Use of High-pressure Injection to Alleviate Type-I Fairy Ring Symptoms in Turfgrass

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SUMMARY. Fairy ring is a common and troublesome disease of turfgrasses maintained on golf course putting greens. Type-I fairy ring is especially destructive due to the development of hydrophobic conditions in the thatch and root zone, thus contributing to turfgrass injury and loss. The objective of this 2-year field study was to evaluate the application and novel delivery method of two fungicides and a soil surfactant for curative control of type-I fairy ring in a 20-year-old creeping bentgrass [*Agrostis palustris* (synonym *A. stolonifera*)] putting green. In both years, all treatments were applied twice on a 28-day interval. In 1998, flutolanil and azoxystrobin fungicides were applied alone and in combination with Primer soil surfactant by a conventional topical spray method, and fungicides without Primer applied via high-pressure injection (HPI). Acceptable type-I fairy ring control was observed in plots treated with flutolanil plus Primer, HPI flutolanil, azoxystrobin alone, azoxystrobin plus Primer, or HPI azoxystrobin. In 1999, treatments were HPI flutolanil, HPI flutolanil plus Primer, HPI azoxystrobin, HPI water only, and aeration only. Acceptable type-I fairy ring control was observed in plots treated with HPI flutolanil plus Primer or HPI azoxystrobin. HPI of fungicides alone or in combination with a soil surfactant

may be a viable option for alleviating type-I fairy ring symptoms on golf course putting greens.

The term “fairy ring” refers to the appearance of circles of mushrooms or rapidly growing, lush green circular bands of grass observed in established turfgrass areas (Couch, 1995; Smiley et al., 1992; Smith et al., 1989; Vargas, 1994). Fairy ring is common among all cultivated turfgrasses worldwide, and on golf courses this disease is frequently observed on putting greens (Couch, 1995; Fidanza, 1999). Turfgrass injury symptoms and damage due to fairy ring are observed at any time during the year, but often occur during periods of hot, dry, and drought-like weather followed by rain events (Couch, 1995; Smith et al., 1989). Shantz and Piemeisel (1917) placed fairy ring disease into three categories or “types” based on visual response of the affected turfgrass stand: type-I fairy rings are those that kill or seriously damage turfgrass; type-II stimulate plant growth as evident by circular bands of dark green turfgrass; and type III do not stimulate turfgrass growth and cause no damage, but produce mushrooms in circles or arcs.

Type-I fairy ring is the most damaging because it will contribute to the formation of soil hydrophobicity or water-repellent soils also known on golf course putting greens as “dry patch” or “localized dry spot” (Karnok and Tucker, 1999). The result is dead turfgrass plants from lack of soil water and nutrients. When the desired movement of water, nutrients, and oxygen is impeded through modified sand-based putting greens, the result is stagnant root environments or hydrophobic conditions contributing to root dieback (Agnew and Carrow, 1985). Several causes for this condition have been attributed to the formation of black layers (Hodges and Campbell, 1997), use of poor quality sand topdressing (Cullimore et al., 1990), and poor water quality (Dean et al., 1996). Fairy ring fungi are also associated with hydrophobic conditions leading to the development of localized dry spot symptoms on putting greens (Blenis et al., 1997; Couch, 1995).

Current strategies for fairy ring control in turfgrass include cultural practices such as core cultivation and aeration, irrigation to thoroughly wet the soil profile, and topical fungicide

and soil surfactant applications aimed at suppressing the fungus and masking injury symptoms (Blenis et al., 1997; Couch, 1995; Dernoeden, 2000; Fidanza, 1999; Hickman et al., 1998; Nadeau et al., 1993; Watschke et al., 1995). Research is sparse, however, regarding innovative pesticide application technology for golf course turf (Rossi, 2002). The use of HPI to insert pesticides directly into the profile of a sand-based USGA-specification (U.S. Golf Assn., Far Hills, N.J.) putting green has been attempted for nematode control (Blackburn et al., 1997). Fungicide applications through HPI, however, have not been investigated for control of fairy ring or other turfgrass diseases. Therefore, the objective of this research was to evaluate curative type-I fairy ring control or symptom reduction from fungicides and a soil surfactant delivered by HPI into fairy ring-affected turfgrass.

Materials and methods

This research was conducted in 1998 and 1999 at Texas A&M University Research and Education Center, Dallas. In both years, studies were conducted on a 20-year-old USGA sand-based putting green of an unknown cultivar of creeping bentgrass mowed daily at 3.9624 mm (0.156 inch) height with a reel mower and clippings removed. This test site had a history of type-I fairy ring symptoms typically appearing during hot and dry periods in June through August.

