This article was downloaded by: [John Dempsey]

On: 24 May 2012, At: 10:11

Publisher: Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK

Acta Agriculturae Scandinavica, Section B - Soil & Plant Science

Publication details, including instructions for authors and subscription information:
<http://www.tandfonline.com/loi/sagb20>

Suppression of *Microdochium nivale* by potassium phosphite in cool-season turfgrasses

John J. Dempsey^a, Ian D. Wilson^a, Peter T. N. Spencer-Phillips^a & Dawn L. Arnold^a

^a Centre for Research in Biosciences, University of the West of England, Bristol, BS16 1QY

Available online: 24 May 2012

To cite this article: John J. Dempsey, Ian D. Wilson, Peter T. N. Spencer-Phillips & Dawn L. Arnold (2012): Suppression of *Microdochium nivale* by potassium phosphite in cool-season turfgrasses, *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science*, 62:sup1, 70-78

To link to this article: <http://dx.doi.org/10.1080/09064710.2012.681392>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.tandfonline.com/page/terms-and-conditions>

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

QUALITY TURF AND EFFICIENT UTILIZATION OF RESOURCES

Suppression of *Microdochium nivale* by potassium phosphite in cool-season turfgrasses

JOHN J. DEMPSEY, IAN D. WILSON, PETER T. N. SPENCER-PHILLIPS
& DAWN L. ARNOLD

Centre for Research in Biosciences, University of the West of England, Bristol BS16 1QY

Abstract

Microdochium nivale (Fr.) Samuels and Hallett (teleomorph *Monographella nivalis* (Schafnitt) is one of the most damaging pathogens of cool-season amenity turfgrasses. The search for new or improved means to reduce susceptibility to *M. nivale* is an ongoing target for turfgrass research. From 2010 to 2012, field studies were conducted at the Curragh Golf Club, Co Kildare, Ireland on *Agrostis canina* L. ssp. *canina* and *Poa annua* L. swards, to evaluate *M. nivale* suppression by 14-day sequential applications of potassium phosphite (KH_2PO_3), applied alone and in combinations with a fungicide (iprodione) and a biostimulant. Treatment effect on turfgrass quality was also determined. Over two years of trials, phosphite treated plots, when compared with untreated controls, exhibited significantly lower percentages ($p < 0.01$) of *M. nivale* incidence. The addition of the biostimulant did not enhance this effect. The iprodione treatments showed significantly higher suppression than the phosphite treatments ($p < 0.01$), and the addition of phosphite significantly enhanced the fungicide control of *M. nivale* ($p < 0.01$). This last combined treatment was most effective overall, with full inhibition on the treated plots. Turfgrass quality on all phosphite treated plots was significantly better ($p < 0.01$) than either the control or iprodione treated plots.

Keywords: *Agrostis* spp., disease suppression, *Poa annua*, trial plots, turfgrass quality.

Introduction

Disease prevention is a major factor, and is one of the more problematic and contentious areas in the successful management of amenity turfgrasses. Pathogenic fungi and oomycetes are the major causal agents (Beard and Oshikazu 1997, Vargas 2005). The ascomycete pathogen, *Microdochium nivale* (Fr.) Samuels and Hallett (teleomorph *Monographella nivalis* (Schafnitt) (Smiley et al. 1992) is regarded as the most important disease of temperate climates, infecting most cool-season species and affecting up to 100% of golf greens in the UK each year (Smiley et al. 1992, Beard and Oshikazu 1997, Mann 2002, Vargas 2005). *M. nivale* was until recently thought to be a single species, with two varieties, var. *M. nivale nivale* and var. *M. nivale majus*, but it is now recognized as two distinct species: *M. nivale* and *M. majus* (Glynn et al. 2005, Hofgaard et al. 2006). *M. majus* differs from *M. nivale* in conidial

morphology and host specificity (Lees et al. 1995, Maurin et al. 1995) and is responsible for many disease complexes in species of wheat, barley and oat (Pettitt et al. 1993, Humphreys et al. 1995, Clement and Parry 1998, Diamond et al. 1998). *M. nivale* proliferates on forage or turfgrasses (Mahuku et al. 1998). Control of *M. nivale* in turfgrass is achieved by implementing Integrated Pest Management (IPM) programmes (Beard and Oshikazu 1997) which reduce disease incidence to acceptable levels. Chemical plant protectants are an integral part of IPM and while the efficacy and safety of these products is not disputed their use sometimes gives rise to a number of issues: adverse public opinion due to the perception of high frequency of use, associated costs of chemicals, possible inhibition of non-target beneficial microorganisms, development of fungicide-resistant populations, and possible legislative restrictions.

