Dollar Spot and Brown Patch Fungicide Management Strategies in Four Creeping Bentgrass Cultivars

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ABSTRACT

New creeping bentgrass (*Agrostis palustris* Huds.) cultivars should be thoroughly evaluated for disease resistance and fungicide application strategies for inclusion in integrated pest management plans. Our objectives were to evaluate dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) and brown patch (*Rhizoctonia solani* Kühn) severity, and turf quality of 'L-93', 'Penncross', 'Providence', and 'Crenshaw' creeping bentgrass managed using preventive, curative, and weather model-based fungicide application strategies. This field study was conducted on a sand-based putting green in Manhattan, KS, from 1997 through 1999. Nonfungicide-treated L-93 exhibited greatest resistance to dollar spot; Penncross and Providence were intermediate; and Crenshaw was most susceptible. Crenshaw exhibited greater brown patch susceptibility than other cultivars in 1998, but was similar to L-93 in 1999. Greater flexibility in imposing a disease control strategy was afforded by using a disease-resistant (i.e., L-93), rather than a disease-susceptible (i.e., Crenshaw) cultivar. Dollar spot was controlled in L-93 using preventive fungicide applications on 14- or 28-d intervals, preventive low-rate applications of chlorothalonil (tetrachloroisophthalonitrile, 3.5 kg a.i. ha^{-1}) every 7 d, or a curative fungicide application when an increase in the disease was observed. In Crenshaw, only the 14-d preventive fungicide regime effectively controlled dollar spot. Considering all cultivars across the 3-yr period, fewer fungicide applications were made using a curative ($n = 11$–17) than a preventive ($n = 30$) strategy. The curative strategy was effective when dollar spot, but not when brown patch was the primary disease.

Golf course superintendents are searching for ways to reduce fungicide applications on creeping bentgrass putting greens. Preventive fungicide applications are commonly used from June through September in the humid transition zone to suppress dollar spot and brown patch and maintain quality of creeping bentgrass greens. The development of new creeping bentgrass cultivars with potential for disease resistance has increased the superintendent's interest in utilizing these cultivars to reduce fungicide inputs. In fact, cultivar comparisons from the National Turfgrass Evaluation Program's 1998 creeping bentgrass cultivar evaluation indicated that there were differences in susceptibility to dollar spot and brown patch (Anonymous, 1999). For example, Penncross and Penn A-1 exhibited relatively good resistance to dollar spot, whereas Crenshaw and Providence were more susceptible. The cultivar L-93 had relatively good resistance to brown patch, but Penn A-4 was more susceptible to *R. solani*.

Creeping bentgrass cultivar recovery after a dollar spot epidemic may be as important as resistance to infection. Kentucky researchers demonstrated that cultivars varied in recovery rate, depending upon whether a fungicide treatment was applied (Vincelli et al., 1997). Some cultivars recovered more quickly from dollar spot following fungicide application; whereas, other cultivars recovered from the disease equally regardless if fungicides were applied. Cultivar response was not consistent across the 2-yr test. No relationship between cultivar susceptibility and recovery rate was observed by Vincelli et al. (1997).

A plethora of fungicides and application strategies are available to effectively suppress dollar spot and brown patch. Most golf course superintendents use a preventive strategy, which usually requires a fungicide application every 14- to 21-d during summer months, when disease is most likely. More recently, results from Michigan experiments indicated that chlorothalonil could be applied every 7 d at less than one-fourth the rate recommended on a 14-d schedule, and still effectively suppress dollar spot (Thompson, 1998). However, this strategy has not been evaluated in other regions of the U.S.

A curative, or post-infection fungicide application strategy is an important component of an integrated pest management program. Fungicides may be applied when a predetermined threshold of disease severity is encountered. Alternatively, weather-based disease warning models have been developed to help time fungicide applications for control of brown patch on turfgrasses (Fidanza et al., 1996; Fidanza and Dernoeden, 1997; Schumann et al., 1994; Gross et al., 1998). Curative, or warning-based approaches ensure that applications are made only when needed, and may result in reduced fungicide input. High susceptibility of creeping bentgrass to dollar spot and brown patch has traditionally precluded the use of these strategies on putting greens. Furthermore, a superintendent's success is commonly measured by the condition of the greens, and a preventive strategy helps to prevent a reduction in quality of the putting surface that may arise with the onset of disease. However, the development of more disease-resistant creeping bentgrass cultivars may allow for curative or warning-based strategies to be successfully employed without noticeable loss in bentgrass quality.

Although information is available on disease resistance in creeping bentgrass cultivars, and differences among fungicides and application schedules for disease control efficacy, we are not aware of any studies that evaluated the performance of creeping cultivars of differing disease susceptibility under varying fungicide application regimes. The objectives of this study were to evaluate dollar spot and brown patch severity, and turf quality of four creeping bentgrass cultivars managed

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Abbreviations: AUDPC, area under the disease progress curve; DMI, demethylation inhibiting fungicide.

using curative and preventive fungicide application strategies.

