NITROGEN SOURCE IMPACT ON DEAD SPOT (*OPHIOSPHAERELLA AGROSTIS*) RECOVERY IN CREEPING BENTGRASS.

John E. Kaminski* and Peter H. Dernoeden

ABSTRACT

Dead spot is a relatively new disease of creeping bentgrass (*Agrostis stolonifera* L.) incited by *Ophiosphaerella agrostis* Dernoeden, M.P.S. Câmara N.R. O'Neill van Berkum et M.E. Palm. Limited information is available with regards to chemical and cultural management strategies for dead spot. Two field studies were designed to evaluate the influence of various fertilizers and iprodione on the recovery of dead spot when applied after or during peak dead spot activity. When applied after peak activity, all N-sources (ammonium sulfate, IBDU, SCU, urea, Ringer Greens Super, and methylene urea) aided in the recovery and healing of dead spot, but none provided for complete recovery prior to winter. Plots treated with ammonium sulfate and IBDU were among the fastest and slowest to recover, respectively. Iprodione (3-(3,5-dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide) failed to improve dead spot recovery when applications were initiated in late summer after most injury was evident. When applied during the early stages of symptom expression, none of five water soluble N-sources ($Ca(NO_3)_2$, KNO_3, $(NH_4)_2SO_4$, urea, and 20-20-20) examined in a second study prevented new infection centers from occurring. The percent of plot area diseased, however, continued to increase in plots not receiving N and significantly less dead spot was observed in all N-treated plots by early to mid-September of the first year (2002). In the second year (2003), dead spot recurred in plots treated with KNO_3, $Ca(NO_3)_2$, 20-20-20, and urea. Conversely, dead spot did not recur in plots receiving $(NH_4)_2SO_4$ or the unfertilized plots. The number of dead spot infection centers per plot in 2003 was positively correlated with pH in plots receiving N and disease incidence appeared to be favored at a pH greater than 6.0 and 6.6 in the mat and soil, respectively.

Abbreviations

IBDU, isobutylidene diurea; SCU, sulfur coated urea; WSN, water soluble nitrogen; fenarimol (α-(2-chlorophenyl)-α-(4-chlorophenyl)-5-pyrimidinemethanol); triadimefon (1-(4-chlorophenoxy)-3,3-dimethly-1-(1*H*-1,2,4-triazol-1-yl)-2-butanone); chlorothalonil (tetrachloroisophthalonitrile); iprodione (3-(3,5-dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide).

Keywords

creeping bentgrass, dead spot, nitrogen, *Ophiosphaerella agrostis*.

INTRODUCTION

Dead spot (*Ophiosphaerella agrostis*) primarily is a disease of newly constructed creeping bentgrass golf greens grown on sand-based root zones (Câmara et al., 2000; Dernoeden et al., 1999). The disease first was discovered on a Maryland golf course in 1998, and since has been found on creeping bentgrass putting greens in at least 11 states (Dernoeden et al., 1999; Kaminski and Dernoeden, 2002). The pathogen also attacks hybrid bermudagrass (*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy) putting greens in Florida and Texas (Kaminski and Dernoeden, 2002; Krausz et al., 2001).

Department of Natural Resource Sciences and Landscape Architecture, University of Maryland, College Park, MD 20742 USA. Contribution of the Maryland Agricultural Experiment Station. *Corresponding author: john.kaminski@uconn.edu

On golf putting greens, dead spot may be active between May and December, but damage by the pathogen is most severe during the summer months (June to August) in the mid-Atlantic region of the USA. As grass in the center of infection centers dies, depressions or pits often form which disrupt both the playability and aesthetic quality of the putting surface. Although *O. agrostis* infection centers remain relatively small (5 to 8 cm diameter), creeping bentgrass regrowth into diseased spots is slow. Hence, spots that have not fully recovered prior to winter remain visible until bentgrass growth resumes the following spring.