The search for new or improved means to reduce susceptibility to *M. nivale* is an ongoing target for turfgrass research. One possible means is the use of phosphite (PO_3^{3-} , Phi) as either a fungicide or biostimulant, as a component of an integrated approach to disease management. Phi is derived from phosphorous acid – H_3PO_3 , which, to prevent phytotoxicity, is commonly modified prior to use with potassium hydroxide (KOH), forming potassium dihydrogen phosphite (KH_2PO_3) or dipotassium hydrogen phosphite (K_2HPO_3) (Ouimette and Coffey 1988). In turfgrass management these form the active substances in numerous products currently marketed worldwide as either fungicides or fertilizers (Landschoot and Cook 2005). In the UK and Ireland over the past number of years, they have been marketed as biostimulants or even called defence activators; this helped stimulate this current research, the aim of which was to determine the effect Phi treatment has on turfgrass, in particular its possible reduction of *M. nivale* incidence.

Throughout the literature there are numerous examples of successful inhibition of phytopathogens by Phi, although the means by which this is achieved is often debated (Abbasi and Lazarovits 2006). Phi has proven very effective in controlling, in a preventative mode of use, oomycete pathogens (Sanders 1983, Cook 2009) with studies reporting Phi inhibition of pathogens by both direct fungistatic means and indirectly through stimulation of plant defence processes (Fenn and Coffey 1984, 1987, Saindrenan et al. 1988, Grant et al. 1990, Jackson et al. 2000, McCarren et al. 2009). There are also a number of studies in the literature reporting the inhibitory properties of Phi against ascomycetes. Phi treatments reduced mycelial growth of *Alternaria alternata* (Fr.) Keissl (Reuveni et al. 2003) and *in*

vitro sensitivity to Phi of *Colletotrichum graminicola* (Ces.) Wilson, has also been reported (Burpee 2005). Hofgaard et al. (2010) concluded that development of *M. majus* in winter wheat (*Triticum aestivum* L.) was significantly reduced by potassium phosphite (K_2HPO_3) treatment. In turfgrass management Phi was first used for the control of oomycete pathogens such as *Pythium* spp. (Cook et al. 2006, Schroetter et al. 2006). It was subsequently combined with Mancozeb, a dithiocarbamate fungicide, to control summer decline of bentgrass (Beard and Oshikazu 1997). Reports of improved turf quality following sequential applications of Phi have also been reported (Vincelli and Dixon 2005, Cook et al. 2006). Dempsey and Owen (2010) determined a significant improvement in *Agrostis stolonifera* L. quality and density following treatment with Phi.

What can be concluded from these studies is that Phi has a complex mode of action, acting both directly on the pathogen and indirectly by stimulating host defence responses. The research confirms that Phi can significantly reduce the occurrence of many oomycete pathogens in numerous plant species, and while there is some evidence for similar success in controlling ascomycete pathogens, there are no studies specifically on the effect Phi may have on *M. nivale* infection in turfgrass.

Therefore, the aims of these field trials were to determine whether Phi can reduce susceptibility to *M. nivale*, whether the addition of a biostimulant could increase the efficacy of Phi to reduce *M. nivale* infection and if the addition of Phi to a standard fungicide (iprodione) could enhance the suppression of *M. nivale* compared with the fungicide alone. The effect Phi treatments had on turfgrass quality were also assessed and quantified during these trials.

Table I. Meteorological data for trial location.

Monthly precipitation (mm)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2012	63.2	19.8	3.3										86.3
2011	34.1	76.2	15.0	30.0	51.5	65.1	53.3	51.6	76.3	165.9	54.8	53.0	726.8
2010	44.1	36.5	58.9	33.0	44.7	44.7	80.2	43.1	102.5	37.0	120.0	65.5	709.7
mean	63.9	48.6	50.3	50.8	58.1	52.6	46.9	68.5	63.3	68.6	65.9	73.6	711.2
Monthly temperature °C													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2012	6.0	6.6	8.9										6.3
2011	3.6	7.0	6.3	11.0	11.4	12.4	14.1	13.6	14.0	11.7	9.9	5.7	10.1
2010	1.5	2.3	5.4	8.3	10.3	14.8	16.0	15.0	13.5	10.1	5.0	−0.4	8.5
mean	4.6	4.6	5.9	7.4	10.1	13.1	14.9	14.5	12.6	10.2	6.5	5.4	9.2

Monthly precipitation (mm) and air temperatures (°C) for experimental periods, means are for the period 1961–1990 (Met_Eireann 2011).

Materials and methods

Trial plots and experimental design

Trial plots were established in 2010 on a sandy/loam soil, pH 7.1, within the area of the turf nursery at the Curragh Golf Club, Co Kildare, Ireland (53.15° N/ 6.80° W 110 m a.s.l.). Kildare has a temperate oceanic climate, with rainfall annual mean of 711 mm and air temperature mean of 9.2 °C; Table I gives monthly and 30-year mean weather data for the location (Met_Eireann 2011). This mild climate gives rise to ideal conditions for turfgrass, with growth almost throughout the entire year. The plots, 2 × 2 m square, were composed of *Poa annua* L., *Agrostis canina* L. ssp. *canina*, variety Avalon and *Agrostis stolonifera* L., variety Penn G-6 and were maintained throughout the trial periods at 6 mm height of cut, using a John Deere 220 pedestrian mower. The *P. annua* sward previously formed part of a now disused fairway and for the 6 years previous to the trials had been maintained as part of a turfgrass nursery. The *A. canina canina* sward was originally established from seed in 2005 and was moved to the trial location as turfgrass sod in 2009. The *A. stolonifera* sward was established from seed in April 2010, however, due to its poor establishment, year one of the trials comprised the *P. annua* and *A. canina canina* plots only, with trial extension to include the *A. stolonifera* plots in year two.

