Published November 1, 2018

Evaluation of a Petroleum-Derived Spray Oil for Control of Microdochium Patch and Turfgrass Spring Performance on Nordic Golf Greens

Trygve S. Aamlid,* Oiva Niemeläinen, Klaus Paaske, David Widmark, Pentti Ruuttunen, and Auli Kedonperä

ABSTRACT

Greenkeepers are looking for alternatives to fungicides for control of turfgrass diseases. Our objective was to evaluate a petroleum-derived spray oil with a blue-green pigment for control of Microdochium patch/pink snow mold (*Microdochium nivale*) on golf course putting greens with various durations of snow cover. The spray oil was applied at rates 27 or 54 L ha^{-1} every third week from late August or September to December, either alone, in tank mixture with potassium phosphite (3 kg PO_3 ha^{-1}) or in tank mixture with half rate of fungicides approved for turf, in five 1-yr trials in the Nordic countries. The oil was as effective or more effective than fungicides and gave, on average, 94 and 98% disease control at rates 27 and 54 L ha^{-1}, respectively. Tank mixtures with half rate of prochloraz + propioconazole and fludioxonil did not increase disease suppression in a trial with 79 d snow cover. Phosphite reduced disease severity in one trial only and did not improve disease control or turfgrass quality when tank-mixed with the oil. The pigment in the spray oil was highly persistent and improved turfgrass greenness except in a trial where the combination of oil and ice cover gave a transitory black color at ice melt. Another trial with long snow cover showed a drop in turfgrass quality in spring as the spray oil prevented normal green-up. In conclusion, this research shows that a spray oil has the potential to reduce fungicide use on Nordic golf courses.

Core Ideas

- Mineral oil was as effective as or more effective than fungicides in controling Microdochium patch.
- Repeated applications of mineral oil in autumn might inhibit turfgrass green-up in spring.
- Mineral oil can reduce conventional fungicide use on Nordic golf courses.

Published in Agron. J. 110:2189–2197 (2018)
doi:10.2134/agronj2018.07.0475

The cool-weather ascomycete causing most damage on Nordic golf courses is *Microdochium nivale* (Fries) Samuels & Hallett. This pathogen causes dead or weakened spots even in the absence of snow cover; such spots are commonly referred to as 'Microdocium patch' (Smiley et al.,1992; Tronsmo et al., 2001). After snow cover, the patches are usually larger and surrounded by a bronze-colored or pink ring, thus the name 'pink snow mold'. While the susceptibility to Microdochium patch/pink snow mold varies among cool-season turfgrass species (Gregos et al., 2011; Aamlid et al., 2012) and ecotypes (Bertrand et al., 2009), breeding for resistance has often encountered difficulties due to genetic variation within the disease complex (Casler et al., 2007).

Up to now, the most common strategy to control microdochium patch/pink snow mold on golf greens has been to spray the greens preventatively with fungicides prior to winter (Aamlid et al., 2015). The number of fungicides approved for this purpose in the five Nordic countries is, however, limited to 2–5 active ingredients per country (Aamlid et al., 2016). These same countries have also implemented the principles for Integrated Pest Management (IPM) requiring cultural measures or low-risk plant protection products to be used before fungicides whenever possible (Aamlid et al., 2016). Among the criteria for 'low risk plant protection products' are that they are not carcinogenic, mutagenic, neutrotoxic, immunotoxic, or toxic to reproduction (EU, 2009). Biological control products would be a viable alternative given these EU regulations, but Nordic field trials did not demonstrated efficacy of such products although some of them reduced fungal growth in vitro (Aamlid et al., 2017).

An alternative method to control Microdochum patch/pink snow mold is the use of resistance activators, i.e., products whose effect is not primarily fungicidal or fungistatic, but which trigger natural defense mechanisms in plants (Hsiang et al., 2011). One such product is a clear, colorless oil composed of food-grade isoparaffins (trade name 'Civitas', Suncor Energy, Mississauga, ON, Canada). In Canada and the United States, this spray oil has been approved for many years for use in turf, and there are several publications showing efficacy against various turfgrass

T.S. Aamlid, Norwegian Institute of Bioeconomy Research (NIBIO), P.O. Box 115, NO-1431 Ås, Norway; O. Niemeläinen, P. Ruuttunen, Auli Kedonperä, Natural Resources Institute Finland, Planta, Tietotie 4 FI-31600, Jokioinen FI-31600, Finland; K. Paaske (retired), Aarhus Univ., Dep. of Agroecology, Forsøgsvej 1, Slagelse DK-4200, Denmark; D. Widmark, HS-konsult AB, P.O. Box 112, Uppsala S-75 106, Sweden; A. Kedonperä, Luonnonvarakeskus Jokioinen, Planta, Tietotie 4, Jokioinen FIN-31600, Finland. Received 31 July 2018. Accepted 22 Aug. 2018. *Corresponding author (trygve.aamlid@nibio.no).

Abbreviations: IPM, integrated pest management.

diseases (Cortes-Barco et al., 2010; McCall and Focht, 2010; Aynardi and Uddin, 2013a, 2013b) including Microdocium patch/pink snow mold (Mattox, 2015; Stricker et al., 2017; Van Dyke and Johnson, 2017). Most of this research was conducted with the oil in a tank mixture with a blue-green pigment containing polychlorinated copper (trade name 'Harmonizer', Suncor Energy, Mississauga, ON, Canada). The two components may either be sold in a two-pack formulation to be mixed on site, or as the premixed single product formulation 'Civitas One' containing 88.8% (w/w) mineral oil.

The blue-green pigment been shown to reduce dollar spot (*Clarireedia* sp.) severity under field conditions (Nash, 2011) and may, like the oil, play a role in activating defense-related genes (Hsiang et al., 2013). In our knowledge the pigment has, however, not been documented to control Microdochium patch/pinks snow mold if applied without the oil. With regard to spring recovery, pigments have been shown to increase canopy temperature (Aamlid and Pettersen, 2013; Braun et al., 2016) and protect turfgrass leaves against ultraviolet radiation (Ervin et al., 2004). Spring stresses due to ultraviolet radiation may well be a special concern under Nordic climate condition with long photoperiods and late snow melt (Kvalbein et al., 2016).

A risk associated with the use of mineral oils is if they can cause phytotoxicity. Acute phytotoxicity implies visible damage such as sunburned leaves and chlorotic or necrotic tissues, while chronic phototoxicity affects stomatal conductance and thus transpiration and the balance between photosynthesis and photorespiration in C_3–plants (Hodgkinson et al., 2002; Finger et al., 2002). Mineral oil resulted in leaf chlorosis within a few hours of application on a creeping bentgrass (*Agrostis stolonifera* L.)/annual bluegrass (*Poa annua*) putting green in summer (daily maximum temperatures in the range 20–35°C), but the chlorosis was masked if the oil was applied in tank mixture with the blue-green pigment (Kreuser and Rossi, 2014). The authors also documented a reduction in turfgrass gas exchange and tiller density after application of the oil, and this chronic phytotoxicity could not be prevented by the pigment. A negative effect on turfgrass quality was also observed by Mattox (2015) when combining oil/pigment with rolling on an annual bluegrass putting green.