Limited information is available with regards to the chemical and cultural management strategies for dead spot. Several fungicides are effective at reducing dead spot severity when applied prior to the onset of disease symptoms (Towers et al., 2000; Wetzel and Butler, 2000; Wetzel and Butler, 2001). Chemical management of dead spot, however, is more difficult once symptoms are present and often fungicides must be applied every 7 to 10 days to arrrest the disease. Various nitrogen (N) sources have been effective for managing several turfgrass diseases. Ammonium-based N fertilizers help to lower soil pH, and have been shown to reduce the severity of several turfgrass diseases including spring dead spot (*Ophiosphaerella korrae* Walker and Smith), summer patch (*Magnaporthe poae* Landschoot and Jackson), and take-all (*Gaeumannomyces graminis* (Sacc.) Arx & Olivier var. *avenae* (E.M. Turner) Dennis) (Davidson and Goss, 1972; Dernoeden, 1987; Dernoeden et al., 1991; Smiley et al., 1992; Smith, 1956). Additionally, applications of manganese (Mn) with $(NH_4)_2SO_4$ reduce the severity of take-all in creeping bentgrass (Hill et al., 1999). Conversely, some alkaline-reacting NO_3-based N-sources are thought to increase the severity of several turfgrass patch diseases (Smiley et al., 1992). In Kentucky bluegrass, applications of $Ca(NO_3)_2$ and $NaNO_3$ generally were associated with increased summer patch severity (Hill et al., 2001; Thompson et al., 1995). The severity of Microdochium patch (*Microdochium nivale* (Fr.) Samuels and Hallett) also was shown to increase with increasing soil pH (Smith, 1958).

The influence of various N-sources, Mn and pH on dead spot incidence, severity and recovery is unknown. Therefore, the primary objectives of this study were to: 1) determine the influence of several N-sources on creeping bentgrass recovery from dead spot; 2) determine curative and preventive effects of N-sources and Mn on dead spot incidence and severity and; 3) elucidate the role of pH on dead spot severity. Secondary objectives were to evaluate the influence of the N-sources on turfgrass quality and other potential pest problems.

MATERIALS AND METHODS

Two field studies were conducted at the University of Maryland Paint Branch Turfgrass Research Facility located in College Park, MD. In August 1999, a research putting green was constructed to United States Golf Association (USGA) specifications (USGA Green Section Staff, 1993). The soil was a modified sand-mix (97% sand, 1% silt, and 2% clay) with a pH of 6.9 and 10 mg organic matter g^{-1} of soil. Turf was 'L-93' creeping bentgrass and was maintained as a golf course putting green. Turf was mowed with a walk-behind mower to a height of 4.0 to 5.0 mm at least 3 times $week^{-1}$. The area routinely was vertical mowed and topdressed in 2000 and 2001. The study areas were irrigated as needed to prevent drought stress.

Autumn Recovery-Study I

In study I, the effect of various N-sources and iprodione (3-(3,5-dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide) on the autumn recovery of dead spot was assessed between September 2000 and July 2001 following seeding in autumn of 1999. Six N-sources were evaluated including isobutylidene diurea (31-0-0); sulfur coated urea (29-0-0; Lesco Elite, Strongsville, OH); urea (46-0-0); $(NH_4)_2SO_4$ (21-0-0); methylene urea (40-0-0); and Ringer Greens Super (10-2-6; 1.5% water soluble N) (Ringer Corporation, Minneapolis, MN). Isobutylidene diurea (IBDU), sulfur-coated urea (SCU) and methylene urea are synthetic slow release organic N-sources that contain 4.6%, 7.3% and 25.5% water soluble nitrogen (WSN), respectively. Urea is a quickly available synthetic organic N-source. Ammonium sulfate is a quickly available inorganic source of N. Ringer Lawn Restore is a slowly available natural organic N-source that contains 1.5% WSN.

In 2000, a total of 120 kg N ha^{-1} were applied between 6 September 2000 and 3 November 2000. Application dates and rates for all treatments are shown in Table 1. Each main plot (i.e., fertilizer treatment) was split and received either iprodione (6.1 kg a.i. ha^{-1} applied on 11 and 22 September; 6 and 20 October; and 3 November 2000) or no fungicide treatment, except for those mentioned below. Iprodione was included to determine if a fungicide effective in managing dead spot would assist in speeding turf recovery (Wetzel and Butler, 2001). In spring 2001, dead spot activity within previously infected spots was minimal and thereafter iprodione treatments were deleted from the study. All other fertilizer and fungicide applications used as part of the routine maintenance of the area are listed in Table 2. All soluble fertilizers and fungicide treatments were applied with a CO_2 pressurized (262 kPa) sprayer calibrated to deliver 1016 L ha^{-1} water. All other fertilizers were applied manually using a shaker bottle. Plots were irrigated immediately after each fertilizer application.