MATERIALS AND METHODS

The study was conducted on a putting green constructed to USGA specifications at the Rocky Ford Turfgrass Research Field in Manhattan, KS. The medium contained 95% sand and 5% clay, and had a pH of 7.5. Four cultivars and six or seven fungicide treatments were arranged randomly in a split-plot design with three replications. The cultivars Penncross, Crenshaw, L-93, and Providence were seeded at 49 kg ha^{-1} in 2.2 × 7.0 m main plots in May 1996. Turf was irrigated daily with approximately 5 mm water, and mowed 6 d wk^{-1} at 4 mm with a triplex greensmower. Turf received N at 216 kg ha^{-1} yr^{-1} in 1997; 238 kg ha^{-1} yr^{-1} in 1998; and 354 kg ha^{-1} yr^{-1} in 1999. Rates and timing for individual N applications varied across years. In general, applications were made every 2 to 4 wk between 20 April and 31 October in each year, to apply N at 25 to 49 kg ha^{-1} from a source containing at least 50% slow-release N, primarily from methylene urea. The remaining N was applied as urea (46-0-0).

Fungicide treatments, including a nonfungicide-treated control, were randomly arranged within each cultivar in 1.0 × 2.2 m subplots. In 1997, a preventive treatment of flutolanil [N-{3-(1-methylethoxy) phenyl}-2-(trifluromethyl) benzamide] at 4.6 kg a.i. ha^{-1} plus triadimefon [1-(4-chlorophenoxy)-3,3-dimethyl-1-(1*H*-1,2,4-triazol-l-yl)-2-butanone] at 0.8 kg a.i. ha^{-1} were applied at monthly intervals, beginning 27 June and continuing through 9 October 1997. Iprodione [3-(3,5-dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidine-carboxamide] at 3.1 kg a.i. ha^{-1}, and iprodione at 3.1 kg a.i. ha^{-1}, plus a pigmented formulation of fosetyl-Al [aluminum tris (O-ethyl phosphonate)] at 9.9 kg a.i. ha^{-1} were applied preventively on 14-d intervals. Fosetyl-Al is primarily used for control of Pythium blight, caused by *Pythium aphanidermatum* (Edson) Fitzp. Although we did not observe Pythium blight, fosetyl-Al was included with iprodione because this combination has been reported to enhance turf quality (Vincelli et al., 1998) in the absence of disease, and is commonly used by golf course superintendents in Kansas as a preventive application.

Iprodione (3.1 kg a.i. ha^{-1}) was applied in 1997 as a curative treatment as soon as initial *S. homoeocarpa* infection centers or brown patch were detected on each cultivar. Thereafter, curative applications were made at subsequent 2-wk intervals only if dollar spot or brown patch were active. Dollar spot was considered to be active if the number of *S. homoeocarpa* infection centers increased from the previous week's rating in two of the three blocks. Brown patch ratings were taken twice weekly, and the disease was considered active if the percentage plot area blighted increased between the ratings. If no disease increase was noted, subsequent fungicide applications were delayed beyond the 2-wk interval until dollar spot or brown patch development again was observed. The total number of fungicide applications in the curative treatment varied among cultivars because of differences in disease susceptibility.

Iprodione (3.1 kg a.i. ha^{-1}) also was applied in 1997 according to a brown patch warning model developed by Fidanza et al. (1996). Timing of fungicide applications was determined by using the regression equation

$$E = -21.5 + 0.15\mathrm{RH} + 1.4\mathrm{T} - 0.033\mathrm{T}^2,$$

where E is an environmental favorability index for brown patch, RH equals the mean daily relative humidity, and T is the minimum daily temperature. Relative humidity and temperature were recorded by a CR-10 weather station (Campbell Scientific, Logan, UT) located ≈30 m from the study area. All variables were summarized beginning and ending at 0600 h. A fungicide was applied within 24 h following a day when $E \geq 6$. No fungicide was applied if an application had been made up to 2 wk preceding this date. This treatment was evaluated only for efficacy in brown patch control, and not for dollar spot suppression or turf quality.

Treatments in 1998 were similar to those described in 1997, except that azoxystrobin (methyl (E)-2-{2-[6-(2-cyanophenoxy) pyrimidin-4-yloxy]phenyl}-3-methoxyacrylate) at 0.3 kg a.i. ha^{-1} plus triadimefon at 0.8 kg a.i. ha^{-1} were applied on a 28 d application interval. Applications began on 18 May and continued through 24 September.

In 1999, chlorothalonil (9.6 kg a.i. ha^{-1}) was used instead of iprodione in the curative application treatment and a preventive, low-rate treatment of chlorothalonil applied at 2.3 kg a.i. ha^{-1} also was evaluated at weekly intervals. The rate of triadimefon was increased to 1.6 kg a.i. ha^{-1} in 1999. Fungicide applications based on the disease warning model were not applied in 1999. Initial fungicide treatments were made on 21 May and continued through 24 September. In all years, fungicides were applied with a CO_2-pressurized (207 kPa) backpack sprayer calibrated to deliver 935 L ha^{-1} through 8003 flat-fan nozzles.