While most research into the effects of mineral oil and pigment on Microdochium patch was conducted in areas with no or occasional snow cover, Van Dyke and Johnson (2017) studied the effect on snow molds (*M. nivale* and *Typhula* sp. not specified) during a 2-yr period on a creeping bentgrass green with continuous snow cover from December through March. Application of mineral oil and pigment gave the same snow mold control as the fungicide pentachloronitrobenzene in the first year, but less than half control compared with pentachloronitrobenzene in the second year. The best turfgrass quality and green-up in spring was observed after application of a tank mixture of oil, pigment and a low rate of the fungicide propiconazole shortly before snow cover. Research in Canada, Minnesota, and Wisconsin has also confirmed that it may be necessary to combine oil and pigment with low fungicides rates to obtain adequate control of pink snow mold or gray snow mold (*Typhula incarnata*) in areas with prolonged snow cover (Kerns, 2012; Van Dyke and Johnson, 2017; B. Nash, Suncor Energy, personal communication, 2018)

In addition to mineral oils, another group of products known to activate defense against turfgrass pathogens are the potassium phosphites (Guest and Grant, 1991; Cook et al., 2009a, 2009b; Dempsey et al., 2012, 2014). Phosphites (PO_3) do not have the same plant nutritional function as PO_4, but they have been shown to control diseases and are therefore classified by the European Union as fungicides (EU, 2013). Their mode of action is partly direct inhibition of the pathogen and partly by inducing host-defense mechanisms (Fenn and Coffey, 1984; Hofgaard et al., 2010; Dempsey et al., 2014). While initial research into the effect of phosphites on turfgrass pathogens was conducted with *Pythium* (Cook et al., 2009a), they have also been shown to control Microdochium patch, although not as effectively as traditional fungicides (Dempsey et al., 2012).

In compliance with international IPM principles (FAO, 2016), the objective of this research was to evaluate the potential of a premixed formulation of mineral oil and pigment, applied either alone or in combination with traditional fungicides or potassium phosphite, to replace the current use of fungicides against Microdochium patch/pink snow mold on Nordic golf courses. Trials were conducted both in the southern/coastal climatic zone and in the northern/continental climatic zone representing contrasting durations of snow cover within the Nordic countries (Aamlid et al., 2012). Besides control of pink snow mold, the trials in the northern zone aimed specifically at assessing turf quality during the first 4 wk after spring snow melt.

MATERIALS AND METHODS

Experimental Sites and Treatments

Field trials on putting greens were conducted during the fall/winter/spring season 2014–2015 at Österåker GC, Sweden, and Sydsjælland GC, Denmark; during 2015–2016 at Sydsjælland GC, Denmark and Lepaa GC, Finland; and during 2016–2017 at Hillside GC, Finland. Detailed information about the experimental sites and turfgrass management can be found in Table 1.

All trials had four replications and were established according to national standards for Good Experimental Practice (e.g., Danish Environmental Protection Agency, 2010) including complete randomization of treatments within each of four blocks. Plot size varied from 3.0 to 5.0 m^2 depending on the experimental sprayers used. An Agrotop plot sprayer (Agrotop GmbH, Obertraubling, Germany) with 1.0 m boom width and nozzles 50 cm apart was used in the Swedish trial; a bicycle track sprayer with 2.0 m boom width, nozzles 25 cm apart and a Lykketronic PX Combi Spray Computer (Kramp GmbH, Strullendorf, Germany) was used in the Danish trials, and a van der Weij plot sprayer (Clarke and Ross 1964) with 1.3 m boom width and nozzles 25 cm apart was used in the Finnish trials. All sprayers operated at a working pressure of 30 kPa and used 110° Hardi flat fan nozzles (Hardi International A/S, Taastrup, Denmark).

The four trials in 2014–2015 and 2015–2016 included nine and 10 treatments, respectively (Table 2). A premixed formulation of mineral oil/pigment (Civitas One, Suncor Energy, Mississauga, ON, Canada), potassium phosphite, fungicides, and tank mixtures were applied in a volume of 800 L ha^{-1} every third week from August/September to November/December (four or five applications altogether; Table 1).

Potassium phosphite was applied as the commercial product Resibase 0–13–17 (DLG Group, Copenhagen, Denmark) at a

Table 1. Information about experimental sites and turfgrass management in the five field trials.

	Österåker GC, Sweden	Sydsjælland GC, Denmark	Sydsjælland GC, Denmark	Lepaa GC, Finland	Hillside GC, Finland
Latitude/longitude	59°29′ N, 18°15′ E	55°11′ N, 11°52′ E	55°11′ N, 11°52′ E	61°07′ N, 24°20′ E	60°26′ N, 24°12′ E
Duration of trial	29 Aug. 2014–8 Apr. 2015	25 Aug. 2014–8 Apr. 2015	28 Aug. 2015–17 Mar. 2016	24 Sept. 2015–10 May 2016	22 Sept. 2016–20 Apr. 2017
Botanical composition†	70% AB, 25% CRB, 5% other	74% RF, 24% COB, 2% AB	80% RF, 18% COB, 2% AB	59% CRB, 34% RF, 7% AB	75% CRB, 16% RF, 8% AB
First application, date	29 Aug. 2014	25 Aug. 2014	28 Aug. 2015	24 Sept. 2015	22 Sept. 2016
Last application, date	29 Nov. 2014	20 Nov. 2014	26 Nov. 2015	1 Dec. 2015	22 Nov. 2016
Number of applications	5	5	5	4	2 or 4
Fungicides used in positive control treatment	Propiconazole‡, 468 g a.i. ha^{-1} × 3 + fludioxonil§, 375 g a.i. ha^{-1}, ×2	Prothioconazole¶, 200 g a.i ha^{-1} ×5	Prothioconazole¶, 200 g a.i ha^{-1}×5	Propiconazole + prochloraz#, 90 + 400 g a.i. ha^{-1} ×2 + fludioxonil, 375 g a.i. ha^{-1}, ×2	See Table 3
Fertilizer rate, g N m^{-2} yr^{-1}	20.0	8.9	8.9	22.7	10.6
Last fertilizer input in autumn, date and rate	9 Oct. 2014, 0.8 g N m^{-2}	25 Nov. 2014, 0.1 g N m^{-2}	25 Nov. 2015, 0.1 g N m^{-2}	15 Sept. 2015, 0.4 g N m^{-2}	28 Nov. 2016, 0.5 g N m^{-2}
Last mowing before winter/mowing height	28 Oct. 2014/4 mm	11 Nov. 2014/7 mm	10 Nov. 2015/7 mm	25 Sept. 2015/3.5 mm	11 Oct. 2016/4 mm
First fertilizer input in spring, date and rate	9 Mar. 2015, 0.4 g N m^{-2}	3 Apr. 2015, 0.6 g N m^{-2}	1 Apr. 2016, 0.6 g N m^{-2}	21 Apr. 2016, 2.8 g N m^{-2}	10 Apr. 2017, 0.2 g N m^{-2}
First mowing in spring/ mowing height	10 Apr. 2015/4.5 mm	6 Mar. 2015/6 mm	12 Mar. 2016/6 mm	23 Apr. 2016/8 mm	24 Apr. 2017/4 mm
Spring assessment	8 Apr. 2015	9 Mar. 2015	17 Mar. 2016	12 Apr., 25 Apr., 10 May 2016	23 Mar., 6 Apr., 20 Apr. 2017

† AB, annual bluegrass (*Poa annua* L.); COB, colonial bentgrass (*Agrostis capillaris* L.); CRB, creeping bentgrass (*Agrostis stolonifera* L.); RF, red fescue (*Festuca rubra* L.).