In 1998, the study consisted of seven curative treatments arranged as a randomized complete-block design with six replications. Individual plot size measured 1.5 × 6.1 m (5 × 20 ft). The treatments were: 1) flutolanil fungicide (Bayer Environmental Science, Montvale, N.J.); 2) flutolanil plus Primer soil surfactant (a proprietary blend of polymeric polyoxyalkylenes and oxoalkenyl hydroxyl polyoxyalkane diyl; Aquatrols Inc., Cherry Hill, N.J.); 3) HPI flutolanil; 4) azoxystrobin fungicide (Syngenta Professional Products, Greensboro, N.C.); 5) azoxystrobin plus Primer; 6) HPI azoxystrobin; and 7) untreated. Flutolanil was applied at a.i. 9.19 kg·ha⁻¹ (8.2 lb/acre), azoxystrobin at a.i. 0.616 kg·ha⁻¹ (0.55 lb/acre), and Primer at 18.7 L·ha⁻¹ (2 gal/acre). At the time of this study, flutolanil was the only fungicide registered for use on fairy ring in turfgrass; Primer was

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a popular soil surfactant often used in combination with flutolanil; and azoxystrobin was used repeatedly on golf course putting greens for other turfgrass diseases during the summer (Dernoeden, 2000; Fidanza, 1999). All non-HPI treatments were applied in a conventional manner from a CO₂ powered backpack sprayer calibrated to deliver 1216.0 L·ha⁻¹ (130 gal/acre) water through three 8008 flat-fan nozzles at 241.3 kPa (35 psi). HPI treatments were applied from a Cushman Enviroject Model 160 (Jacobsen Inc., Charlotte, N.C.) through a high-pressure injector using a 327.7 cm³ (20 inch³) accumulator calibrated to deliver 7669.9 L·ha⁻¹ (820 gal/acre) water at 17,237 kPa (2500 psi). Injector ports were spaced 10.2 cm (4 inches) apart along a 1.2-m-long (4 ft) boom at a height of 5.1 cm (2 inches), and pulsed intermittently as the vehicle traveled 4.8 km·h⁻¹ (3 mph). Water penetration into the putting green profile was measured as approximately 5.1 cm deep on a 25.8-cm² (4 inch²) spacing. Type-I fairy ring symptoms first appeared in late June 1998. All treatments were applied twice on a 28-d interval on 8 July and 5 Aug. 1998. The 28-d interval corresponded with product label recommendation for flutolanil. Disease severity was determined visually by estimating percent plot area with type-I symptoms on a linear 0 to 100% scale, where 0 = no symptoms, and 100 = entire plot area affected. Severity assessments were recorded every 2 weeks from 8 July through 2 Sept. 1998. Acceptable disease control for a golf course putting green was determined as ≤5% plot area affected with type-I fairy ring symptoms. Soil infiltration was measured using a double-ring infiltrometer (Betrand, 1965) on 3–4 Aug. and 1–2 Sept. 1998 with a Turf-tec Infiltrometer (Turf-tec International, Coral Springs, Fla.). In each plot, one infiltration measurement was conducted in an area exhibiting type-I fairy ring symptoms, and one measurement in an area with healthy turfgrass and no symptoms present. Soil water was measured only on 2 Aug. 1998 with an Aquaterr Soil Moisture Meter 200 (Geneq Inc., Montreal, Canada) and recorded as percent soil water saturation based on soil electrical conductivity. In each plot, soil moisture was measured in three areas with and three areas without type-I fairy ring symptoms present.

In 1999, the study consisted of five curative treatments: 1) HPI flutolanil; 2) HPI flutolanil plus Primer; 3) HPI azoxystrobin; 4) HPI water only; and 5) aeration only. Aeration or core cultivation was included because it is a common cultural practice for suppressing type-I fairy ring symptoms on golf course putting greens (Couch, 1995; Dernoeden, 2000; Fidanza, 2003). Plot size again measured 1.5 × 6.1 m and treatments were arranged as a randomized block design with six replications. Product application rates and HPI delivery methods were the same as described in 1998. Plots subjected to aeration received one pass from a 7.6-cm-deep (3 inches) solid-tine aerifier (AeroKing; Jacobsen, Inc., Charlotte, N.C.). Type-I fairy ring symptoms first appeared in mid-June 1999. All treatments were applied twice on an approximate 28-d interval on 1 and 28 Jul 1999. Disease severity was observed every 2 weeks from 1 July through 25 Aug. 1999, however, soil infiltration and soil moisture was not measured in this 1999 study.