Data Collection and Analysis

Plots were rated weekly by counting the number of *S. homeocarpa* infection centers and visually estimating the percentage (0–100% linear scale) of plot area blighted (foliar necrosis) by *R. solani*. Disease development was a result of natural infection, and *S. homoeocarpa* and *R. solani* AG 2-2 IIIB were consistently isolated from bentgrass exhibiting symptoms of dollar spot and brown patch, respectively. The presence of *R. solani* in leaves of blighted plants during each brown patch epidemic was confirmed microscopically. No other diseases were detected in any year of the study. Severity ratings were used to calculate the area under the disease progress curve (AUDPC) in each year (Campbell and Madden, 1991). The AUDPC is expressed as percent disease (brown patch) or number of *S. homoeocarpa* infection centers (dollar spot) × day, and describes the course of the epidemic with time (Waggoner, 1981). Analysis of variance on all ratings was performed with the PROC MIXED procedure (SAS Institute, 1989), and used a Saterthwaite adjustment for split plot analysis of variance (Milliken and Johnson, 1984). Means were separated using Fisher's protected least significant difference test ($P < 0.05$). Turf quality was rated visually once weekly on a 0 to 9 scale, where 0 equals brown, dead turf; 6 equals minimum acceptable putting green quality; and 9 equals optimum color, density, and uniformity. Turf quality data are presented as the percentage of rating dates in each year that a given cultivar and fungicide combination resulted in acceptable quality.

RESULTS

A significant cultivar × fungicide interaction was observed for dollar spot in all 3 yr, and for brown patch in 1998 and 1999 (analysis not shown). This was the result of greater disease severity and lower efficacy of certain fungicide treatments in Crenshaw.

1997

Dollar spot was first observed in nonfungicide-treated turf on 25 July, peaked on 19 September, and continued until ratings ceased on 9 October (Fig. 1). Crenshaw had the highest dollar spot severity, followed by Providence (Table 1). The cultivar L-93 and Penn-

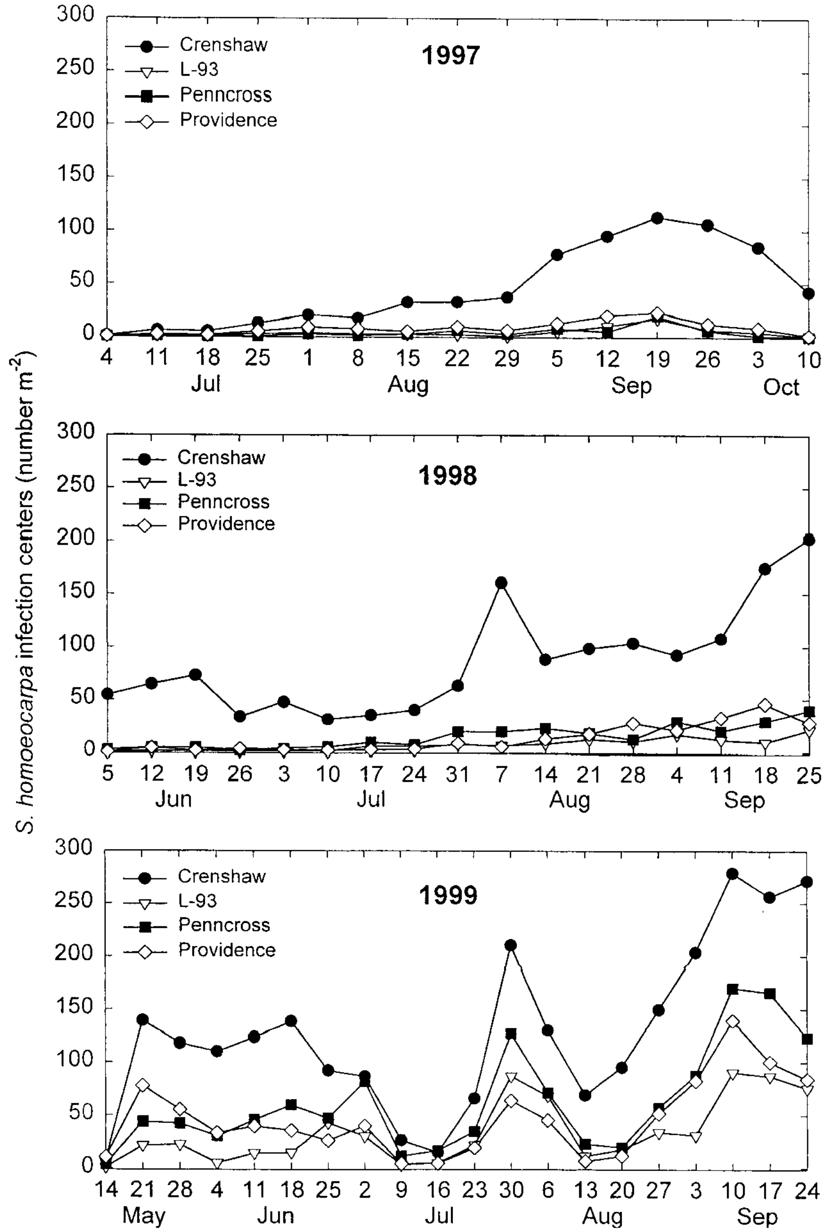

Fig. 1. The number of *S. hoemocarpa* infection centers in four nonfungicide-treated creeping bentgrass cultivars, 1997 to 1999.

cross had the fewest *S. homoeocarpa* infection centers. Fungicides applied on a 14-d preventive program suppressed dollar spot in all cultivars (Table 1). Similarly, triadimefon + flutolanil applied preventively on a 28-d interval also provided nearly total suppression of dollar spot in all cultivars except Crenshaw.