Nutritional inputs

Granular nutrient inputs (Andersons 21:3:21) were applied at the beginning of May and September 2010 and 2011, at a rate of 30 g m⁻¹, giving annual nutritional inputs (ANI) of 126 kg N ha⁻¹, 7.9 kg P ha⁻¹ (in the form of P₂O₅), 105 kg K ha⁻¹. Two applications per annum were considered sufficient, as the N source contained 84.25% polymer coated urea giving a sustained release. A late-season application of a 21% nitrogen product could be construed as excessive and not representative of best management practices as it could encourage *M. nivale* infection, however, as *M. nivale* infection was the focus of this study it was deemed appropriate. Further nutrient inputs were supplied as part of the treatment applications and are detailed below. No irrigation inputs were required.

Treatments

Treatments were arranged in a randomized complete block design with five replications and comprised sequential applications, applied biweekly from September 2010 to March 2011 and from September 2011 to March 2012, using 20 L

knapsack sprayers operating at 6 bar, calibrated to deliver 800 L ha⁻¹. Treatments comprised:

1. PK Plus 3:7:18 (Grigg Bros, 14% KH₂PO₃, specific gravity 1.37, pH 7.05) applied at 20 L ha⁻¹ (ANI: 11.5 kg N ha⁻¹, 11.7 kg P ha⁻¹ (in the form of P₂O₅), 57.3 kg K ha⁻¹), 53.7 kg PO₃³⁻ ha⁻¹.
2. PK Plus (20 L ha⁻¹) + Ultraplex Biostimulant (Grigg Bros, 5-0-3, specific gravity 1.26, pH 2.5) applied at 10 l ha⁻¹ (ANI: 20.5 kg N ha⁻¹, 11.7 kg P ha⁻¹ (in the form of P₂O₅), 61.7 kg K ha⁻¹), 53.7 kg PO₃³⁻ ha⁻¹.
3. Chipco Green (Bayer, 255 g L iprodione) applied at 20 L ha⁻¹.
4. Chipco Green (20 L ha⁻¹) + PK Plus (20 L ha⁻¹) (ANI: 11.5 kg N ha⁻¹, 11.7 kg P ha⁻¹ (in the form of P₂O₅), 57.3 kg K ha⁻¹), 53.7 kg PO₃³⁻ ha⁻¹.
5. NPK control (3:7:18 to match nutritional input of PK Plus) applied at 20 L ha⁻¹ (ANI: 11.5 kg N ha⁻¹, 11.7 kg P ha⁻¹ (in the form of P₂O₅), 57.3 kg K ha⁻¹).
6. Untreated control.

Biweekly applications of iprodione to control *M. nivale* would be considered excessive for routine turfgrass management, as it could lead to resistance in the pathogen population; this rate was used during the trials to ensure maximum suppression.

Data collection and analysis

Trial plots were assessed monthly for *M. nivale* occurrence from September 2010 to March 2011 and from September 2011 to March 2012, and rated on a scale of 0–100, evaluation being percentage of plot area affected by disease: 0 being no incidence and 100 being 100% coverage (Bruneau et al. 2000). Turf quality (which excluded the impact of disease within each plot) was also measured during both trial periods; this was assessed visually and marked on a scale of 1–10 (1 = dead turf, 5 = acceptable, 10 = excellent) (Horvath et al. 2007). For both disease incidence and turf quality, data were subject to analysis of variance (ANOVA) using SPSS Statistics 19.0 and significant treatment differences were separated by Tukey least significant difference test (LSD) at *p* < 0.01. Because the plots were of two turfgrass species each with different growth habits and susceptibilities to *M. nivale*, plus the fact that the *A. canina canina* plots were located in a significantly more shaded area compared with the *P. annua* plots, thus increasing the disease pressure, data analyses were carried out and reported separately for each species.

Results

Disease incidence

In both years of the study *M. nivale* occurrence developed naturally, with high levels of infection from October 2010 to February 2011 and from September 2011 to February 2012. Analysis of the data determined significant differences in treatment effect ($p < 0.01$) (Table II).

In year one, *M. nivale* became active mid October 2010, with disease incidence progressively increasing and peaking, following a 3-week covering of snow, at the end of December 2010. Disease pressure declined from the end of January 2011 and became non-existent from mid February 2011, until environmental conditions allowed re-emergence in September 2011. Table III shows treatment effect on percent *M. nivale* incidence on the trial plots ($n = 5$) for each of the months of the first year's trial.