Data from each study were subjected to analysis of variance conducted on Statistical Analysis Software (SAS Institute, 1987). Treatment means were separated by Fisher's protected least significance difference test at $P < 0.05$, and infiltration and soil moisture data were subjected to predetermined, single degree-of-freedom contrasts.

Results and discussion

Investigations of fairy ring on golf course turf typically consist of 1-

year field studies (Blenis et al., 1997; Fidanza, 1999; Hickman et al., 1998; Nadeau et al., 1993). This field study was unique in that it was conducted over 2 consecutive years at the same location. In both years, type-I fairy ring symptoms were attributed to *Lycoperdon pyriforme*, a basidiomycete identified by its characteristic "puffball" fruiting body or mushroom frequently observed on this creeping bentgrass putting green (Arora, 1986; Miller, 1972).

In 1998, an average 9.9% plot area with type-I fairy ring symptoms or turf injury were observed at the start of this study on 8 July 1998 (Table 1). By 22 July 1998, all fungicide-treated plots averaged 8.6% plot area affected while turf injury continued to increase significantly to an average of 19.2% in untreated plots (Table 1). On 5 Aug. 1998, average turf injury in untreated plots was greatest at 29.3% plot area affected (Table 1). Also on 5 Aug. 1998, acceptable disease control (i.e., ≤5% plot area with symptoms or turf injury) was observed in plots treated with flutolanil plus Primer; however, all fungicide-treated plots had significantly fewer symptoms vs. untreated plots (Table 1). Flutolanil plus Primer has been effective for treating turf affected with fairy ring in other field studies (Fidanza, 1999; Hickman et al., 1998). After one application in this field study, flutolanil plus Primer provided better control vs. flutolanil alone or HPI flutolanil. Poor or unacceptable fairy ring control could be attributed to movement of fungicide

Table 1. Effect of fungicide and soil surfactant treatments on type-I fairy ring severity on a creeping bentgrass putting green in 1998.

Treatments ^a	8 July	22 July	5 Aug.	19 Aug.	2 Sept.
----- Plot area with type-I fairy ring symptoms (%) ^b -----					
Flutolanil	10.2 a ^c	8.4 b	18.3 bc	20.1 a	16.7 a
Flutolanil + Primer	12.3 a	7.1 b	4.3 d	3.0 b	<1.0 b
HPI flutolanil	5.7 a	7.6 b	16.5 b	3.5 b	4.2 b
Azoxystrobin	12.0 a	10.2 b	9.2 cd	10.4 b	2.2 b
Azoxystrobin + Primer	9.2 a	11.5 b	18.1 b	7.4 b	3.7 b
HPI azoxystrobin	9.5 a	6.5 b	7.2 cd	3.8 b	3.3 b
Untreated	10.7 a	19.2 a	29.3 a	27.5 a	18.7 a

^aTreatments applied on a 28-d interval on 8 July and 5 Aug. 1998. Fungicide treatment application rates were flutolanil a.i. 9.19 kg·ha⁻¹ (8.2 lb/acre) or azoxystrobin a.i. 0.616 kg·ha⁻¹ (0.55 lb/acre). Primer soil surfactant was applied at 18.7 L·ha⁻¹ (2 gal/acre). All treatments were applied via CO₂-powered back-pack sprayer from three 8008 flat-fan nozzles at 241.3 kPa (35 psi) in 1216.0 L·ha⁻¹ (130 gal/acre) water except those indicated as HPI (high-pressure injection). HPI treatments were applied with a Cushman Enviroject Model 160 (Jacobsen Inc., Charlotte, N.C.) from injector ports calibrated to deliver 7669.9 L·ha⁻¹ (820 gal/acre) water at 17,237 kPa (2500 psi).

^bFairy ring severity determined by percent plot area exhibiting type-I symptoms on a linear 0 to 100% scale, where 0 = no symptoms, and 100 = entire plot area affected. Acceptable disease control was determined as ≤5% plot area with visible type-I fairy ring symptoms.