Dollar spot levels were equivalent in all cultivars treated curatively with iprodione except Crenshaw, which had a greater number of infection centers (Table 1). The cultivars L-93, Penncross, and Providence each required two curative applications to suppress dollar spot, whereas Crenshaw required three. The season-long level of dollar spot control provided using curative applications ($n = 2$) was comparable to that provided by nine preventive applications of iprodione or iprodione + fosetyl-Al (14-d interval) in all cultivars except Crenshaw. Turf quality ratings for turf treated curatively with iprodione were in the acceptable range on 64% (Penncross) to 100% (L-93) of rating dates (Table 2).

The weather-based brown patch warning model predicted outbreaks on 29 June; 11, 20, and 28 July; 11, 12, 18, 19, 30, and 31 August; and 10 and 30 September. Iprodione was applied on only 1 and 21 July, however, for scouting of the plot area showed no symptoms of brown patch in August and September. If iprodione had been applied on the occurrence of all false predictions, a total of five applications would have been made. Brown patch, however, was not visually detected among any of the treatments in 1997.

1998

Dollar spot was observed in nonfungicide-treated Crenshaw when ratings began in early June (Fig. 1), but

Table 1. Fungicide strategies and dollar spot control in four creeping bentgrass cultivars in Manhattan, KS, from 1997 to 1999.

	Application		AUDPC†			
Fungicide treatment	**Frequency**	**no. yr^{-1}**	**Crenshaw**	**Penncross**	**Providence**	**L-93**
			1997			
Iprodione	14 day	9	19a‡A§	15aA	10aA	4aA
Iprodione + fosetyl-Al	14 day	9	25aA	2aA	1aA	3aA
Triadimefon + flutolanil	28 day	5	242bB	15aA	7aA	11aA
Iprodione	as needed	3,2,2,2¶	179bB	29abA	40aA	31abA
No fungicide	n/a	0	1679cC	126bA	329bB	148bA
			1998			
Iprodione	14 day	10	72aA	6aA	7aA	4aA
Iprodione + fosetyl-Al	14 day	10	210aA	11aA	5aA	7aA
Triadimefon + flutolanil	28 day	5	936cB	30aA	31aA	37aA
Triadimefon + azoxystrobin	28 day	5	481bB	116aA	70aA	18aA
Iprodione	as needed	6,5,5,4¶	191aA	30aA	54aA	60aA
No fungicide	n/a	0	4202dC	614bB	760bB	285bA
			1999			
Chlorothalonil	7 day	20	3045dB	414aA	720bA	82aA
Chlorothalonil	14 day	11	256aA	36aA	48aA	11aA
Iprodione + fosetyl-Al	14 day	11	382aA	88aA	29aA	8aA
Triadimefon + flutolanil	28 day	6	852bB	91aA	26aA	45aA
Triadimefon + azoxystrobin	28 day	6	1301cB	398aA	119aA	58aA
Chlorothalonil	as needed	8,7,7,5¶	1410cB	384aA	442abA	308aA
No fungicide	n/a	0	6459eD	3112bC	2299cB	1609bA

† Area under disease progress curve (AUDPC) represents counts of *S. homoeocarpa* infection centers each year as follows: 17 June to 9 October, 1997; 18 May to 24 September 1998; 21 May to 24 September 1999. AUDPC is expressed as number of infection centers × day.

‡ Column means within years not followed by the same letter (a, b, c, d, e) are significantly different ($P \leq 0.05$) according to Fisher's protected LSD test.

§ Row means within years not followed by the same letter (A, B, C, D) are significantly different ($P \leq 0.05$) according to Fisher's protected LSD test.

¶ Number of curative applications for Crenshaw, Penncross, Providence, and L-93, respectively.

Table 2. Fungicide strategies and quality of four creeping bentgrass cultivars in Manhattan, KS, from 1997 to 1999.

	Application		Rating dates with acceptable quality†			
Fungicide treatment	**Frequency**	**no. yr^{-1}**	**Crenshaw**	**Penncross**	**Providence**	**L-93**
			1997			
Iprodione	14 day	9	100	93	93	93
Iprodione + fosetyl-Al	14 day	9	93	100	100	100
Triadimefon + flutolanil	28 day	5	36	71	93	93
Iprodione	as needed	3,2,2,2‡	79	64	86	100
No fungicide	n/a	0	14	43	36	71
			1998			
Iprodione	14 day	10	94	88	65	100
Iprodione + fosetyl-Al	14 day	10	100	88	100	100
Triadimefon + flutolanil	28 day	5	59	94	82	100
Triadimefon + azoxystrobin	28 day	5	53	94	82	100
Iprodione	as needed	6,5,5,4‡	82	71	65	41
No fungicide	n/a	0	0	23	23	41
			1999			
Chlorothalonil	7 day	20	0	44	50	100
Chlorothalonil	14 day	11	100	100	100	100
Iprodione + fosetyl-Al	14 day	11	100	100	100	100
Triadimefon + flutolanil	28 day	6	75	87	100	100
Triadimefon + azoxystrobin	28 day	6	56	87	100	100
Chlorothalonil	as needed	8,7,7,5‡	56	37	87	81
No fungicide	n/a	0	0	0	19	44

† Plots were rated on 14 dates from 27 June to 9 October, 1997; 17 dates from 2 June to 24 September 1998; and 16 dates from 4 June to 1 October 1999. Data are a percentage of weekly visual ratings when turf received a score of ≥6.