In year two disease pressure became evident earlier than in the previous year with *M. nivale* incidence beginning mid September and remaining at high levels to mid December 2011. From January 2012 disease pressure declined gradually and ceased in March 2012. Table IV shows treatment effect on

percent *M. nivale* incidence on the trial plots ($n = 5$) for each of the months of the second year's trials. During the second year, the trials were extended to include *A. stolonifera* plots, but as only one year's data are available they are not included in the full analysis.

Data from both years' trials, as shown in Figures 1 and 2, determined that in both turfgrass species the control and NPK control plots displayed the highest mean values of disease incidence ($p < 0.01$) ranging from 32 to 59%, levels of disease cover which would be unacceptable on any golf green. The application of Phi (Griggs PK Plus) reduced the incidence of the disease by more than 50%, with mean values ranging from 14 to 21%, significantly lower ($p < 0.01$) than the control and NPK control plots. The addition of the biostimulant and surfactant package (Ultrplex) to the PK Plus treatments, did not cause any significant reduction in disease incidence compared with the PK Plus treatment alone.

The plots which received iprodione (Chipco Green) treatments, as would be expected, displayed very high disease reductions, 92% less disease incidence than the control and NPK control and 33% less than the PK plus, PK Plus/Ultrplex treatments. However, despite the fact that the Chipco Green applications were applied at an extreme rate on a 2-week cycle, *M. nivale* was not fully inhibited. The treatments which were most effective at reducing *M. nivale* incidence ($p < 0.01$) were the combination of Chipco Green and PK Plus. These fully inhibited *M. nivale* incidence on the *P. annua* plots and on the *A. canina canina* plots reduced it by 93% compared with the control plots.

Table II. Analysis of variance of treatment effect on *M. nivale* incidence on trial plots.

Factor	df	F	Sig.
<i>P. annua</i> year 1	5	10281.01	0.00
<i>P. annua</i> year 2	5	9036.21	0.00
<i>A. canina canina</i> year 1	5	15522.24	0.00
<i>A. canina canina</i> year 2	5	14496.91	0.00

Table III. Treatment effect on percent *M. nivale* incidence on trial plots in year one.

Treatment	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
<i>Poa annua</i> plots							
PK Plus	0.0a	4.9a	10.1a	25.1a	26.8a	16.6a	14.2a
Pk Plus + Ultrplex	0.0a	5.0a	9.7a	23.4a	27.9a	15.4a	12.1a
Chipco Green	0.0a	0.0b	2.9b	5.6b	6.3b	2.8b	0.0b
Chipco Green + PK Plus	0.0a	0.0b	0.0c	0.0c	0.0c	0.0c	0.0b
NPK control	0.0a	15.6c	37.9d	48.8d	58.4d	47.3d	35.4c
Control	0.0a	15.6c	38.2d	48.8d	60.4d	49.5d	38.1c
<i>Agrostis canina canina</i> plots							
PK Plus	0.0a	14.8a	21.6a	28.7a	27.8a	16.9a	13.7a
Pk Plus + Ultrplex	0.0a	14.2a	21.2a	27.6a	27.2a	16.0a	13.9a
Chipco Green	0.0a	0.0a	5.6b	12.1b	10.1b	4.2b	1.2b
Chipco Green + PK Plus	0.0a	0.0a	5.0b	6.7c	6.1c	3.1b	0.0b
NPK control	0.0a	22.3c	69.1c	72.4d	71.8d	49.5c	34.6c
Control	0.0a	23.2c	70.1c	74.2d	70.6d	50.4c	37.8c

Means ($n = 5$) followed by the same letter within a column are not significantly different at $p < 0.01$ according to Tukey least significant difference test (LSD).

Table IV. Treatment effect on percent *M. nivale* incidence on trial plots in year two.

Treatment	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12
<i>Poa annua</i> plots							
PK Plus	4.6a	15.6a	22.9a	25.3a	25.8a	16.6a	11.2a
Pk Plus + Ultraplex	4.6a	15.4a	21.9a	24.7a	24.9a	15.4a	11.0a
Chipco Green	0.0b	5.5b	8.3b	7.2b	5.3b	2.8b	0.0b
Chipco Green + PK Plus	0.0b	0.0c	0.0c	0.0c	0.0c	0.0c	0.0b
NPK control	12.4c	38.8d	50.2d	41.8d	40.4d	37.3d	29.4c
Control	17.6c	40.7d	48.4d	41.8d	41.4d	36.5d	29.5c
<i>Agrostis canina canina</i> plots							
PK Plus	8.3a	22.3a	26.3a	25.6a	27.8a	16.9a	13.7a
Pk Plus + Ultraplex	7.5a	20.6a	24.8a	22.3a	27.2a	16.0a	13.9a
Chipco Green	0.0b	5.3b	10.7b	12.3b	10.1b	4.2b	1.2b
Chipco Green + PK Plus	0.0b	2.3c	7.0c	7.9c	6.1c	3.1b	0.0b
NPK control	23.5c	66.8d	71.2d	70.6d	71.8d	49.5c	34.6c
Control	24.8c	67.3d	72.8d	72.8d	70.6d	50.4c	37.8c

Means ($n = 5$), followed by the same letter within a column are not significantly different at $p < 0.01$ according to Tukey least significant difference test (LSD).