Main plots measured 1.5 by 3.0 m, and were arranged as a randomized complete split-block design with four replications. A mix of tall fescue (*Festuca arundinacae* Schreb.) seed and wheat (*Triticum aestivum* L.) bran 50/50% v/v inoculum, consisting of a single isolate (OpVA-1), was prepared using the method described by Kaminski et al., 2002. Approximately 0.5 g of inoculum was placed at the soil surface in a grid pattern spaced on 0.9 meter centers on 8 October 1999. The numbers of dead spot infection centers per plot were counted. Due to variation in initial disease incidence, data from each rating date were transformed as a percent of infection centers per plot based on the initial rating date (13 September 2000) and these data represented dead spot recovery. Percent dead spot recovery and actual infection center data were analyzed using PROC MIXED procedure (SAS Institute Inc., 2000).

Curative Management and Recovery-Study II

Study II was conducted on a separate area seeded in 1999 on the aforementioned USGA research green. In study I, mostly slow release N-sources were evaluated in what was to be a long term study. The decline of dead spot in the second year precluded further data collection. In study II, only water soluble N-sources were evaluated to determine if acid or alkaline reacting fertilizer varied in their ability to promote dead spot recovery. In study II, the fertilizers were applied at low rates generally used by

Table 1. Number of dead spot infection centers and percent change in the original number of infection centers in 'L-93' creeping bentgrass as influence by six N-sources, 2000 to 2001.

	Percent change in no. dead spots per plot†						Dead spot infection centers per plot		
	2000			2001			2001		
Fertilizer‡	6 Oct	3 Nov	29 Nov	15 May	18 June	24 July	15 May	18 June	24 July
	%						no.		
Ammonium sulfate	-30 c§	-55 c	-59 b	-45 a	-90 c	-100 c	14 a	3 b	0 b
IBDU	+24 ab	-14 a	-14 a	-12 a	-60 b	-83 b	19 a	8 b	3 b
Methylene urea	-20 c	-44 bc	-45 b	-27 a	-73 bc	-95 bc	15 a	7 b	1 b
Ringer Greens Super	-21 c	-22 ab	-43 b	-46 a	-72 bc	-89 bc	12 a	7 b	3 b
Sulfur coated urea	+2 bc	-53 c	-51 b	-32 a	-78 bc	-89 bc	11 a	3 b	2 b
Urea	-15 c	-48 bc	-43 b	-48 a	-82 c	-94 bc	12 a	4 b	2 b
Untreated	+41 a	-3 a	+4 a	-5 a	-18 a	-42 a	26 a	25 a	16 a

† The percent change of infection centers within each plot was based on the initial rating (13 September 2000) of the number of infection centers.

‡ Fertilizer treatments were applied as follows: 24 kg N ha $^{-1}$ on 6 and 22 September; 6 and 20 October and 3 November 2000 and 49 kg N ha $^{-1}$ on 1 May; 24 kg N ha $^{-1}$ on 22 May, 8 June, and 13 July 2001.

§ Means in a column followed by the same letter are not significantly different (P=0.05) according to Tukey's protected least significant difference test.

Table 2. Fertilizer and fungicides applied as part of the routine maintenance schedule for the creeping bentgrass putting greens in Study I and Study II.

Treatment	Rate	Date
Study I (2000-2001)		
19-25-5	24 kg N ha $^{-1}$	22 May 2000
19-25-5	24 kg N ha $^{-1}$	8 June 2000
21-7-16	24 kg N ha $^{-1}$	13 July 2000
Fenarimol	0.4 kg a.i. ha $^{-1}$	15 September 2000
Triadimefon	1.5 kg a.i. ha $^{-1}$	20 October 2000
Fenarimol + chlorothalonil	0.4 + 6.1 kg a.i. ha $^{-1}$	10 November 2000
0-46-0	24 kg P_2O_5 ha $^{-1}$	29 May 2001
Study II (2001-2003)		
19-25-5	49 kg N ha $^{-1}$	1 and 24 September 2001
19-25-5	49 kg N ha $^{-1}$	10 and 30 October 2001
46-0-0	49 kg N ha $^{-1}$	1 May 2002
46-0-0	24 kg N ha $^{-1}$	15 May 2002
46-0-0	12 kg N ha $^{-1}$	31 May; 7 and 21 June 2002
Propiconazole + chlorothalonil	0.9 + 6.1 kg a.i. ha $^{-1}$	13 September 2002
Propiconazole + chlorothalonil	0.9 + 6.1 kg a.i. ha $^{-1}$	14 May 2003
Propiconazole + chlorothalonil	0.9 + 6.1 kg a.i. ha $^{-1}$	9 June 2003