‡ Number of curative applications for Crenshaw, Penncross, Providence, and L-93, respectively.

was not observed in other cultivars until 13 July. The disease remained active through 24 September, at which time ratings ceased. Nonfungicide-treated Crenshaw had the highest number of *S. homoeocarpa* infection centers, followed by Providence and Penncross. The cultivar L-93 had fewer infection centers than all other cultivars. All nonfungicide-treated cultivars exhibited acceptable quality on ≤41% of rating dates (Table 2).

Brown patch was observed the second week of July, and peak infection occurred in late August (Fig. 2). Crenshaw had a higher level of brown patch blighting than all other cultivars in nonfungicide-treated turf (Table 3).

Both the 14- and 28-d preventive fungicide schedules suppressed dollar spot (Table 1) and brown patch (Table 3) in Penncross, Providence, and L-93. The 28-d preventive schedule of triadimefon did not adequately control dollar spot in Crenshaw (Table 1). Better brown patch control, however, was observed in turf treated on a 28-d schedule with triadimefon + flutolanil or triadimefon + azoxystrobin than on a 14-d schedule with iprodione or iprodione + fosetyl-Al.

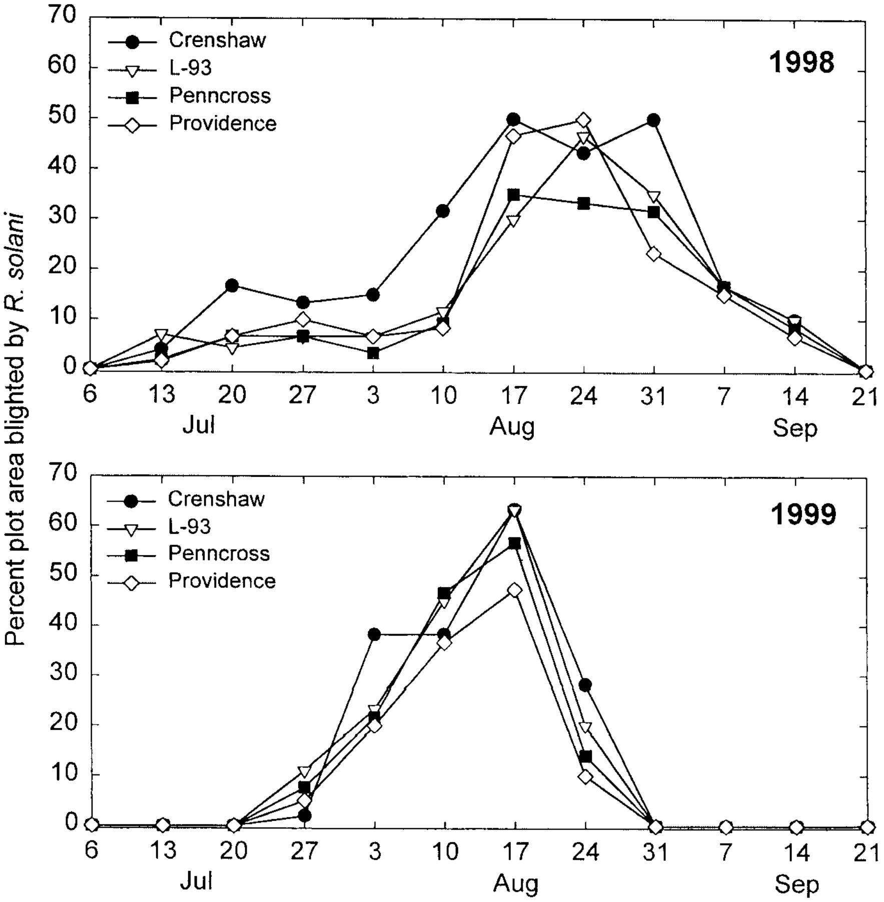

Fig. 2. Brown patch occurrence in nonfungicide-treated creeping bentgrass cultivars, 1998 and 1999.

Dollar spot was observed prior to 13 July and after 14 September, whereas both dollar spot and brown patch were active between these dates (Fig. 1 and 2). The cultivar L-93 received four curative iprodione applications, Penncross and Providence received five applications, and Crenshaw was treated on six occasions. Dollar spot suppression in each cultivar except Crenshaw using the curative schedule was not significantly different from that provided by 10 preventive applications of iprodione made on 2-wk intervals (Table 1). However, curative applications were less effective in controlling brown patch (Table 3). The poorest control occurred in L-93, which received a fungicide application only after brown patch development, whereas the best overall con-

Table 3. Fungicide strategies and brown patch control in four creeping bentgrass cultivars in Manhattan, KS, from 1997 to 1999.

