab	2
XR11004 (M)	1	3 b	2
XR11003 (F)	2	7 b	2
<i>Untreated^x</i>	2	26	7.5
Probability			
Fungicide	NS ^z	NS	NS
Nozzle	NS	*	NS
Fungicide x Nozzle	NS	NS	NS
v	Dollar spot was rated by counting the number of infection centers per plot (4 m ²).		
w	Treatments were applied on May 27 and June 10 and 24.		
x	Means for each main factor and within each column followed by the same letter are not significantly different (P=0.05) according to Fisher's		

Table 2. Dollar spot (*Sclerotinia homoeocarpa*) infection centers as influenced by chlorothalonil, propiconazole, and a tank-mix applied using five different nozzles at Country Club of Farmington 2005.

41 infection centers within the untreated control plots (Table 4). The main effect of fungicide was significant on all rating dates and plots treated with chlorothalonil + propiconazole provided acceptable suppression of dollar spot throughout the study. Plots treated with propiconazole provided similar suppression to the tank-mix on 80% of the rating dates. However, unacceptable disease pressure was observed within plots treated with propiconazole only on two rating dates approximately 14 to 16 DAT. Although providing acceptable suppression of dollar spot on 3 out of 5 rating dates, plots treated with chlorothalonil generally had the greatest number of infection centers compared to other treatments.

Compared across all fungicide-treated

plots, dollar spot suppression was consistently better when fungicide treatments were applied through AI11004, TT11003, XR11004, or XR11003 nozzles versus the 1/4TTJ04 nozzle. On August 16, dollar spot suppression among nozzles ranked as follows: XR11004 = XR11003 > AI11004 = TT11003 > 1/4TTJ04 nozzles. On this final rating date, only those fungicides applied through the XR nozzles provided acceptable control. When applied on a 14-day interval, all nozzles except 1/4TTJ04 facilitated a similar amount of seasonal disease reduction (Figure 1), and the greatest suppression of dollar spot was achieved when chlorothalonil and propiconazole were tank-mixed (Figure 2).

The overall goal of this study was to deter-

Treatment ^w	Dollar Spot (no.) ^v			
	July 20	July 27	August 5	August 24
<u>Fungicide</u>				
Chlorothalonil	3 ^x	4	4	8 a
Propiconazole	3	4	3	5 b
Chlorothalonil + Propiconazole	2	3	1	4 b
<u>Nozzle (droplet size)^y</u>				
TTJ1104 (EC)	<1	4	4	7
AI11004 (VC)	2	3	2	5
TT11003 (C)	3	3	1	5
XR11004 (M)	4	4	3	5
R11003 (F)	3	4	3	6
<u>Untreated</u>	13	1	14	25
Probability				
Fungicide	NS ^z	NS	NS	***
Nozzle	NS	NS	NS	NS
Fungicide x Nozzle	NS	NS	NS	NS
^v Dollar spot was rated by counting the number of infection centers per plot (2.5 sq m). ^w Treatments were applied on May 23; June 6 and 20 ; July 2 and 20; and August 5. ^x Means for each main factor and within each column followed by the same letter are not significantly different (P=0.05) according to Fisher's protected least significant difference test. Dollar spot levels within untreated plots are shown for comparison purposes, but are not included in the statistical analysis. ^y Droplet sizes are as follows: EC = extremely coarse; VC = very coarse; C = coarse; M = medium; and F = fine. ^z *** indicates significance at 0.001. NS = not significant.				

Table 3. Dollar spot (*Sclerotinia homoeocarpa*) infection centers as influenced by chlorothalonil, propiconazole, and a tank-mix applied using five different nozzles at Bellewood Golf Club 2005.

mine dollar spot control from two fungicides with different modes of activity when applied through five different nozzles. Regardless of nozzle type evaluated in this study, all fungicides reduced dollar spot compared to the untreated control. The 1/4TTJ04 nozzle produced the largest water droplet size and provided highly variable and often times poor control of dollar spot regardless of fungicide mode of activity. Although fungicides used to control dollar spot may be more efficacious when applied using a nozzle that produces fine to coarse droplet sizes, the potential for spray

drift and/or negative off-target environmental impacts may increase (11). The use of nozzles such as the Air Induction and Turbo TeeJet offer drift-reducing advantages compared to the standard extended range tips and also provided improved suppression when compared to flat-fan nozzles that produce extremely coarse droplets (15, 17).

In years where dollar spot pressure is low, the impact of nozzle type on disease control may not be observed. During periods of high dollar spot pressure, however, the impact of nozzle like-

Treatment ^W	Dollar Spot (no.) ^V				
	June 14	July 2	July 18	August 2	August 16
<i>Fungicide</i>					
Chlorothalonil	5 a ^X	1	18 a	8 a	15a
Propiconazole	2 b	0	12 b	4 b	12 ab
Chlorothalonil + Propiconazole	<1 b	0	7 c	4 b	9 b
<i>Nozzle (droplet size)^Y</i>					
TTJ1104 (EC)	2	<1	18 a	11 a	24 a
AI11004 (VC)	2	<1	11 b	4 b	13 b
TT11003 (C)	4	<1	9 b	4 b	12 b
XR11004 (M)	2	<1	12 b	3 b	6 c
XR11003 (F)	3	0	10 b	4 b	5 c
<i>Untreated^X</i>	13	9	33	26	41
Probability					
Fungicide	* z	NS	***	***	**
Nozzle	NS	NS	**	***	***
Fungicide x Nozzle	NS	NS	NS	NS	NS
<p>^V Dollar spot was rated by counting the number of infection centers per plot (2.5 m²).</p> <p>^W Treatments were applied on June 6 and 20; July 2 and 18; and August 2.</p> <p>^X Means for each main factor and within each column followed by the same letter are not significantly different (P=0.05) according to Fisher's protected least significant difference test. Dollar spot levels within untreated plots are shown for comparison purposes, but are not included in the statistical analysis.</p> <p>^Y Droplet sizes are as follows: EC = extremely coarse; VC = very coarse; C = coarse; M = medium; and F = fine.</p> <p>Z *, **, *** indicates significance at 0.05, 0.01, and 0.001, respectively. NS = not significant.</p>					

Table 4. Dollar spot (*Sclerotinia homoeocarpa*) infection centers as influenced by chlorothalonil, propiconazole, and a tank-mix applied using five different nozzles at Royal Oaks Country Club 2005.

ly plays a larger role in the suppression of the disease. To achieve maximum dollar spot control, nozzle types that produce fine to coarse droplet sizes will provide the greatest level of suppression.

Additionally, excellent disease and drift management may be achieved by selecting nozzles that incorporate improved technology such as air induction. This information may be useful for managing dollar spot and potentially other foliar diseases, but its usefulness on root and crown-inhabiting pathogens remains unclear. In an effort

to improve fungicide efficacy and reduce environmental and economic costs, future research should continue to evaluate the impact of nozzle type and application techniques.

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