superintendents in the summer. In the autumn, higher rates of N were applied. Due to a dramatic decrease in disease activity in 2001, the site (0.06 ha) was fumigated with methyl bromide (98% methyl bromide + 2% chloropicrin) on 23 August 2001. On 30 August, the area was seeded to 'L-93' creeping bentgrass as previously described. On 21 March 2002, the area was inoculated with two isolates (OpOH-1 and OpVA-1) of *O. agrostis* as previously described.

The effect of N-sources and Mn on dead spot incidence and severity was assessed between June 2002 and November 2003. Five water-soluble N-sources were assessed including $Ca(NO_3)_2$ (15.5-0-0), KNO_3 (13-0-44), $(NH_4)_2SO_4$ (21-0-0), urea (46-0-0), and a complete fertilizer (20-20-20; Nutriculture; Plant Marvel Laboratories, Inc., Chicago Heights, IL). The complete fertilizer contained 3.87% ammoniacal, 5.87% nitrate, and 10.26% urea N-sources. In addition, Mn ($MnSO_4$; VWR scientific, West Chester, PA) was applied alone or in combination with urea. All treatment rates and dates of application are listed in Table 3. All fertilizer and Mn treatments were applied as described previously. Only N treatments in which $\geq$12 kg N ha^{-1} were applied were immediately watered-in to prevent burning. Dead spot was active prior to initiation of the study.

Dead spot incidence and severity were rated by counting the number of infection centers and percent disease per plot. In 2003, dead spot recovery was rated visually on a 0 to 5 scale in which 0.0 = infection centers completely healed, 3.0 = bare spots with visible bentgrass encroachment and 5.0 = bare spots with no visible bentgrass encroachment. Recurring dead spot infection centers also were counted between 21 August and 7 October 2003. In 2003, ratings were made on several other pests and stress problems. Yellow patch (*Rhizoctonia cerealis* Van der Hoeven) and algae (species unknown) were rated visually on a linear 0 to 100% scale where 0 = plots entirely void of yellow patch or algae and 100 = entire plot area affected by yellow patch or blackened by algae. Sod webworm (*Crambus* spp.) damage was rated by counting the number of damaged spots per plot.

Soil and mat pH were determined one month after treatment initiation (26 July 2002) and also after the recurrence of dead spot in the second year (29 August 2003). To measure [H$^+$], four soil cores (19 mm diameter) were removed from each plot and immediately processed. All green leaf tissue was removed and the 0 to 2.5 cm organic matter zone (organic matter plus roots and sand or mat layer) from each core was separated into small pieces by hand. Similarly, the 2.5 to 5.0 cm soil zone was separated. The four cores for each depth and from each replicate were combined and mixed together. A total of 10 g were removed from the total sample and placed into a small plastic cup. When all samples were weighed, 20 ml ddH$_2$0 were added to each cup and allowed to set for 30 minutes. After 30 minutes, cups were briefly agitated and allowed to set for an additional 30 minutes prior to measuring pH. Following calibration, pH was measured using a Model 8000 pH meter (VWR, West Chester, PA). All data were subjected to analysis of variance using the PROC MIXED function of SAS (SAS Institute Inc., 2000) and means were separated using Tukey's protected least significant difference t-test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Autumn Recovery-Study I

Dead Spot Recovery

In 2000, disease symptoms first appeared on 8 June and the disease was allowed to progress throughout the area prior to treatment initiation on 6 September. Although few new infection centers occurred after treatment initiation, *O. agrostis* infection centers remained active into November 2000. Dead spot incidence in 2001 was minimal and only a few active infection centers were present throughout the study site. Inactive infection centers, however, continued to recover throughout late spring and early summer of 2001. Regardless of data analyses, there were no fertilizer by fungicide interactions and the main effect of fungicide was not significant on any rating date. The main effect of fertilizer on the number of infection centers per plot and percent change in the number of infection centers (percent dead spot recovery), however, was significant on several rating dates.