‡ Banner Maxx (Syngenta Crop Protection AG, Basel, Switzerland).

§ Medallion TL (Syngenta Crop Protection AG, Basel, Switzerland).

¶ Proline EC 250 (Bayer Crop Science Monheim, Germany).

Basso (Adama Agricultural Solutions Ltd. Israel).

Table 2. Experimental applications at approximately 4-wk intervals from August/September to November/December in trials at Österåker GK, Sweden (2014–2015); Sydsjælland GK, Denmark (2014–2015 and 2015–2016); and Lepaa GK, Finland (2015–2016).

No.	Product	Rate
1	Untreated control	
2	Premixed oil/pigment†, half rate	27 L ha^{-1} (20.62 kg mineral oil ha^{-1})
3	Premixed oil/pigment, full rate	54 L ha^{-1} (41.24 kg mineral oil ha^{-1})
4	Potassium phosphite‡	7.5 L ha^{-1} (3 kg PO_3 ha^{-1})
5	Premixed oil/pigment + potassium phosphite, tank mix	27 + 7.5 L ha^{-1}
6	Premixed oil/pigment + potassium phosphite, tank mix	54 + 7.5 L ha^{-1}
7	Fungicide(s) depending on national registration, full rate§	
8	Premixed oil/pigment, half rate + fungicides, half rate, tank mix	27 L ha^{-1} + fungicides
9	Premixed oil/pigment full rate + fungicides, half rate, tank mix	54 L ha^{-1} + fungicides
10	Fungicides, half rate¶	

† Civitas One (Suncor Energy, Mississauga, Ontario, Canada).

‡ Resibase 0–13–17 (DLG Group, Copenhagen, Denmark).

§ See Table 1 for info about fungicides and rates.

¶ Included in 2015–2016 only.

rate of 7.5 L = 3 kg PO_3 ha^{-1} per application. The entire P content in Resibase 0–13–17 is in the form of phosphite, and there are no other nutrients except for K. The seasonal input of K in treatments 4–6 was 7.5 kg K ha^{-1} in the trials at Österåker GK and Sydsjælland GK and 6.0 kg K ha^{-1} in the trial at Lepaa GC; these inputs were not adjusted to the same levels in the other treatments.

The trial at Hillside GC, Finland, in 2016–2017 was conducted according to a modified plan without phosphite and treatments including two or four applications of either mineral oil or half rate fungicide or their sequential combination (Table 3). In this trial fungicides were always applied in a volume of 400 L ha^{-1}, while the mineral oil was applied in a volume of 800 L ha^{-1}, as in the previous trials.

Weather Conditions

Sydsjælland GC, Denmark has a mild winter climate with only a few, scattered days with snow cover during winter. The climate at Lepaa and Hillside GC, Finland is much colder with normally at least 100 d of snow cover, while the climate at

Table 3. Experimental treatments in the trial at Hillside GC, Finland, 2016–2017.

No.	Application timing in 2016			
	22 Sept.	13 Oct.	31 Oct.	22 Nov.
1	Untreated control			
2	Premixed oil/pigment† 27 L ha^{-1}	–	Premixed oil/pigment† 27 L ha^{-1}	–
3	Premixed oil/pigment† 54 L ha^{-1}	–	Premixed oil/pigment† 54 L ha^{-1}	–
4	Premixed oil/pigment† 27 L ha^{-1}	Premixed oil/pigment† 27 L ha^{-1}	Premixed oil/pigment† 27 L ha^{-1}	Premixed oil/pigment† 27 L ha^{-1}
5	Premixed oil/pigment† 54 L ha^{-1}	Premixed oil/pigment† 54 L ha^{-1}	Premixed oil/pigment† 54 L ha^{-1}	Premixed oil/pigment† 54 L ha^{-1}
6	–	Propiconazole + prochoraz‡, 45 + 200 g a.i. ha^{-1}	–	Fludioxonil§, 188 g a.i. ha^{-1}
7	Propiconazole + prochoraz‡, 45 + 200 g a.i. ha^{-1}	Propiconazole + prochoraz‡, 45 + 200 g a.i. ha^{-1}	Fludioxonil§, 188 g a.i. ha^{-1}	Fludioxonil§, 188 g a.i. ha^{-1}
8	Premixed oil/pigment† 27 L ha^{-1}	Propiconazole + prochoraz‡, 45 + 200 g a.i. ha^{-1}	Premixed oil/pigment† 27 L ha^{-1}	Fludioxonil§, 188 g a.i. ha^{-1}
9	Premixed oil/pigment† 54 L ha^{-1}	Propiconazole + prochoraz‡, 45 + 200 g a.i. ha^{-1}	Premixed oil/pigment† 54 L ha^{-1}	Fludioxonil§, 188 g a.i. ha^{-1}

†Civitas One (Suncor Energy, Mississauga, ON, Canada)

‡ Basso (Adama Agricultural Solutions Ltd., Israel)

§ Medallion TL (Syngenta Crop Protection AG, Basel, Switzerland)

Table 4. Information about temperature, precipitation and snow cover during the course of the five trials (long-term normal values are given in parentheses). Data from official weather stations belonging to the State Meteorological Services in each country.

Experimental site	Österåker GC, Sweden	Sydsjælland GC, Denmark	Sydsjælland GC, Denmark	Lepaa GC, Finland	Hillside GC, Finland
Official weather station (distance from experimental site	Stockholm (20 km)	Brandelev (3 km)	Brandelev (3 km)	Lepaa-Hattula (1 km)	Vihti-Maasoja (11 km)
Mean temp., Sept.–Nov. (30 yr normal), °C	9.5 (7.3)	11.4 (9.3)	9.9 (9.3)	6.7 (5.8)	4.6 (5.0)
Mean temp., Dec.–Feb. (30 yr normal), °C	0.9 (–2.4)	2.3 (0.6)	2.6 (0.6)	–3.8 (–4.8)	–2.9 (–5.3)
Mean temp., Mar.–Apr. (30 yr normal), °C	5.7 (2.3)	5.8 (4.4)	4.7 (4.4)	2.1 (1.5)	1.2 (0.4)
Total precip., Sept.–Apr. (30 yr normal), mm	430 (320)	500 (379)	508 (379)	335 (300)	293 (398)
Days with snow cover	52	10	9	79	125

Österåker GC, Sweden, is intermediate. During the course of the these trials, the fall, winter and spring seasons were mostly warmer than the 30 yr normal, while the precipitation was higher except at Hillside GC in 2016–2017 (Table 4).