	Application			AUDPC†			
Fungicide treatment	**Frequency**	**no. yr^{-1}**		**Crenshaw**	**Penncross**	**Providence**	**L-93**
			1998				
Iprodione	14 day	10		132bc‡B§	2aAB	52aAB	1aA
Iprodione + fosetyl-Al	14 day	10		99abA	12aA	15aA	21aA
Triadimefon + flutolanil	28 day	5		17aA	5aA	1aA	4aA
Triadimefon + azoxystrobin	28 day	5		12aA	1aA	1aA	0aA
Iprodione	as needed	6,5,5,4¶		81abA	94abA	180bAB	253bB
Iprodione (brown patch model)	as needed	4		218cB	44aA	242bB	27aA
No fungicide	n/a	0		308dB	170bA	225bAB	183bA
			1999				
Chlorothalonil	7 day	20		108bC	113bC	56bB	20aA
Iprodione	14 day	11		2aA	0aA	1aA	1aA
Iprodione + fosetyl-Al	14 day	11		14aA	1aA	1aA	0aA
Triadimefon + flutolanil	28 day	6		2aA	0aA	0aA	0aA
Triadimefon + azoxystrobin	28 day	6		7aA	0aA	3aA	0aA
Chlorothalonil	as needed	8,7,7,5¶		5aA	20aA	5aA	56bB
No fungicide	n/a	0		132bC	100bAB	82bA	118cBC

† AUDPC = Area under disease progress curve, representing weekly brown patch ratings for percent area blighted, estimated from 10 July 1 to September 1998, and from 7 July to 2 September 1999.

‡ Column means within years not followed by the same letter (a, b, c, d) are significantly different ($P \leq 0.05$) according to Fisher's protected LSD test.

§ Row means within years not followed by the same letter (A, B, C) are significantly different ($P \leq 0.05$) according to Fisher's protected LSD test.

¶ Number of curative applications for Crenshaw, Penncross, Providence, and L-93, respectively.

trol occurred in Crenshaw, which had received a curative application for dollar spot 1 wk prior to the onset of brown patch. The brown patch outbreak resulted in L-93 treated on a curative schedule, having acceptable quality on only 41% of all rating dates (Table 2).

The disease warning model predicted brown patch outbreaks on 11 June, 13 and 28 July, and on 28 August. This coincided with observed increases in brown patch in nonfungicide-treated plots on 13 and 28 July and 28 August, but not 11 June (Fig. 2). Fungicide applications based on the model suppressed brown patch, compared with nonfungicide-treated plots in L-93 and Penncross, but not in Crenshaw or Providence (Table 3).

1999

Sclerotinia homoeocarpa infection centers were higher in 1999 than in the previous two years (Fig. 1). For example, at peak infection the total number of infection centers in nonfungicide-treated Crenshaw was >250 m^{-2}, compared with <125 m^{-2} in 1997. Infection centers were first observed on 21 May, and the dollar spot was present throughout the summer until ratings ceased on 24 September. Ranking of cultivars for dollar spot severity in nonfungicide-treated turf, from highest to lowest, was Crenshaw > Penncross > Providence > L-93 (Table 1).

Brown patch was initially observed on 26 July, and continued through 18 August (Fig. 2). Crenshaw had greater brown patch levels than all other cultivars, except L-93. The 14-d preventive schedule was effective in suppressing both dollar spot and brown patch in all cultivars (Table 1). The 28-d fungicide application schedule resulted in poor dollar spot control in Crenshaw, when compared with all other cultivars. Chlorothalonil (2.3 kg a.i. ha^{-1}) applied preventively on a 7-d interval provided nearly complete suppression of dollar spot in L-93, whereas the other cultivars exhibited a modest increase in dollar spot in late June and July within this treatment (data not shown), resulting in higher seasonal AUDPC's (Table 1). The weekly low rate chlorothalonil application regime failed to adequately suppress brown patch and maintain quality in all cultivars except L-93 (Tables 2 and 3).

Across the entire season, L-93 received five curative chlorothalonil applications; Penncross and Providence received seven; and Crenshaw received eight. This compared with 11 applications on a 14-d preventive spray program. Crenshaw treated curatively had a higher number of *S. homoeocarpa* infection centers than any other cultivar (Table 1). Chlorothalonil (9.6 kg a.i. ha^{-1}) applied curatively provided acceptable quality on 37% (Penncross) to 87% (Providence) of rating dates (Table 2).

DISCUSSION

The four bentgrass cultivars evaluated varied in disease susceptibility and responses to fungicide application strategies. Nonfungicide-treated L-93 generally showed the greatest resistance to dollar spot, Penncross and Providence were intermediate, and Crenshaw was most susceptible. These results are similar to previous reports (Fraser, 1997, 1999; Landschoot and McNitt, 1996). Cultivar response to brown patch in nonfungicide-treated turf was more variable, with Crenshaw being most susceptible in 1998, but similar in level of *R. solani* blighting to L-93 in 1999.