Table 3. Impact of various nitrogen-sources and manganese on the development of new *Ophiosphaerella agrostis* infection centers in an 'L-93' creeping bentgrass putting green, 2003.

	New *O. agrostis* infection centers per plot				
Treatment†	21 Aug	13 Sept	23 Sept	27 Sept	7 Oct
			no.		
Calcium nitrate	2.8 a‡	2.3 ab	6.5 ab	12.5 a	9.0 ab
Potassium nitrate	1.8 a	3.8 a	9.8 a	15.3 a	13.3 a
Ammonium sulfate	0.0 b	0.0 b	0.0 c	0.0 b	0.0 c
Urea	1.8 a	1.5 ab	4.5 abc	9.3 ab	5.8 bc
Urea + manganese	1.5 ab	2.3 ab	4.3 bc	6.8 ab	5.8 bc
Manganese	0.0 b	0.0 b	0.0 c	0.0 b	0.0 c
20-20-20	0.0 b	0.0 b	1.0 c	6.3 ab	5.8 bc
Unfertilized	0.0 b	0.0 b	0.0 c	0.0 b	0.0 c

† Nitrogen treatments were applied as follows: 12 kg N ha^{-1} on 29 April; 14 and 30 May, 12 and 26 June, and 11 July; 5 kg N ha^{-1} applied 18 and 28 July; 12 kg N ha^{-1} on 13 and 27 September; and 24 kg N ha^{-1} on 19 November 2003.

‡ Means in a column followed by the same letter are not significantly different (P=0.05) according to Tukey's protected least significant difference test.

The change in percent dead spot based on the initial rating (13 September) increased in the untreated plots and in plots treated with either IBDU or SCU on 6 October (Table 1). On 6 October (1 month after the initial fertilizer application), plots treated with $(NH_4)_2SO_4$ had the greatest reduction (30%) in dead spot. The percent dead spot change in $(NH_4)_2SO_4$-treated plots, however, was not significantly different than the percentages observed in plots treated with methylene urea, Ringer Greens Super, urea or SCU on 6 October. By 29 November, dead spot recovery was observed in all plots treated with N; however, the percent change in plots treated with IBDU was not significantly different from the untreated control.

There was no reactivation of dead spot in the study site in 2001. Recovery from the disease was minimal until temperatures increased in early June 2001. On 15 May, there were no differences in percent change in the number of dead spots among plots receiving N (12 to 48% recovery per plot), when compared to the unfertilized control (5% recovery per plot). Despite the application of N to the untreated control plots on 22 May 2001, little recovery (18%) was observed in these plots by 18 June (Table 1). All plots treated with N, however, exhibited a large reduction in dead spots with the number of infection centers ranging from 3 to 8 per plot and percent recovery $\leq$60%. Although not statistically significant, ammonium