This total inhibition could indicate either differing modes of suppression or a possible synergistic effect.

Turfgrass quality

Table V shows data on turfgrass quality from the *P. annua* and *A. canina canina* plots over the two trial periods. Turf quality at the beginning of both periods was uniform for all treatment plots, as the trials continued however, the quality of the control and

NPK controls became progressively poorer, in comparison with the PK Plus and PK Plus/Ultraplex treatments. The Chipco Green treated plots, even with significantly less disease incidence than the PK Plus and PK Plus/Ultraplex treated plots, produced a poorer quality sward than the Phi treatments. The PK Plus/Chipco Green treatment produced the highest quality ratings overall. By the end of each trial period, the quality of all Phi treated swards was far superior to all other treatment regimes.

Figure 1. Treatment effect on percent occurrence of *M. nivale* on *P. annua* trial plots. Data are mean values from September 2010 to March 2011 and from September 2011 to March 2012 ($n = 5$), letters indicate significant differences at $p < 0.01$ according to Tukey least significant difference test (LSD).

Figure 2. Treatment effect on percent occurrence of *M. nivale* on *A. canina canina* trial plots. Data are mean values from September 2010 to March 2011 and from September 2011 to March 2012 ($n = 5$), letters indicate significant differences at $p < 0.01$ according to Tukey least significant difference test (LSD).

Discussion

The data from the 2 years of these field trials have shown that, through periods of high disease pressure, as a result of sequential applications of Phi, there were significant and consistent reductions of *M. nivale* incidence in two commonly used cool-season turfgrasses. These trial results are supported by a previous study where significant disease reduction was reported in Phi-treated *A. stolonifera* (Dempsey and Owen 2010).

The mode of action of Phi in reducing *M. nivale* occurrence in these field trials has yet to be fully determined; there are numerous published reports showing Phi-mediated reduction of plant pathogens by both direct fungistatic means and indirectly through stimulation of plant defence processes (Fenn and Coffey 1987, Grant et al. 1990, Jackson et al. 2000, McCarren et al. 2009). Fenn and Coffey (1987) for example, reported direct inhibition of *Phytophthora* spp. in Phi-treated *Persea indica* L.; while a study involving a number of *Phytophthora* species determined that Phi interfered with phosphate metabolism, by causing an accumulation of polyphosphate and pyrophosphate, resulting in a decrease in the pathogen's growth (Niere et al. 1994). In 2000, data were published showing that Phi inhibited enzymes of the glycolytic and phosphogluconate pathways, thus disrupting metabolism in *Phytophthora* spp. (Stehmann and Grant 2000). The possibility that Phi had a direct fungistatic effect

on *M. nivale* in these field trials is a distinct possibility and *in vitro* research in this area is currently being carried out. Previously published *in vitro* studies into the inhibitory effect Phi has on the growth of ascomycetes have shown promising results. Reuveni et al. (2003) reported mycelial growth of *Alternaria alternata* (Fr.) Keissl, was sensitive to Phi with an *in vitro* EC_{50} value (the effective dose which reduces growth to 50% of the growth of controls) of $278 \mu\text{g ml}^{-1}$ and Burpee (2005) reported *in vitro* sensitivity to Phi of *Colletotrichum graminicola* (Ces.) Wilson, with an EC_{50} value of 121.9 mg ml^{-1} (EC_{50} values are of the active ingredients of the products used in both studies – no data available to calculate exact PO_3^{3-} values). The most relevant research to the results of these field trials was by Hofgaard et al. (2010), who reported reduced *in vitro* growth of *M. majus*, when potassium phosphite (K_2HPO_3) was added to the growth medium (Hofgaard et al. 2010).

That disease suppression in these field trials was due to possible indirect inhibition of *M. nivale* by Phi, through stimulation or enhancement of inducible plant defence mechanisms is also a possibility. Jackson et al. (2000) in a study of pathogen-infected *Eucalyptus marginata* L. concluded that Phi accumulations *in planta* led to stimulation of host defences. Phi treatment resulted in induced rapid defence responses, including release of Reactive Oxygen Species, localized cell death and an increase in defence-related phenolic compounds in *Arabidopsis*

Table V. Treatment effect on turfgrass quality, assessed on a scale of 1–10.