None of the cultivars exhibited season-long acceptable quality without fungicide treatment (Table 2). Quality of nonfungicide-treated L-93 was acceptable on 71% of rating dates in 1997, 41% of rating dates in 1998, and 44% of rating dates in 1999. Most of the unacceptable ratings in 1998 and 1999 occurred after mid-July, when brown patch and dollar spot were active, and not earlier in the growing season when dollar spot was the only disease evident. Therefore, a less stringent fungicide program early in the growing season on a dollar spot resistant cultivar such as L-93 may be feasible. A more resistant cultivar also may be more amenable to other dollar spot control strategies, including the application of biological control agents (Goodman and Burpee, 1991; Nelson and Craft, 1991; Rodriquez and Pfender, 1997) or organic amendments (Nelson and Craft, 1992). Several fungicide application strategies have been used for controlling dollar spot and brown patch in creeping bentgrass putting greens. These include applying fungicides at routine intervals (every 7–28 d) to prevent disease development, applying fungicides only when disease symptoms reach some predetermined action threshold, or making applications on a weather-based disease forecasting system. We found that the efficacy of each schedule was dependent on the disease susceptibility of creeping bentgrass cultivar.

Overall, applications of iprodione, iprodione + fosetyl-Al or chlorothalonil applied on a preventive 14-d interval were effective in providing season-long control of both dollar spot and brown patch in all cultivars. However, as previously stated, this often resulted in excessive application of fungicides to L-93, Penncross, and Providence during periods of low disease pressure. Application of fosetyl-Al with iprodione did not increase brown patch or dollar spot control over iprodione alone. Nonetheless, the percentage of rating dates with acceptable turf quality was increased on certain cultivars (e.g., Penncross and Providence in 1998 and Providence in 1999) with this fungicide combination. We suspect that the pigment contained in the fosetyl-Al formulation stained the creeping bentgrass leaves, improved color, and resulted in higher turf quality ratings.

Preventive applications of triadimefon (with either flutolanil or azoxystrobin for brown patch control) on a 28-d interval also provided excellent dollar spot suppression in all cultivars except Crenshaw. Fungicide efficacy diminished after 14- to 21-d in Crenshaw, presumably because of its high susceptibility to dollar spot. We did not detect resistance to triadimefon in *S. homoeocarpa* isolates collected from Crenshaw (data not shown) in 1999. Nevertheless, the intense dollar spot pressure on Crenshaw, coupled with continuous use of a demethylation inhibiting fungicide (DMI), such as triademefon, could rapidly result in selection of DMI-resistant strains of *S. homoeocarpa*. Golembiewski et al. (1995) suggested limiting the use of DMI's during periods when dollar spot is severe. This could severely restrict the use of DMI fungicides on highly susceptible cultivars such as Crenshaw, which is prone to dollar spot throughout the growing season in Kansas.

In a Michigan study, dollar spot control on creeping bentgrass was similar, using weekly or biweekly applications of chlorothalonil, even though the weekly applications resulted in approximately a 50% reduction in the amount of fungicide applied during the experiment (Thompson, 1998). We also observed season-long dollar spot and brown patch control (1999 only) when reduced rates of chlorothalonil were applied weekly to L-93. However, this fungicide schedule did not provide satisfactory dollar spot or brown patch control in the other cultivars tested. Although the reduced rate treatment can result in significant reductions in overall fungicide usage in a dollar spot resistant cultivar such as L-93, this advantage may be somewhat offset by higher machinery and labor costs associated with more frequent fungicide applications.

An alternative approach for brown patch control is the use of weather-based forecasting systems. Fidanza et al (1996) accurately predicted 85% of brown patch outbreaks on perennial ryegrass (*Lolium perenne* L.) using an infection model based on air temperature and relative humidity. We found the model accurately predicted three brown patch episodes in 1998, but falsely predicted five episodes in 1997 and one in 1998. Fidanza et al. (1996) suggested that model accuracy could be improved by canceling a predicted application if the air temperature dropped below 15°C within 24 h of warning. However, in Kansas the air temperature never dropped below 15°C within 24 h of any predicted brown patch outbreak in 1997 or 1998. Model accuracy may have been influenced by the fact that it was developed for use on fairway-height perennial ryegrass grown on fine-textured soil. Additional refinement is needed before this weather-based model can be used to consistently predict brown patch outbreaks on sand-based creeping bentgrass putting greens.

Curative applications of iprodione and chlorothalonil provided equivalent levels of dollar spot control as preventive treatments, and resulted in acceptable turf quality in L-93 during dollar spot outbreaks, but with fewer fungicide applications. Curative applications may be an effective and economical means of suppressing dollar spot on golf courses with limited budgets or in more arid regions where disease development is limited, provided that resistant creeping bentgrass cultivars are used and brown patch is rarely observed. The planting of the dollar spot-susceptible cultivar Crenshaw would preclude the use of a curative fungicide schedule. Although curative fungicide applications were effective in suppressing dollar spot, they did not adequately control brown patch in any cultivar. Unlike the more progressive increase in dollar spot with time, brown patch developed rapidly, with some plots exceeding 10% of the plot within 24 h of initial symptoms. Damage also persisted for several weeks after the initial infection because of slow bentgrass recovery during hot weather. Therefore, curative fungicide applications, while effective in suppressing further brown patch development, did not result in acceptable turfgrass quality. The inability of curative fungicide treatments to provide acceptable brown patch control and quality would preclude widespread acceptance by superintendents of this strategy in creeping bentgrass greens, regardless of cultivar.