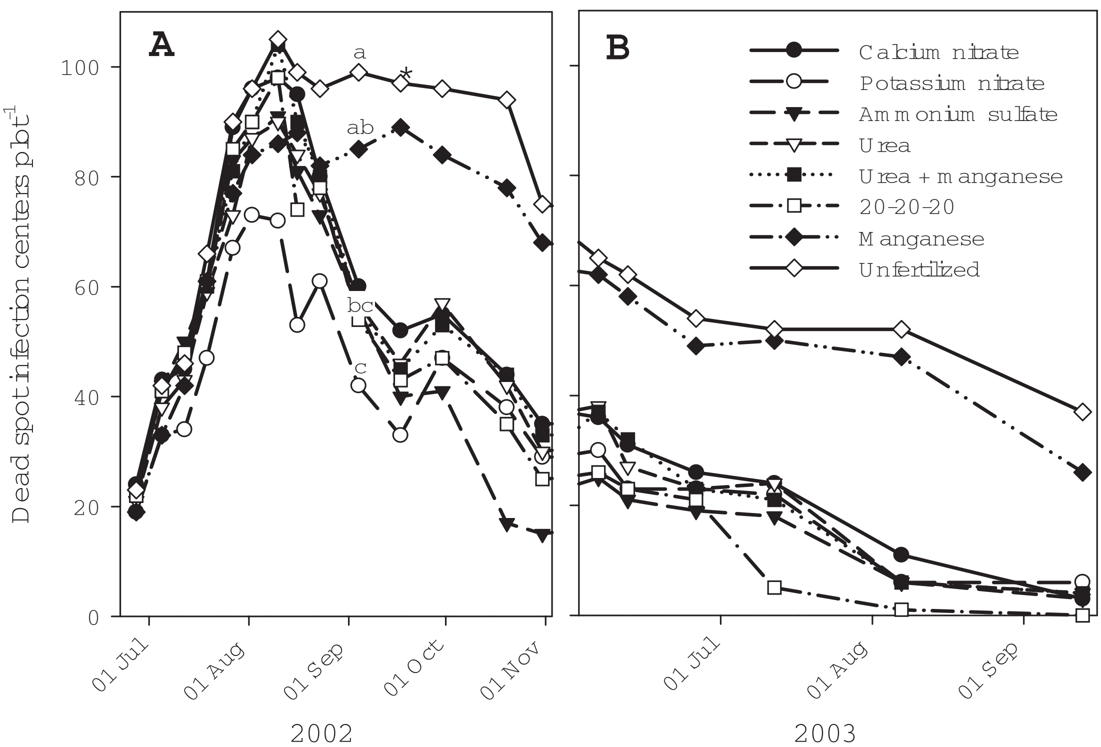

Figure 1. Impact of various nitrogen (N)-sources and manganese on dead spot incidence and recovery in an 'L-93' creeping bentgrass putting green, 2002 (A) and 2003 (B). Significant differences ($P \leq 0.05$), according to Tukey's protected least significant difference test, among treatments first appeared on 4 September 2002 and are indicated by different letters. There were no differences among N-sources on any rating date between 17 September 2002 (*) and the final rating date (23 September 2003). During the aforementioned period, all N-sources reduced dead spot severity, when compared to plots not receiving N (unfertilized and manganese).

sulfate-treated plots continued to exhibit the greatest recovery and by the final rating date (24 July) there were no visible dead spots in those plots. By 24 July, the application of N to turf in the untreated control plots appeared to result in moderate levels of disease recovery (42%), and those plots had 16 dead spots per plot by the end of the study. All treatments receiving N between September 2000 and 13 July 2001, however, resulted in a reduction in total number of dead spots by 18 June 2001, when compared to the untreated control.

Although dead spot remained active until November 2000, iprodione applications did not have an impact on dead spot recovery. Iprodione has been used with varying success with respect to dead spot management. Wetzel and Butler (2001) reported excellent preventive dead spot control with iprodione (3.1 kg a.i ha^{-1}) applied on a 14 day interval. On the other hand, Towers et al. (2000) found that iprodione provided only fair disease control when applied at similar rates and spray intervals as used in the aforementioned study. Curative dead spot control with iprodione, however, was less effective even when applied at 6.1 kg a.i. ha^{-1} on a 7 day interval (Wetzel and Butler, 2000). In this study, iprodione may have had little or no curative activity or it was too late to use the fungicide after numerous infection centers were allowed to develop during the summer. As previously observed, dead spots were very slow to recover as stolon growth into the center of infected spots appears to be inhibited (Kaminski and Dernoeden, 2002). The use of fungicides, therefore, may be unnecessary once the development of new infection centers slows. While $(NH_4)_2SO_4$ was somewhat more effective in promoting recovery it was unexpected to find that none of the N-sources was superior.

Curative Management and Recovery-Study II

Slow and rapid release N-sources were applied in study I after the majority of new infection centers had appeared and increases in patch diameter had slowed. In study II, water soluble N-sources were evaluated in frequent and low rate applications in a foliar feeding program to determine if this would be a more efficient method of suppressing dead spot severity and promoting disease recovery.