<i>Poa annua</i> plots							
Treatment	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
PK Plus	5.0a	6.5a	7.5b	8.0b	9.0b	9.0b	9.5b
Pk Plus + Ultraplex	5.0a	7.0b	7.5b	8.0b	9.0b	9.0b	9.5b
Chipco Green	5.0a	6.0a	5.5a	5.0a	4.0a	4.5a	5.5a
Chipco Green + PK Plus	5.0a	7.0b	7.5b	8.0b	9.5b	9.5b	9.5b
NPK control	5.0a	6.0a	5.5a	4.5a	3.0a	3.5a	3.5a
Control	5.0a	5.0a	4.5a	4.5a	2.5a	3.0a	3.0a
	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12
PK Plus	6.0a	7.5b	8.0b	8.5b	9.5b	9.5b	9.5b
Pk Plus + Ultraplex	6.0a	8.0b	8.0b	9.0b	10.0b	9.5b	9.5b
Chipco Green	6.0a	6.0a	5.0a	5.0a	4.5a	5.0a	5.5a
Chipco Green + PK Plus	6.0a	7.0a	8.5b	9.0b	9.5b	9.5b	9.5b
NPK control	6.0a	5.0a	4.5a	4.0a	3.0a	3.0a	3.0a
Control	6.0a	5.0a	4.0a	3.0a	3.5a	3.5a	4.5a
<i>Agrostis canina canina</i> plots							
	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
PK Plus	5.0a	6.5b	8.0b	9.0b	9.0b	9.5b	9.5b
Pk Plus + Ultraplex	5.0a	7.0b	8.5b	9.5b	9.5b	9.5b	9.5b
Chipco Green	5.0a	5.0a	5.5a	5.0a	4.0a	4.0a	4.5a
Chipco Green + PK Plus	5.0a	7.5b	8.5b	9.5b	9.5b	10.0b	10.0b
NPK control	5.0a	4.0a	3.5a	3.5a	2.0a	2.5a	2.5a
Control	5.0a	4.0a	3.5a	3.0a	1.5a	2.0a	2.0a
	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12
PK Plus	6.0a	7.5b	8.0b	9.0b	9.5b	9.5b	9.5b
Pk Plus + Ultraplex	6.0a	7.5b	8.5b	9.5b	9.5b	9.5b	10.0b
Chipco Green	6.0a	5.0a	5.0a	5.0a	4.5a	4.5a	4.5a
Chipco Green + PK Plus	6.0a	8.0b	8.5b	9.5b	10.0b	10.0b	10.0b
NPK control	6.0a	5.0a	4.0a	3.5a	3.0a	3.5a	3.5a
Control	6.0a	5.0a	4.0a	3.0a	3.0a	3.5a	3.5a

Means (n = 5), followed by the same letter within a column are not significantly different at $p < 0.01$ according to Tukey least significant difference test (LSD).

thaliana L. (Daniel and Guest 2006) and Saindrenan et al. (1988) determined that Phi treatment enhanced the rate and magnitude of phytoalexin accumulation in *Vigna unguiculata* L. Analysis of Phi-treated turfgrass tissues with the aim to determine any increased synthesis of stress-related compounds would be beneficial.

The more likely hypothesis to explain the Phi-mediated disease reductions in these field trials is that *M. nivale* reduction was due to the combined effects of direct inhibition of the pathogen and enhanced host defence responses. Phi-induced effects on *M. nivale* metabolism may slow hyphal growth *in planta*, allowing increased time for the infected plant to respond. Phi may also induce the release of stress metabolites in *M. nivale*, enabling a more rapid recognition of the pathogen by the host plant. A more efficient recognition process allows a more rapid and hence more effective defence response, thus limiting the development of disease.

Turfgrass quality

Turfgrass quality is a vital aspect of turfgrass management and is determined by a combination of colour, density, uniformity and texture. The search for products or procedures which improve quality is constant. The data obtained over the 2 years of these trials, as shown in Table V, determined there was significantly better visual quality on all Phi-treated plots. These data are supported by a previous study by Dempsey and Owen (2010) who reported significant improvement of quality in Phi-treated *A. stolonifera*.

The reasons for the increase in turf quality could be attributed to a number of possible factors; firstly Phi treatments could inhibit pathogenic soil micro-organisms such as oomycetes and algae – while not displaying disease symptoms these could have a debilitating effect on turfgrass development. Phi has proven efficacy in reducing these organisms

(Abbasi and Lazarovits 2006, Daniel and Guest 2006), thus allowing for the healthier development of the turfgrass. A second possibility is that the reduction of *M. nivale* allowed unrestricted growth and development, thus allowing for the improvement of the treated turfgrass. A further factor which could be considered is that Phi influenced a change in growth habit, Schroetter et al. in their 2006 study found that Phi applications to maize (*Zea mays* L.) led to an abnormality in growth habit, with the treated samples exhibiting an increase in lateral tillering, this could be a reason for the improvement, especially in the increase in turf density. Any of the possible factors above could have, either separately or in tandem, have led to the improvement in the turf quality; further study in this area is currently underway.

While the ability of Phi to lessen *M. nivale* incidence and improve turf quality was clearly demonstrated during these trials, a number of anomalies do require discussion. *M. nivale* incidence was consistently and significantly greater on the *A. canina canina* plots compared with the *P. annua*. This is due to a number of factors. The site of the *A. canina canina* sward, while in the same general area as the *P. annua* plots, was subject to extreme shading from trees, especially during the autumn and winter months. This ensured that environmental conditions for *M. nivale* occurrence were at an optimum. The *P. annua* plots had optimum light conditions and excellent air movement. A second factor to be considered is that *A. canina canina*, when not previously hardened by low temperatures, is highly susceptible to *M. nivale* infection (Espevig 2011), furthermore of six varieties of *A. canina canina* used in the study by Espevig, Avalon, the variety used in these field trials, proved more susceptible than all others.