We demonstrated that cultivar selection influences fungicide requirements and the potential for flexibility in developing a disease-control program. Use of a cultivar with good resistance to disease, such as the dollar spot resistant L-93, resulted in good turf quality when a 28-d preventive fungicide program was employed. The use of L-93 also provides the superintendent with the flexibility to use low rates of chlorothalonil on a 7-d preventive schedule. Furthermore, considering all cultivars across the 3-yr period, fewer fungicide applications were made using a curative (n = 11–17) than a 14-d preventive (n = 30) strategy. A curative strategy could be employed when environmental conditions are favorable for dollar spot, but not brown patch.

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Penman Monteith Crop Coefficients for Use with Desert Turf Systems

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ABSTRACT

Irrigation scheduling systems which estimate actual evapotranspiration (ETa) by adjusting reference evapotranspiration (ETo) with crop coefficients (*K_c*s) have been suggested as a means of improving irrigation management of turfgrass in the desert southwest. The objective of this study was to develop turfgrass *K_c*s for use with ETo computed by the Penman Monteith Equation recommended by the United Nations Food and Agricultural Organization (FAO). Crop coefficients were developed for fairway quality 'Tifway' bermudagrass (*Cynodon dactylon* L. × *C. transvaalinsis* Davy) in summer and overseeded 'Froghair' intermediate ryegrass (*Lolium perenne* × *L. multiflorum*) in winter by relating daily measurements of ETa obtained from weighing lysimeters to ETo computed with meteorological data. Monthly and seasonal *K_c*s were developed by (i) computing the mean of individual daily *K_c*s, (ii) dividing cumulative ETa by cumulative ETo for the period, and (iii) computing the slope of least squares regression lines relating ETa to ETo. The three computation procedures did not greatly affect the resulting *K_c* value. Bermudagrass *K_c*s ranged from 0.78 in June to 0.83 in September, with monthly variation related to turf growth rate. Use of a constant *K_c* of 0.80 would suffice for estimating ETa in summer. Monthly *K_c*s for intermediate ryegrass ranged from 0.78 in January to 0.90 in April and varied in relation to mean air temperature. Increased bulk surface resistance resulting from chill-induced reductions in stomatal conductance and/or a reduction in turf growth rate and leaf area index may lower ETa and *K_c*s during the colder winter months, making use of a constant seasonal *K_c* less suitable in winter. An inverse linear relationship was obtained between the coefficient of variation of mean monthly *K_c* and the ratio of measured to theoretical clear sky solar radiation, indicating *K_c*s are less reliable during periods of cloudy weather.

POPULATION GROWTH and an expanding tourism industry have led to a rapid increase in the amount of land dedicated to irrigated turfgrass in the desert southwest (DSW). The water requirement of DSW turfgrass is quite high because of the arid climate which generates high rates of evaporative demand, limited precipitation, and mild winter temperatures that allow for year round culture of turfgrass. Local, state, and federal agencies charged with monitoring and/or securing water supplies are particularly concerned about the rapid expansion of urban irrigation in the DSW, and there is growing public pressure to regulate irrigation of turfgrass strictly. Scientific irrigation scheduling regimes which compute irrigation water requirements on the basis of estimates of actual evapotranspiration (ETa) have been suggested as one means of improving irrigation management of turfgrass. The required values of ETa are usually obtained by multiplying estimates of reference ET (ETo) computed from meteorological data by a correction factor known as a crop coefficient (K_c).

Daily values of ETo are readily available from public weather networks in the region (Snyder et al., 1985; Brown et al., 1988; Mott and Sammis, 1990; Devitt et al., 1992), and many golf courses and parks operate on-site weather stations to provide local ETo data. With this widespread availability of ETo data, access to reliable K_cs becomes a limiting factor when implementing scientific irrigation scheduling systems for turfgrass. A number of studies have addressed the water requirements of turfgrass grown in the DSW (Erie et al., 1982; Kneebone and Pepper, 1982; Devitt et al., 1992; Garrott and Mancino, 1994), but only a few studies have presented K_cs. Tovey et al. (1969) used drainage lysimeters to examine the water use of Tifway and 'Tifgreen' bermudagrass during the summer at Reno, NV. Bermudagrass K_cs based on the Penman Equation (Penman, 1963) averaged 0.89 when irrigation was applied weekly. Kopec et al. (1991) used ETa obtained from small bucket lysimeters to compute K_cs for 'Midiron' bermudagrass in summer and perennial ryegrass (*Lolium perenne* L.) in winter. Bermudagrass K_cs based on the modified Penman Equation (Snyder and Pruitt, 1985; Brown, 1998) ranged from 0.83 during mid-season to 0.72 during transition to winter dormancy. Crop coefficients for perennial ryegrass averaged 0.87, but decreased to about 0.50 during cold weather.

Devitt et al. (1992) installed drainage lysimeters on

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Abbreviations: agl, above ground level; DSW, desert southwest; ETa, actual evapotranspiration; ETo, reference evapotranspiration; FAO, United Nations Food and Agricultural Organization; gr, growth rate; K_cs, crop coefficients; KDTRF, Karsten Desert Turf Research Facility; LAI, leaf area index; P, precipitation; VER, vertical extension rate.