^cData are means of six replications, and means in a column followed by the same letter are not significantly different at $P \leq 0.05$ according to Fisher's protected least significant different test.

past the target area in soils with high sand content (Gelernter and Stowell, 1999), possibly due to the excessive amount of water carrier and extreme pressure from HPI-treated turf, and that flutolanil as a fungicide is not an effective soil wetting agent and has no effect on soil hydrophobicity (Karnok and Tucker, 2001). In contrast to all flutolanil-treated plots by 5 Aug. 1998, plots treated with azoxystrobin alone or HPI azoxystrobin had significantly fewer symptoms vs. azoxystrobin plus Primer (Table 1). On 19 Aug. 1998, all fungicide-treated plots except those treated with flutolanil alone exhibited improved turf recovery or reduction in disease symptoms compared to 5 Aug. 1998 (Table 1). This trend continued through 2 Sept. 1998, where acceptable control was observed on all fungicide-treated plots except those treated with flutolanil alone, although slight turf recovery was observed in plots treated with flutolanil alone or untreated plots (Table 1). In this 1998 study, two topical applications of flutolanil alone was not effective for curative control of type-I fairy ring; however, acceptable control was observed in plots that received two applications of HPI flutolanil, azoxystrobin alone, azoxystrobin plus Primer, HPI azoxystrobin, or after one application of flutolanil plus Primer (Table 1). Soil infiltration results were inconclusive with no significant differences among treatments or sampling areas on either assessment date (data not shown), with an average of 510.54 and 574.04 mm·h⁻¹ (20.1 and 22.6 inches/h) on 3–4 Aug. and 1–2 Sept. 1998, respectively. The water drop penetration test may be a better method for comparing treatment effects on water infiltration in soils affected with type-I fairy ring (Fidanza, 2003; Karnok and Tucker, 2001). Soil moisture was used only to compare soil water status (i.e., percentage of soil water saturation) among treatments and sampling areas. Percent soil water saturation was significantly (i.e., $P < 0.05$) greater in plot areas without type-I fairy ring symptoms in contrast to areas with symptoms (data not shown). In plot areas without symptoms, soil moisture status was statistically similar among all treatments (Table 2). In plot areas with symptoms, greatest percent soil moisture was measured in plots treated with Primer, although statistically similar to plots treated with flutolanil or HPI flutolanil

(Table 2). A nonsignificant correlation was observed between percent plot area with symptoms vs. percent soil moisture (data not shown).

In 1999, an average 10.4% plot area with symptoms were observed at the initiation of this study on 1 July 1999 (Table 3). All plots exhibited a reduction in symptoms to an acceptable $\leq 4.5\%$ average plot area affected on 15 and 28 July 1999 (Table 3). After the second application, this trend continued on 11 Aug. 1999 to $\leq 5.8\%$ average plot area affected (Table 3). By 25 Aug. 1999, turf injury increased dramatically in those plots treated with HPI flutolanil, HPI water, or aeration, which may suggest that a shorter application interval may be necessary for achieving acceptable disease control and turf recovery (Table 3). Also, by 25 Aug. 1998, acceptable disease control was observed in those plots treated with HPI flutolanil plus Primer or HPI azoxystrobin.

In conclusion, data from the 1998 and 1999 studies suggest the importance of including a soil surfactant with flutolanil to help alleviate hydrophobic conditions associated with type-I fairy ring, although either fungicide-applied HPI or azoxystrobin applied with or without a soil surfactant was equally effective. The exact effect of HPI water or aeration on type-I fairy ring symptoms was not possible to determine without an untreated control as a comparison.

Conventional application of fungicides has been effective but not consistent for fairy ring control in turfgrass (Fidanza, 1999; Smith et al., 1989; Watschke et al., 1995). Conventional or topical applications of soil surfactants have been used to treat localized dry spot or hydrophobic areas on putting green turf (Karnok and Tucker, 1999, 2001); however, those products offer no control of fairy ring fungi that contribute to the development of hydrophobic conditions (Couch, 1995). A major impediment to use of foliar-applied fungicides is lack of penetration into the thatch or root zone where fairy ring fungi are growing and therefore the fungicide is not effective (Couch, 1995). Most fungicides have a high affinity for organic matter and are marginally mobile in soil after foliar application (Lickfeldt and Branham, 1995). A conventional curative fairy ring control program for golf course putting greens includes irrigating the target area to field capacity, followed by the topical application of a fungicide plus soil surfactant and immediately irrigated again to essentially move the fungicide to the target thatch or root zone (Couch, 1995). The application of fungicides and soil surfactants via HPI could provide an alternative method of product delivery and placement for both curative and possibly preventive control of fairy ring. Future research should investigate the delivery

Table 2. Effect of fungicide and soil surfactant treatments on soil moisture in plot areas with and without type-I fairy ring symptoms on a creeping bentgrass putting green in 1998.