There were no significant differences in treatment effect on either disease incidence or turf quality between the NPK control and untreated control plots in both trialled species. The N amount supplied by the treatment (11.5 kg ha⁻¹) was relatively small, less than 10% of the total annual N input of 126 kg ha⁻¹ and so it could be expected not to have a significant effect on either disease or quality. However, it could have been assumed that the application of relatively high amounts of K (57.3 kg ha⁻¹) would have contributed to a reduction in disease incidence, but this was not the case. A more interesting and significant comparison is between the PK Plus and the NPK treatments. Both received identical nutritional inputs, the only difference being the Phi component of PK Plus (53.7 kg PO₃³⁻ ha⁻¹). This addition stimulated reduced

disease incidence and a significant improvement in turfgrass quality in both turfgrass species.

These trial assessments are continuing and will gather further data to enhance the results from this present study. Further research to determine the processes involved in the Phi-mediated reduction of *M. nivale* is required and is presently underway. A wide range of laboratory procedures are currently being undertaken to determine the fungistatic properties of Phi and to evaluate Phi-mediated induction of secondary metabolic defence processes leading to induced resistance in treated turfgrasses.

In summary, what can be concluded from the results of these field trials is that routine and sequential applications of Phi, as part of an integrated disease management programme, while not reducing *M. nivale* to an acceptable level, will significantly reduce the incidence and severity of the disease. Furthermore, the addition of Phi to iprodione can significantly enhance suppression of *M. nivale*. Phi treatment also gave rise to significant improvement in turfgrass quality when compared with the untreated plots.

References

- Abbasi, P. A., & Lazarovits, G. (2006). Seed treatment with phosphonate (AG3) Suppresses *Pythium* damping-off of cucumber seedlings. *Plant Disease*, 90, 459–464.
- Beard, J., & Oshikazu, T. (1997). *Colour atlas of turfgrass diseases*. Chichester: John Wiley and Sons.
- Bruneau, A. H., Newell, A. J., & Crossley, F. M. E. (2000). Comparative performance of Bentgrass species and cultivars in close mown turf. *Journal of Turfgrass Science*, 76, 63–69.
- Burpee, L. L. (2005). Sensitivity of *Colletotrichum graminicola* to phosphonate fungicides. *International Turfgrass Society Research Journal*, 10, 163–169.
- Clement, J. A., & Parry, D. W. (1998). Stem-base disease and fungal colonisation of winter wheat grown in compost inoculated with *Fusarium culmorum*, *F. graminearum* and *Microdochium nivale*. *European Journal of Plant Pathology*, 104, 323–330.
- Cook, J., Landschoot, P. J., & Schlossberg, M. J. (2006). Phosphonate products for disease control and putting green quality. *Golf Course Management*, April, 93–96.
- Cook, P. J. (2009). *Inhibition of Pythium spp. and suppression of Pythium blight and anthracnose with phosphonate fungicides*. MSc dissertation. Altoona, PA: Pennsylvania State University.
- Daniel, R., & Guest, D. (2006). Defence responses induced by potassium phosphonate in *Phytophthora palmivora*-challenged *Arabidopsis thaliana*. *Physiological and Molecular Plant Pathology*, 67, 194–201.
- Dempsey, J. & Owen, A. G. (2010). The effect of phosphite treatments on the growth and disease susceptibility of *Agrostis stolonifera* L. 2nd European Turfgrass Society Conference, Angers, France, European Turfgrass Society.
- Diamond, H., Cooke, B. M., & Clegg, B. (1998). Morphology of sporodochia of *Microdochium nivale* var. *nivale* on cereal hosts using cryoscanning electron microscopy. *Mycologist*, 12, 118–120.