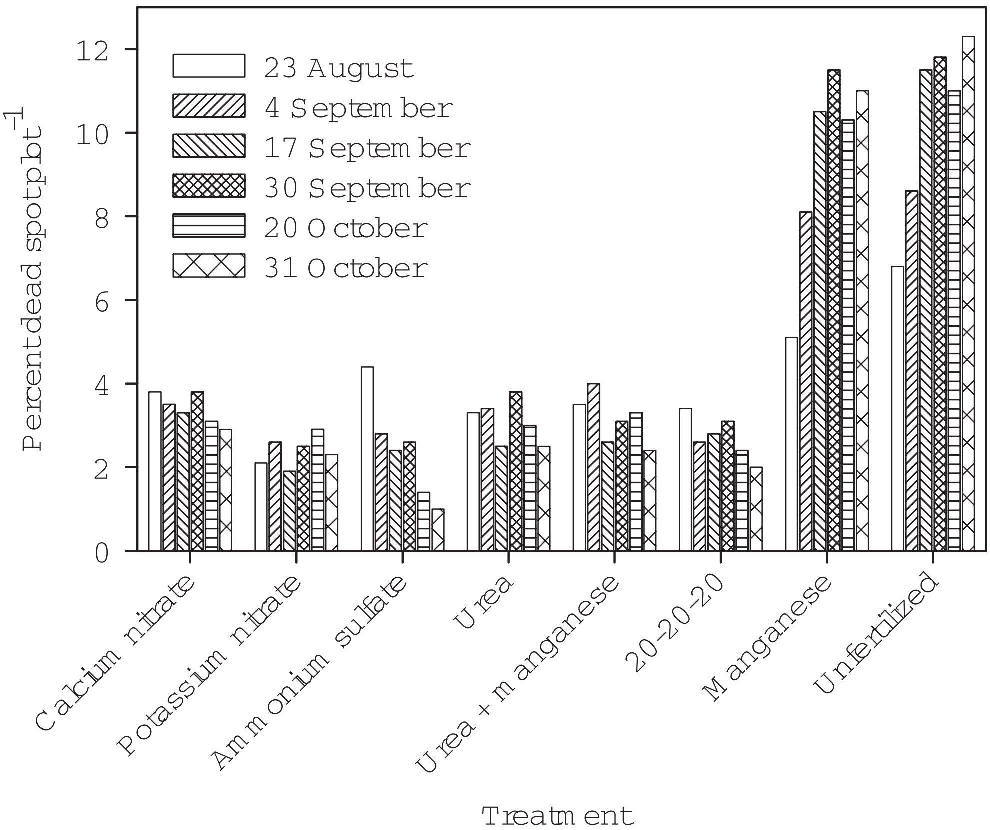

Fig. 2. Impact of various nitrogen (N)-sources and manganese on percent of plot area damaged by dead spot in an 'L-93' creeping bentgrass putting green, 2002. After 23 August, all plots in which N was applied had significantly less dead spot ($P \leq 0.0001$), when compared to the unfertilized control or manganese alone. There were no differences in percent dead spot among plots receiving N on any rating date.

Dead Spot Incidence. This site was fumigated on 23 August 2001 and seeded with 'L-93' creeping bentgrass one week later. *O. agrostis* infection was first noticed on 12 May 2002 and treatments were initiated on 28 June. On 27 June, there was an average of 21 *O. agrostis* infection centers per plot. The number of infection centers continued to increase throughout the summer, with most dead spots appearing by early to mid-August. By late August, the bentgrass in all plots had begun to recover, and there were no dead spot differences among treatments. On 4 September, plots treated with KNO_3 had the fewest number of infection centers (42 per plot), but disease levels were similar among all plots in which N was applied (Figure 1). Disease levels continued to decrease in all fertilized plots (except Mn alone) until mid-September. Between 17 and 30 September, the number of infection centers per plot increased in all fertilized plots. During this period, plots treated with KNO_3, urea, or urea + Mn had an increase of 14, 11 and 8 infection centers per plot, respectively. Conversely, $(NH_4)_2SO_4$-treated plots only had an increase of one infection per plot. Thereafter, the most rapid recovery occurred in plots receiving N, regardless of source. On the final 2002 rating date (31 October), plots treated with $(NH_4)_2SO_4$ had the fewest number of infection centers (15 per plot) (Figure 1).

In 2003, College Park, MD experienced excessively wet weather conditions and moderate temperatures throughout the spring and early summer. As a result, there was no reactivation of dead spot at this time. Recovery of dead spots from the previous year was slow and few differences among N-sources existed until mid-June (Figure 1; all data not shown). Between 12 June and 12 July, the number of infection centers in 20-20-20-treated plots declined greatly from 23 to 5 spots per plot. After 12 July, diseased spots continued to heal in all plots receiving N and no differences were observed among fertilizer treatments.