Assessments and Statistical Analyses

Except during periods with snow or ice cover, Microdochium patch/pink snow mold were assessed at 3-wk intervals from September to spring in all trials by visually estimating the percentage of each plot exhibiting symptoms. Pathogen identity was confirmed in samples sent to NIBIO Turfgrass Diagnostic Lab., NIBIO Landvik, Norway, (https://www.nibio.no/en/services/diagnostics-of-turfgrass-diseases?locationfilter=true, accessed 10 July 2018) whenever evaluators were in doubt about symptoms. Turfgrass color intensity (rated on a one to nine scale, with one being completely brown/tan and nine being the most freshly green turf) and turfgrass quality (rated on a one to nine scale, with nine being the highest quality and 5.0 being the lowest value for acceptable turf) were assessed visually on the same dates on the whole plot, including diseased areas but excluding border areas that had not received full coverage from the experimental sprayers. The trials in Sweden and Denmark were discontinued after the first spring assessment in March or early April, but in Finland there were two more observations at 2-wk intervals to evaluate recovery after snow melt. Because of a misunderstanding, turfgrass quality was not assessed in the trial at Österåker GC in 2014–2015.

The experimental data from discrete observations in the Swedish trial was analyzed using PROC ANOVA version 9.4 (SAS Institute, Cary, NC) and the data from Denmark and Finland using ARM software (Gylling Data Management Inc., Brookings, SD). Homogenity if variance was tested using Bartlett's test and analyses performed on log-transformed or arcsin-transformed data if necessary to comply with the assumptions for ANOVA. Means were separated using the Student Neuman Keul multiple comparison test at $P \le 0.05$.

RESULTS

Effect of Treatments on Disease Development

There were no symptoms of Microdochium patch in any of the trials at the start of treatments in late August or September. Patches started to appear from mid-October and increased until the last observation before snow cover in late November or December (Tables 5 and 6). In all sites and years, the highest disease severity was at the first assessment in spring. Despite only

Table 5. Effects of mineral oil/pigment, potassium phosphite, fungicides and combinations on percentage of plot area showing symptoms Microdochium patch/pink snow mold at the last assessment in fall and first assessment in spring in four trials, 2014–2015 and 2015–2016.

	Österåker, Sweden, 2014–2015		Sydsjælland, Denmark, 2014–2015		Sydsjælland, Denmark, 2015–2016		Lepaa, Finland, 2015–2016	
	8 Dec.	8 Apr.	4 Dec.	9 Mar.	21 Dec.	17 Mar.	21 Dec.	12 Apr.
Untreated control	3.1 a†	5.5 a	20.0 a	30.0 a	37.5 a	47.5 a	12.0 a	17.5 b
Premixed oil/pigment, 27 L ha^{-1}	0.3 b	1.2 b	0.4 b	0.7 b	2.0 c	2.8 c	2.0 b	1.3 d
Premixed oil/pigment, 54 L ha^{-1}	0.0 b	1.8 b	0.0 b	0.0 b	0.0 c	0.0 c	0.9 b	0.2 d
Potassium phosphite, 7.5 L ha^{-1}	0.8 b	2.5 b	23.8 a	33.8 a	30.0 b	43.8 a	10.0 a	22.5 a
As 2 + 4, tank mixture	0.1 b	0.5 b	0.1 b	0.1 b	0.0 c	0.3 c	0.6 b	0.2 d
As 3 + 4, tank mixture	0.0 b	0.3 b	0.0 b	0.0 b	0.0 c	0.0 c	0.0 b	0.3 d
Fungicides‡	0.2 b	0.8 b	0.3 b	0.1 b	0.0 c	2.8 c	8.8 a	10.3 c
As 2 + half rate fungicides, tank mix	0.1 b	0.4 b	0.0 b	0.0 b	0.0 c	0.0 c	0.0 b	0.2 d
As 3 + half rate fungicides, tank mix	0.0 b	1.0 b	0.0 b	0.0 b	0.0 c	0.0 c	0.1 b	0.1 d
Fungicides, half rate	–	–	–	–	3.3 c	23.8 b	9.5 a	12.5 c
P-value	***	*	***	***	***	***	***	***

***, * Significant at $P \leq 0.001$ and $P \leq 0.05$, respectively.

† Means followed by the same letter within columns are not significantly different according to the Student-Newman-Keul multiple comparison test ($P \leq 0.05$).

‡ See Table 1 for info about fungicides.

Table 6. Percentage of microdochium patch/pink snow mold, turfgrass color intensity, and turfgrass quality at the last assessment in fall and first assessment in spring in trial at Hillside GC, Finland, 2016–2017.

	Microdochium patch/pink snow mold, % of plot area		Turfgrass color, (1–9, 9 is most intensely green)		Turfgrass quality (1–9, 9 is highest quality)	
	22 Nov.	23 Mar.	22 Nov.	23 Mar.	22 Nov.	23 Mar.
Untreated control	0	0.3	6.0 c†	6.0	5.0 c	5.5
Premixed oil/pigment, 27 L ha^{-1} ×2	0	0.9	7.0 b	5.0	5.8 b	4.5
Premixed oil/pigment, 54 L ha^{-1} ×2	0	0.8	7.5 b	3.8	6.8 a	4.3
Premixed oil/pigment, 27 L ha^{-1} ×4	0	0.4	7.5 b	4.8	7.0 a	4.3
Premixed oil/pigment, 54 L ha^{-1} ×4	0	0.3	8.0 a	4.5	7.0 a	4.0
Fungicides‡, half rate ×2	0	0.5	6.0 c	6.0	5.3 c	6.5
Fungicides, half rate ×4	0	0.5	6.0 c	5.8	5.0 c	5.8
Premixed oil/pigment, 27 L ha^{-1} ha ×2 + fungicides, half rate ×2	0	0.5	7.0 b	4.8	6.0 b	4.8
Premixed oil/pigment, 54 L ha^{-1} ha ×2 + fungicides, half rate ×2	0	0.7	7.0 b	4.3	6.8 a	4.3
P-value	NS	NS	***	NS	***	NS

*** Significant at $P \leq 0.001$. NS, not significant.

† Means followed by the same letter within columns are not significantly different according to the Student-Newman-Keul multiple comparison test ($P \leq 0.05$).

‡ See Table 3 for info about fungicides and rates.

9–10 d of snow cover in the Danish trials as opposed to 52–125 d in the Swedish and Finnish trials, the most severe outbreaks of disease (up to 47.5% on untreated plots) were observed on the red fescue (*Festuca rubra* L.) dominated greens at Sydsjælland GC, Denmark (Table 5). The lowest disease severity with no symptoms before winter and less than 1% in spring was seen in the creeping bentgrass trial established according to the revised experimental plan at Hillside GC, Finland in 2016–2017 (Table 6).

Application of the mineral oil with pigment was equally effective as the fungicides in controlling disease in the trials in Sweden and Denmark, and significantly more effective than the fungicides in 2015–2016 at Lepaa GC, Finland (Table 5). On average for the last assessment before winter and first assessment in spring in the four trials shown in Table 5, the repeated applications of oil/pigment suppressed disease by 94% when applied at 27 L ha^{-1}, while a doubling of the rate to 54 L ha^{-1} ha increased suppression to 98%.