- Espevig, T. (2011). *Winter hardiness and management of velvet bentgrass (Agrostis canina) on golf greens in the Nordic climate*. PhD dissertation. Norwegian University of Life Sciences.
- Fenn, M. E., & Coffey, M. D. (1984). Studies on the in vitro and in vivo antifungal activity of Fosetyl-Al and phosphorus acid. *Phytopathology*, 74, 606–611.
- Fenn, M., & Coffey, M. D. (1987). Phosphonate fungicides for control of diseases caused by *Phytophthora*. *California Avocado Society 1987 Yearbook*, 71, 241–249.
- Glynn, N. C., Hare, M. C., Parry, D. W., & Edwards, S. G. (2005). Phylogenetic analysis of EF-1 α gene sequences from isolates of *Microdochium nivale* leads to elevation of varieties *majus* and *nivale* to species status. *Mycological Research*, 109, 872–880.
- Grant, B. R., Dunstan, R. H., Griffith, J. M., Niere, J. O., & Smillie, R. H. (1990). The mechanism of phosphonic (phosphorous) acid action in *Phytophthora*. *Australasian Plant Pathology*, 19, 115–121.
- Hofgaard, I., Wanner, L., Hageskal, G., Henriksen, B., Klemsdal, S., & Tronsmo, A. (2006). Isolates of *Microdochium nivale* and *M. majus* differentiated by pathogenicity on perennial ryegrass (*Lolium perenne* L.) and in vitro growth at low temperature. *Journal of Phytopathology*, 154, 267–274.
- Hofgaard, I. S., Ergon, Å., Henriksen, B., & Tronsmo, A. M. (2010). The effect of potential resistance inducers on development of *Microdochium majus* and *Fusarium culmorum* in winter wheat. *European Journal of Plant Pathology*, 128, 269–281.
- Horvath, B. J., McCall, D. S., Ervin, E. H., & Zhang, X. (2007). Physiological effects of phosphite formulations on turfgrass challenged with *Pythium* and heat stress. *Virginia Turfgrass Journal*, January–February, 14–15.
- Humphreys, J., Cooke, B. M., & Storey, T. (1995). Effects of seed-borne *Microdochium nivale* on establishment and grain yield of winter-sown wheat. *Plant Varieties and Seeds*, 8, 107–117.
- Jackson, T. J., Burgessa, T., Colquhoun, I., & Hardy, G. E. S. (2000). Action of the fungicide phosphite on *Eucalyptus marginata* inoculated with *Phytophthora cinnamomi*. *Plant Pathology*, 49, 147–154.
- Landschoot, P. J. & Cook, J. (2005). Sorting out the phosphonate products. *Golf Course Management*, November, 73–77.
- Lees, A., Nicholson, P., Rezanoor, H., & Parry, D. (1995). Analysis of variation within *Microdochium nivale* from wheat evidence for a distinct sub-group. *Mycological Research*, 99, 103–109.
- Mahuku, G., Hsiang, T., & Yang, L. (1998). Genetic diversity of *Microdochium nivale* isolates from turfgrass. *Mycological Research*, 102, 559–567.
- Mann, R. (2002). In vitro fungicide sensitivity of *Microdochium nivale* isolates from the UK. *Journal of Turfgrass and Sports Surface Science*, 78, 25–30.
- Maurin, N., Rezanoor, H. N., Lamkadmi, Z., Somé, A., & Nicholson, P. (1995). A comparison of biological, molecular and enzymatic markers to investigate variability within *Microdochium nivale* (Fries) Samuels and Hallett. *Agronomie*, 15, 39–47.
- McCarren, K. L., McComb, J. A., Shearer, B. L., & Hardy, G. E. S. J. (2009). In vitro influence of phosphite on chlamydospore production and viability of *Phytophthora cinnamomi*. *Forest Pathology*, 39, 210–216.
- Met Eireann. (2011). Monthly weather data. Available at: <http://www.met.ie/climate/monthly-data.asp?Num=3723> (Accessed 14 December 2011).
- Niere, J. O., Deangelis, G., & Grant, B. R. (1994). The effect of phosphonate on the acid-soluble phosphorus components in the genus *Phytophthora*. *Microbiology*, 140, 1661–1670.
- Ouimette, D. G., & Coffey, M. D. (1988). Quantitative analysis of organic phosphonates, phosphonate, and other inorganic anions in plants and soil by using high-performance ion chromatography. *Phytopathology*, 78, 1150–1155.
- Pettitt, T. R., Parry, D. W., & Polley, R. W. (1993). Improved estimation of the incidence of *Microdochium nivale* in winter wheat stems in England and Wales, during 1992, by use of benomyl agar. *Mycological Research*, 97, 1172–1174.
- Reuveni, M., Sheglov, D., & Cohen, Y. (2003). Control of moldy-core decay in apple fruits by β -aminobutyric acids and potassium phosphites. *Plant Disease*, 87, 933–936.
- Saindrenan, P., Barchietto, T., Avelino, J., & Bombeix, O. (1988). Effects of phosphite on phytoalexin accumulation in leaves of cowpea infected with *Phytophthora cryptogea*. *Physiological and Molecular Plant Pathology*, 32, 425–435.
- Sanders, P. L. (1983). Control of *Pythium* spp. and *Pythium* blight of turfgrass with fosetyl aluminum. *Plant Disease*, 67, 1382–1383.
- Schroetter, S., Angeles-Wedler, D., Kreuzig, R., & Schnug, E. (2006). Effects of phosphite on phosphorus supply in corn (*Zea mays*). *Landbauforschung Völknerode*, 56, 87–99.
- Smiley, R., Dernoeden, P., & Clarke, B. (1992). *Compendium of turfgrass diseases*. St Paul, MN: APS Press.
- Stehmann, C., & Grant, B. (2000). Inhibition of enzymes of the glycolytic pathway and hexose monophosphate bypass by phosphonate. *Pesticide Biochemistry and Physiology*, 67, 13–24.
- Vargas, J. (2005). *Management of turfgrass diseases*. Chichester: John Wiley and Sons.
- Vincelli, P., & Dixon, E. (2005). Performance of selected phosphite fungicides on greens. *Golf Course Management*, July, 77–81.