Treatments ^a	Plot area with type-I fairy ring symptoms	Plot area without type-I fairy ring symptoms
----- Soil water saturation (%) ^b -----		
Flutolanil	35.1 bc ^x	77.9 a ^x
Flutolanil + Primer	50.1 b	93.3 a
HPI flutolanil	35.8 bc	89.2 a
Azoxystrobin	22.1 c	77.8 a
Azoxystrobin + Primer	68.3 a	89.6 a
HPI azoxystrobin	25.1 c	85.2 a
Untreated	24.8 c	88.3 a

^aTreatments applied on a 28-d interval on 8 July and 5 Aug. 1998. Fungicide treatment application rates were flutolanil a.i. 9.19 kg·ha⁻¹ (8.2 lb/acre) or azoxystrobin a.i. 0.616 kg·ha⁻¹ (0.55 lb/acre). Primer soil surfactant was applied at 18.7 L·ha⁻¹ (2 gal/acre). All treatments were applied via CO₂-powered back-pack sprayer from three 8008 flat-fan nozzles at 241.3 kPa (35 psi) in 1216.0 L·ha⁻¹ (130 gal/acre) water except those indicated as HPI (high-pressure injection). HPI treatments were applied with a Cushman Enviroject Model 160 (Jacobsen Inc., Charlotte, N.C.) from injector ports calibrated to deliver 7669.9 L·ha⁻¹ (820 gal/acre) water at 17,237 kPa (2500 psi).

^bSoil moisture was determined on 2 Aug. 1998 with an Aquaterr Soil Moisture Meter 200 (Geneq Inc., Montreal, Canada). In each plot, three measurements were recorded in areas with type-I fairy ring symptoms, and three measurements in areas without symptoms. Table values listed represent means of soil moisture as percent of soil water saturation.

^xOrthogonal contrast revealed a significant ($P \leq 0.05$) difference in soil moisture between plot areas with versus without type-I fairy ring symptoms (data not shown). Therefore, soil moisture data presented separately for plot areas with and without symptoms, and data are means of six replications, and means in a column followed by the same letter are not significantly different at $P \leq 0.05$ according to Fisher's protected least significant different test.

Table 3. Effect of fungicide and soil surfactant treatments on type-I fairy ring severity on a creeping bentgrass putting green in 1999.

Treatments ^a	1 July	15 July	28 July	11 Aug.	25 Aug.
----- Plot area with type-I fairy ring symptoms (%) ^b -----					
HPI flutolanil	7.5 a ^x	2.6 a	2.3 a	3.6 a	15.2 b
HPI flutolanil + Primer	11.2 a	3.5 a	<1.0 a	<1.0 a	1.3 c
HPI azoxystrobin	9.3 a	2.5 a	<1.0 a	1.8 a	3.7 c
HPI water	14.2 a	1.4 a	4.5 a	5.8 a	38.3 a
Aeration	9.8 a	<1.0 a	2.5 a	4.2 a	22.7 a

^aTreatments applied on a 28-d interval on 1 and 28 July 1999. Fungicide treatment application rates were flutolanil a.i. 9.19 kg·ha⁻¹ (8.2 lb/acre) or azoxystrobin a.i. 0.616 kg·ha⁻¹ (0.55 lb/acre). Primer soil surfactant was applied at 18.7 L·ha⁻¹ (2 gal/acre). HPI (high-pressure injection) treatments were applied with a Cushman Enviroject Model 160 (Jacobsen Inc., Charlotte, N.C.) from injector ports calibrated to deliver 7669.9 L·ha⁻¹ (820 gal/acre) water at 17,237 kPa (2500 psi), and the aeration treatment consisted of a single pass over entire plot area with 7.6-cm-deep (3 inches) solid-tine aerifier (AcroKing, Jacobsen Inc., Charlotte, N.C.).

^bFairy ring severity determined by percent plot area exhibiting type-I symptoms on a linear 0 to 100% scale, where 0 = no symptoms, and 100 = entire plot area affected. Acceptable disease control was determined as ≤5% plot area with visible type-I fairy ring symptoms.

^xData are means of six replications, and means in a column followed by the same letter are not significantly different at $P \leq 0.05$ according to Fisher's protected least significant different test.

of turfgrass disease management strategies (i.e., fungicides, soil surfactants, cultural practices) via HPI for fairy ring and other disease complexes of turfgrasses. The use of HPI for effective turfgrass disease control may depend on the pathogen complex and disease symptoms present in conjunction with the selected fungicide and soil surfactant.

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