Application of potassium phosphite reduced disease significantly at Österåker GC in 2014–2015 and at the last assessment before snow cover at Sydsjælland GC in 2014–2015 (Table 5). No significant reduction was observed in any of the other trials. There was also no significant effect of phosphite when added to the half or full rate of oil/pigment (treatments 5 and 6) in any of the trials.

Half rate of fungicides were included in the two trials in 2015–2016. No significant difference between half and full rate was observed when applying propiconazole + prochloraz and fludioxonil at Lepaa GC. Prothioconazole was less effective at the spring assessment after application of only half rate at Sydsjælland GC. Tank mixture of the half rate of oil/pigment and half rate of fungicide gave better control than full rate of fungicide at Lepaa

Table 7. Effects of mineral oil/pigment, potassium phosphite, fungicides and combinations on turfgrass color intensity (1–9, 9 is most intensely green) at the last assessment in fall and first assessment in spring in four trials, 2014–2015 and 2015–2016.

	Österåker, Sweden 2014–2015		Sydsjælland, Denmark 2014–2015		Sydsjælland, Denmark 2015–2016		Lepaa, Finland 2015–2016	
	8 Dec.	8 Apr.	4 Dec.	9 Mar.	21 Dec.	17 Mar.	21 Dec.	12 Apr.
Untreated control	6.0 b†	6.0	4.3 b	4.0 c	3.3 e	2.8 d	4.8 cd	2.0 b
Premixed oil/pigment, 27 L ha^{-1}	7.0 a	6.0	6.0 a	5.0 b	6.0 c	5.5 bc	6.0 abc	5.0 a
Premixed oil/pigment, 54 L ha^{-1}	7.0 a	6.0	7.0 a	5.3 b	8.0 a	7.0 a	6.8 a	5.0 a
Potassium phosphite, 7.5 L ha^{-1}	6.3 b	5.8	4.3 b	3.5 d	3.3 e	2.8 d	5.0 bcd	2.3 b
As 2 + 4, tank mixture	6.8 a	5.8	6.3 ab	5.0 b	6.8 b	6.3 ab	6.8 a	5.0 a
As 3 + 4, tank mixture	7.0 a	6.0	7.0 a	6.0 a	8.0 a	7.0 a	6.5 ab	5.0 a
Fungicides‡	6.0 b	6.0	6.0 a	6.0 a	7.0 b	4.8 c	5.5 abcd	2.5 b
As 2 + half rate fungicides, tank mix	7.0 a	6.0	7.0 a	5.5 ab	8.0 a	6.3 ab	7.0 a	5.5 a
As 3 + half rate fungicides, tank mix	7.0 a	6.0	7.0 a	6.0 a	8.0 a	7.3 a	7.0 a	5.5 a
Fungicides, half rate	–	–	–	–	5.5 d	3.3 d	4.3 d	2.0 b
P-value	***	NS	***	***	***	***	***	***

*** Significant at $P \le 0.001$. NS, not significant.

† Means followed by the same letter within columns are not significantly different according to the Student-Newman-Keul multiple comparison test ($P \le 0.05$).

‡ See Table 1 for info about fungicides.

Table 8. Effects of mineral oil/pigment, potassium phosphite, fungicides and combinations on turfgrass quality (1–9, 9 is highest quality, 5 is lowest acceptable quality) at the last assessment in fall and first assessment in spring in three trials, 2014–2015 and 2015–2016.

	Sydsjælland, Denmark 2 014–2015		Sydsjælland, Denmark 2015–2016		Lepaa, Finland 2015–2016	
	4 Dec.	9 Mar.	21 Dec.	17 Mar.	21 Dec.	12 Apr.
Untreated control	3.5 b†	2.5 b	3.0 d	2.5 d	4.5 d	1.0 c
Premixed oil/pigment, 27 L ha^{-1}	6.3 a	5.0 a	5.8 c	5.8 b	6.3 b	4.5 a
Premixed oil/pigment, 54 L ha^{-1}	7.0 a	5.3 a	8.0 a	7.3 ab	7.0 a	4.3 ab
Potassium phosphite, 7.5 L ha^{-1}	2.8 c	2.3 b	3.3 d	2.5 d	5.0 c	1.0 a
As 2 + 4, tank mixture	6.5 a	5.3 a	6.8 b	6.0 ab	7.0 a	4.0 ab
As 3 + 4, tank mixture	7.0 a	5.3 a	8.0 a	7.0 ab	7.0 a	4.0 ab
Fungicides‡	6.8 a	5.8 a	7.8 a	4.8 c	5.3 c	1.5 c
As 2 + half rate fungicides, tank mix.	7.0 a	5.8 a	8.0 a	6.8 ab	7.0 a	4.8 a
As 3 + half rate fungicides, tank mix.	7.0 a	5.5 a	8.0 a	7.3 a	7.0 a	3.5 b
Fungicides, half rate	–	–	5.5 c	3.0 d	5.0 c	1.3 c
P-value	***	***	***	***	***	***

*** Significant at $P \le 0.001$.

† Means followed by the same letter within columns are not significantly different according to the Student-Newman-Keul multiple comparison test ($P \le 0.05$).

‡ See Table 1 for info about fungicides.

GC, but was not significantly different from the full rate of fungicide at Sydsjælland GC (Table 5). There was no effect of either oil/pigment, fungicides or their sequential combinations in the trial at Hillside GC in 2016–2017 (Table 6).

Turfgrass Color Intensity

Application of oil with pigment caused a more intensely green color up to snowfall in all trials in 2014–2015 and 2015–2016 (Table 7). Except at Österåker GC in 2014–2015, this color effect also persisted after snow melt in spring. A significant color difference due to rate of oil/pigment was only observed at Sydsjælland GC in 2015–2016. At Hillside GC in 2016–2017, the green color before winter was significantly more intense on plots receiving four applications of the full rate of oil/pigment than on plots receiving the product at lower rates or lower frequencies (Table 6). However, at snowmelt, some of the plots treated with oil/pigment had an unattractive and uneven black color resulting in an insignificant trend to lower scores for color intensity.

Potassium phosphite had no effect on turfgrass color intensity in any of the trials, but it enhanced the color effect of the high rate of oil/pigment in spring 2015 and of the low rate of oil/pigment in fall 2016, in both cases when compared with the corresponding rates of oil/pigment alone in the trials at Sydsjælland GC (Table 7). A similar improvement, although not significant, was observed in December 2015 when adding phosphite to the low rate of oil/pigment at Lepaa GC.

Repeated applications of prothioconazole improved turfgrass color significantly compared to the untreated control in both trials at Sydsjælland GC. In 2015–2016, there was also a significant effect of fungicide rate as the color intensity on 17 March had reverted almost back to the control level on plots that had received half fungicide rate, but remained better than in the untreated control on plots that had received full rate. Similarly, the color improvement after adding half rate of prothioconazole to the low rate of oil/pigment was also stronger in the fall than in the spring (Table 7).

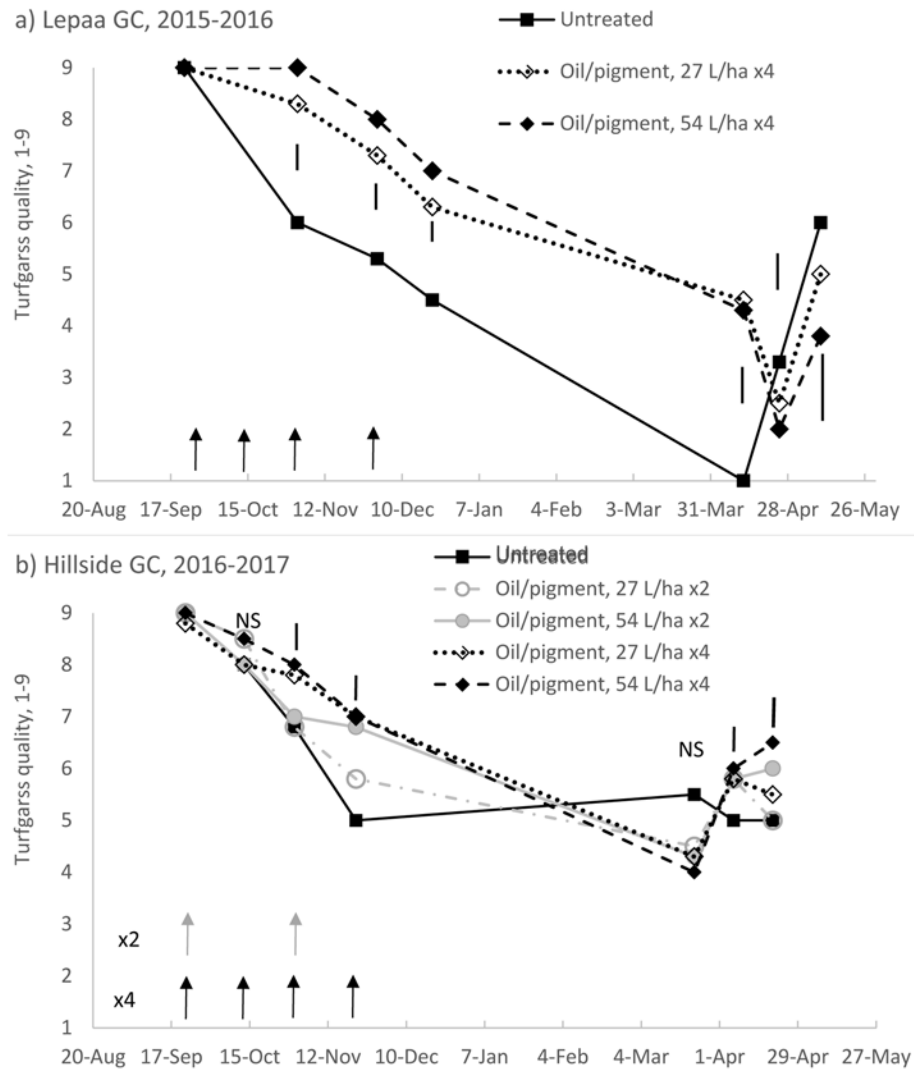

Fig. 1. Turfgrass quality in the Finnish trials at (a) Lepaa GC in 2015–2016 and (b) Hillside GC in 2016–2017 as affected by mineral oil/pigment at various applications rates and frequencies. Application dates are indicated by arrows and least significant differences (*P* ≤ 0.05) by vertical bars.

As opposed to the color improvement with prothioconazole at Sydsjælland GC, there was no color effect of sequential applications of propiconazole and fludioxonil at Österåker GC in 2014–2015 (Table 7) or after sequential applications of propiconazole + prochoraz and fludioxonil at Hillside GC in 2016–2017 (Table 6). A trend to improved color was observed after application of propiconazole + prochoraz and fludioxonil at Lepaa GC in 2015–2016, but the effect was not significant and only occurred at the high fungicide rate.

Turfgrass Quality

Mineral oil with pigment caused significant improvements in turfgrass quality at Sydsjælland GC in both years and at Lepaa GC in 2015–2016 (Table 8). Averaged across the late fall and early spring assessments in those three trials, 77% of the quality improvement after application of the full rate was achieved also at the half application rate. The positive effect of oil/pigment after the long snow cover at Lepaa GC was, however, transitory and followed by a reduction in turfgrass quality during the green-up phase (Fig. 1a). This situation was opposite at Hillside GC in 2016–2017 where the oil/pigment caused a quality reduction at the first assessment irrespective of application rate or frequency, but where the quality improved after that, notably after four applications at the full rate (Fig. 1b).

Potassium phosphite had no effect on turf quality when applied alone in the trials and Sydsjælland GC and Lepaa GC, but improved turfgrass quality in the fall if added to the lower rate of oil/pigment in the two trials in 2015–2016. In the same trials, a similar improvement in turf quality also occurred after adding half fungicide rate to the low rate of oil/pigment (Table 8).

DISCUSSION

The high efficacy of application of mineral oil with pigment against Microdochium patch in these trials is in line with American results (Cortes-Barco et al., 2010; Mattox, 2015; Stricker et al., 2017; Van Dyke and Johnson 2017) and promising from an IPM perspective aiming for replacement of conventional fungicides with low-risk alternatives (Aamlid et al., 2016). The full rate of oil/pigment controlled Microdochium patch/pink snow mold to the same degree or better than the full rate of fungicides, and the product was also less sensitive than the fungicides to a 50% reduction in application rate. When comparing the oil/pigment product to fungicides at Lepaa GC in 2015–2016, the efficacy is, however, likely to be overrated as the fungicide control treatment gave surprisingly poor control of Microdochium patch/pink snow mold in this trial. Propiconazole + prochloraz was chosen for this treatment because they are currently the only systemic fungicides approved for use on turfgrass in Finland, but the commercial product 'Basso' is dominated by prochloraz, which in former trials proved to be inadequate for control of winter diseases (Aamlid et al., 2009) and which has therefore been withdrawn from the market in Sweden and Norway. It is still surprising that fludioxonil which was used for the two last applications at Lepaa GC did not exert better control as this compound, along with propiconazole and prothioconazole, showed high efficacy against Microdochium patch/pink snow mold in earlier fungicide evaluations in the Nordic countries (Aamlid et al., 2015).

Another product that failed to control microdochium patch/pink snow mold except at Österåker GK was potassium phosphite. Dempsey et al. (2012) and Mattox (2015), both working in climates with little or no snow cover similar to that at Sydsjælland GC, documented at least 60% reduction in microdochium patch on annual bluegrass and velvet bentgrass (*Agrostis canina*) greens using similar rates of phosphite per application as in our trials. However, as the application frequency in their trials was 50% higher (2- instead of 3-wk intervals), it may still be that the total amount of phosphite applied in our trials was too low not only to have a direct fungistatic effect, but also to activate plant defense mechanisms. Another explanation may be that Dempsey et al. (2012) and Mattox (2015) used PK Plus 3–7–18 (Griggs Brothers Inc., Idaho Falls, ID), i.e., a different commercial product than the one used in our trials. Variable efficacy of different commercial formulations of phosphites for control of anthracnose basal rot (*Colletotrichum cereale*) was documented by Cook et al. (2009b).

The most severe damage by microdochium patch in these trials was found on the red fescue-dominated greens in the mildest winter climate at Sydsjælland GK. This result was unexpected as red fescue is usually considered less susceptible to these diseases than bentgrasses and annual bluegrass (Aamlid et al., 2012). Our results are, however, in agreement with the general experience that Microdochium patch does not require a snow cover to develop (Årsvoll, 1975; Smiley et al., 1992; Tronsmo et al., 2001), and it is also a common observation that the symptoms become more distinct if not confounded with any type of abiotic winter damage.

Besides control of Microdochium patch/pink snow mold, one of the objectives of this research was to study the effect of oil/pigment on turfgrass color intensity at snowmelt and subsequent green-up in spring. Here, the Finnish trials showed different reaction patterns in the 2 yr. In 2015–2016, the plots treated with oil and pigment at Lepaa GC came out of the winter with significantly better color than the untreated control plots and plots treated with fungicide, but the turf soon thinned out on exposure to the bright sunlight in April. The reason for this decline in quality may have been the combination of repeated applications and no removal of mineral oil from the turf surface in the fall as mowing was discontinued on 25 September. These observations are consistent with Kreuser and Rossi (2014) and shows that the risk for phytotoxic effect occur not only during the growing season, but also after snowmelt if applications of oil/pigment in the fall are too high or frequent.

The trial at Hillside GC in 2016–2017 was laid out according to a revised protocol to see if the risk for phytotoxicity in spring due to application of oil/pigment in fall could be alleviated by a reduction in the application rate or application frequency. The winter of 2016–2017 was, however, characterized by temperature fluctuations with melting episodes causing ice to accumulate on the frozen surface under the snow. Since *M. nivale* requires oxygen, hypoxia under the ice explains why there was virtually no development of pink snow mold in this trial (Tronsmo et al., 2013) and it may also explain why the turf had an almost black color at ice melt. While unattractive at the first assessment, this dark color may well have had a positive function in protecting the turf against oxidative stress (Ervin et al., 2004) and enhancing green-up, which, unlike in the previous year, was faster on plots receiving oil/pigment than on unsprayed control plots.

The attempt to reduce the total input of oil/pigment at Hillside GC in 2016–2017 by a reduction in either application rate or application frequency revealed no difference in turfgrass quality at the two first assessments after snow melt. At the final assessment on 20 April, the quality was slightly higher after two applications of 54 L ha^{-1} than after four applications of 27 L ha^{-1}, but the difference was not significant and more than outweighed by higher quality in the fall with the lighter and more frequent application treatment. While weather conditions and thus the chances for degradation and volatilization of mineral oil will vary from year to year, equally important as application rate and application frequency are probably turfgrass growth rates and to what extent the mineral oil is removed from turfgrass leaves by mowing. All in all, the results from the two Finnish trials suggest an application rate of 27 L ha^{-1} every third week as a good compromise between microdochium-control, a high turfgrass quality in the fall, and an acceptable risk for phytotoxicity after snow melt in spring.

CONCLUSION

This project has shown good prospects for a combined mineral oil/pigment product to substantially reduce the need for conventional fungicides for control of Microdochoum patch/pink snow mold on Nordic golf courses. While further research is needed to optimize application patterns depending on turfgrass species, management practices and climatic conditions, a tentative recommendation for Nordic putting greens would be to apply the combined mineral oil/pigment product at 27–54 L ha^{-1} and 3-wk intervals from early September to late November, with the lowest application rates in areas with early growth cessation and a long snow cover.

ACKNOWLEDGMENTS

This research was funded by the Scandinavian Turfgrass and Environment Research Foundation (STERF) and by Suncor Energy, Canada. We thank Mr. Brady Nash, Suncor Energy, and Agronomy Journal's reviewers editorial team for helpful criticism of this manuscript.

REFERENCES

Aamlid, T.S., T. Espevig, and A. Tronsmo. 2017. Microbiological products for control of *Microdochium nivale* on golf Greens. Crop Sci. 57:559–566. doi:10.2135/cropsci2016.05.0301

Aamlid, T.S., T. Espevig, B. Molteberg, A. Tronsmo, O.M. Eklo, I.S. Hofgaard, G.H. Ludvigsen, and M. Almvik. 2009. Disease control and leaching potential of fungicides on golf greens with and without organic amendment to the sand-based root zone. Int. Turfgrass Soc. Res. J. 11:903–917.

Aamlid, T.S., A. Kvalbein, K.J. Hesselsøe, A.M.D. Jensen, P. Edman, T. Espevig, and M. Strandberg. 2016. Research and development programme within integrated pest management. Scandinavian Turfgrass and Environment Research Foundation. www.sterf.org (accessed 20 Feb. 2018).

Aamlid, T.S., and T. Pettersen. 2013. Effect of the turf colorant Transition HC on infection with *Microdochium nivale*, winter survival and spring recovery on a Scandinavian putting green. Bioforsk Report 8(87):1–23.

Aamlid, T.S., G. Thorvaldsson, F. Enger, and T. Pettersen. 2012. Turfgrass species and varieties for integrated pest management of Scandinavian putting greens. Acta Agriculturae Scandinavica, Section B Soil & Plant Sci. 62(Suppl. 1):10–23.

Aamlid, T.S., W.M. Waalen, and T. Espevig. 2015. Fungicide strategies for the control of turfgrass winter diseases. Acta Agriculturae Scandinavica, Section B Soil & Plant Sci. 65:161–169.

Årsvoll, K. 1975. Fungi causing winter damage on cultivated grasses in Norway. Agricultural University of Norway, Ås, Norway.

Aynardi, B., and W. Uddin. 2013a. Controlling brown patch on a colonial bentgrass fairway 2012. Plant Dis. Mgt. Rpt. 7:18.

Aynardi, B., and W. Uddin. 2013b. Control of *Pythium* foliar blight in perennial ryegrass using fungicides 2012. Plant Dis. Mgt. Rpt. 7:T022.

Bertrand, A., Y. Castonguay, J. Cloutier, L. Couture, T. Hsiang, J. Dionne, and S. Laberge. 2009. Genetic diversity for pink snow mold resistance in greens-type annual bluegrass. Crop Sci. 49:589–599. doi:10.2135/cropsci2008.06.0303

Braun, R., J. Fry, M. Kennelly, D. Bremer, and J. Griffin. 2016. Colorant application volume and color persistence on a 'Chisholm' zoysiagrass lawn. Horttechnology 26:314–319.

Casler, M., G. Jung, S. Bughrara, A. Hamblin, C. Williamson, and T. Voigt. 2007. Development of creeping bentgrass with multiple pest resistance. USGA Green Section Record 45(1):15–19.

Clarke, G.S., and A.A. Ross. 1964. A small-scale variable dosage (logarithimic) sprayer. Weed Res. 4:249–255. doi:10.1111/j.1365-3180.1964.tb00294.x

Cook, J., P. Landschoot, and M. Schlossberg. 2009a. Inhibition of *Pythium* spp. and suppression of *Pythium* blight of turfgrasses with phosphonate fungicides. Plant Dis. 93:809–814. doi:10.1094/PDIS-93-8-0809

Cook, P.J., P. Landschoot, and M. Schlossberg. 2009b. Suppression of anthracnose basal rot and improved putting green quality with phosphonate fungicides. Int. Turfgrass Soc. Res. J. 11:181–194.

Cortes-Barco, A.M., P.H. Goodwin, and T. Hsiang. 2010. Induced systemic resistance against three foliar diseases of *Agrostis strolonifera* by (2R,3R)-butanediol or an isoparaffin mixture. Ann. Appl. Biol. 157:179–189. doi:10.1111/j.1744-7348.2010.00417.x

Danish Environmental Protection Agency. 2010. GEP – good experimental practice. http://eng.mst.dk/chemicals/pesticides/gep-good-experimental-practice. (accessed 9 July 2018).

Dempsey, J.J., I.D. Wilson, P.T.N. Spencer-Phillips, and D.L. Arnold. 2012. Suppression of *Microdochium nivale* by potassium phosphite in cool-season turfgrasses. Acta Agriculturae Scandinavica, Section B Soil & Plant Sci. 62(Supplement 1):70–78.

Dempsey, J.J., I. Wilson, P.T.N. Spencer-Phillips, and D. Arnold. 2014. Phosphite mediated inhibition of the Ascomycete pathogens *Microdochium nivale* and *Microdochium majus* in the Gramineae. The Dundee Conference: Crop Protection in Northern Britain, 25–26 Feb. 2014, Dundee, Scotland. p. 89–94.

Ervin, E., X. Zhang, and J.H. Fike. 2004. Ultraviolet-B radiation damage on Kentucky bluegrass. I: Antioxidant and colorant effects. HortScience 39:1465–1470.

EU. 2009. Regulation (EC) no. 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC. Off. J. Eur. Union L 309:1–50.

EU. 2013. EU pesticides database. Potassium phosphites. http://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/?event=activesubstance.detail&language=EN&selectedID=1747 (accessed 8 July 2018).

FAO. 2016. FAO's definition of IPM. Food and Agriculture Organization of the United Nations. http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/ipm/more-ipm/en/ (accessed 9 July 2018).

Fenn, M.E., and M.D. Coffey. 1984. Studies on the in vitro and in vivo antifugal activity of fosetyl-Al and phosphorus acid. Phytopathology 74:606–611. doi:10.1094/Phyto-74-606

Finger, S.A., T.K. Wolf, and A.B. Baudoin. 2002. Effects of horticultural oils on the photosynthesis, fruit maturity, and crop yield of winegrapes. Am. J. Enol. Vitic. 53:116–124.

Gregos, J., M.D. Casler, and J. Stier. 2011. Resistance of closely mown fine fescue and bentgrass species to snow mold pathogens. Plant Dis. 95:847–852. doi:10.1094/PDIS-11-10-0791

Guest, D., and B. Grant. 1991. The complex action of phophonates as antifugal agents. Biol. Rev. Camb. Philos. Soc. 66:159–187. doi:10.1111/j.1469-185X.1991.tb01139.x

Hodgkinson, M.C., D. Johnson, and G. Smith. 2002. Causes of phytotoxicity induced by petroleum-derived spray oil. In: G.A.C. Beattie, D.M. Watson, M.L. Stevens, D.J. Rae, and R.N. Spooner-Hart, editors, Spray oil beyond 2000. University of Western Sydney, Sydney, NSW, Australia.

Hofgaard, I., Å. Ergon, B. Henriksen, and A.M. Tronsmo. 2010. The effect of potential resistance inducers on development of *Microdochium majus* and *Fusarium culmorum* in winter wheat. Eur. J. Plant Pathol. 128:269–281. doi:10.1007/s10658-010-9662-5

Hsiang, T., P.H. Goodwin, and A.M. Cortes-Barco. 2011. Plant defense activators and control of turfgrass diseases. Outlooks on Pest Management 22:160–164. doi:10.1564/22aug04

Hsiang, T., P. Goodwin, A. Cortes-Barco, B. Nash, and J. Tung. 2013 Activating disease resistance in turfgrasses against fungal pathogens: Civitas and Harmonizer. In: Imai R., M. Yoshida, and N. Matsumoto, editors, Plant and microbe adaptations to cold in a changing world. Springer, New York.

Kerns, J. 2012. How do plants defend themselves from pathogens? Hole Notes 44(1):10–13.

Kreuser, W.C., and F. Rossi. 2014. The horticultural spray oil Civitas™ causes chronic phytotoxicity on cool-season golf turf. HortScience 49:1217–1224.

Kvalbein, A., T. Espevig, W. Waalen, and T.S. Aamlid. 2016. Spring stresses. The difficult transition into a new growing season. STERF/CTRF Fact sheet turfgrass winter survival. www.sterf.org (accessed 20 Feb. 2018).

Mattox, C. 2015. Managing microdochium patch using non-traditional fungicides on annual bluegrass putting greens. M.S. thesis, Oregon State Univ., Corvallis.

McCall, D.S., and J.T. Focht. 2010. Evaluation of Civitas for control of gray leaf spot in Virginia, 2009. Plant Disease Management Reports 4:15.

Nash, B. 2011. Activation of disease resistance and defense gene expression in *Agrostis stolonifera* and *Nicotiana benthamiana* by a copper-containing pigment and a benzothiadiazole derivative. M.S. thesis, Univ. of Guelph, Guelph, ON, Canada.

Smiley, R., P. Dernoeden, and B. Clarke. 1992. Compendium of turfgrass diseases. APS Press, St. Paul, MN.

Stricker, S., T. Hsiang, and A. Bertrand. 2017. Reaction of bentgrass cultivars to resistance activator and elevated CO_2 levels when challenged with *Microdochium nivale*, the cause of Microdochium patch. Int. Turfgrass Soc. Res. J. 13:229–232.

Tronsmo, A., T. Espevig, L. Hjeljord, and T.S. Aamlid. 2013. Evaluation of freezing tolerance and susceptibility to Microdochium nivale of velvet bentgrass cultivars in controlled environments. Int. Turfgrass Soc. Res. J. 12:69–80.

Tronsmo, A.M., T. Hsiang, H. Okuyama, and T. Nakajima. 2001. Low temperature diseases caused by *Microdochium nivale*. In: N. Iriki, D.A. Gaudet, A.M. Tronsmo, N. Matsumoto, M. Yoshida, and A. Nishimune, editors, Low temperature plant microbe interactions under snow. Hokkaido National Agricultural Experiment Station, Sapporo, Japan. p. 75–86.

Van Dyke, A., and P.G. Johnson. 2017. Cultural, organic, and biological methods for snow mold control on putting greens in the Intermountain West. Crop. Forage and Turfgrass Management 3:1–6. doi:10.2134/cftm2017.04.0030