Although recovery of inactive diseased spots was occurring, new infection centers appeared in mid-August 2003. Between 21 August and 27 September, new infection centers developed in plots treated with $Ca(NO_3)_2$, KNO_3, urea, urea + Mn, and 20-20-20 (Table 3). No new or reactivated dead spots were observed in $(NH_4)_2SO_4$-treated

Table 4. Impact of various nitrogen-sources and manganese on dead spot recovery in an 'L-93' creeping bentgrass putting green, 2003.

Treatment†	Dead spot recovery 30 May	26 June	12 July	29 July
	0-5 scale‡			
Calcium nitrate	2.3 b§	1.1 b	1.4 b	0.9 b
Potassium nitrate	1.5 bc	0.9 b	0.8 c	0.4 bc
Ammonium sulfate	1.0 c	0.5 b	0.5 c	0.3 bc
Urea	2.0 b	1.3 b	1.0 bc	0.5 bc
Urea + manganese	2.0 b	1.0 b	0.6 c	0.3 bc
Manganese	4.1 a	4.4 a	4.3 a	3.9 a
20-20-20	1.5 bc	0.9 b	0.5 c	0.1 c
Unfertilized	4.4 a	4.1 a	4.4 a	3.9 a

† Nitrogen treatments were applied as follows: 12 kg N ha^{-1} on 29 April, 14 and 30 May, 12 and 26 June, 11 July; 5 kg N ha^{-1} applied 18 and 28 July; 12 kg N ha^{-1} on 13 and 27 September; and 24 kg N ha^{-1} on 19 November 2003.

‡ Dead spot severity was rated visually on a 0 to 5 scale; where 0.0 = infection centers completely healed, 3.0 = bare spots with visible bentgrass encroachment and 5.0 = bare spots with no visible bentgrass encroachment.

§ Means in a column followed by the same letter are not significantly different (P=0.05) according to Tukey's protected least significant difference test.

plots on any rating date. Although no new infection centers were observed in plots not receiving N, poor quality and reduced turf density may have inhibited the ability to see any new spots. Except on 21 August, plots treated with KNO_3 had the greatest number of new *O. agrostis* infection centers. On 21 August, plots treated with $Ca(NO_3)_2$ had the greatest number of *O. agrostis* infection centers, but the number of infection centers was similar to those plots treated with KNO_3, urea and urea + Mn. Dead spot incidence in 20-20-20-treated plots was delayed and no new infection centers were present until 23 September. After 23 September, *O. agrostis* infection centers in the 20-20-20-treated plots increased dramatically and by 27 September the number of centers was similar to all treatments in which dead spot recurred. After 27 September, the number of infection centers began to decrease.

Dead Spot Recovery. Dead spot severity and recovery were visually rated on a 0 to 100 percent scale in 2002 and on a 0 to 5 recovery scale in 2003, respectively. There were no differences in the percent of plot area diseased (1.5 to 5.1%) among treatments between 2 and 16 August 2002 (data not shown). The impact of N-applications on dead spot, however, was apparent between late August and October. During this period, percent area diseased decreased or remained relatively stable within plots receiving N, while the percent plot area diseased continued to increase in all plots not receiving N (Figure 2). Creeping bentgrass treated with $(NH_4)_2SO_4$ had the least amount of disease (1%) prior to winter.

Despite the application of N throughout the spring and summer in 2003, slow recovery was observed

Table 5. Impact of various nitrogen-sources and manganese on mat and soil pH in an 'L-93' creeping bentgrass putting green, 2002-2003.

	26 July 2002	29 Aug 2003	
Treatment†	Mat‡	Mat	Soil
		pH	
Calcium nitrate	6.58 a§	6.61 ab	6.89 ab
Potassium nitrate	6.59 a	6.76 a	7.02 a
Ammonium sulfate	6.24 c	5.57 d	6.36 c
Urea	6.42 b	6.44 bc	6.78 ab
Urea + manganese	6.49 ab	6.29 c	6.71 b
Manganese	6.44 b	6.50 abc	6.84 ab
20-20-20	6.46 b	6.32 c	6.72 b
Unfertilized	6.41 b	6.51 abc	6.81 ab

† Nitrogen treatments were applied as follows: 5 kg N ha^{-1} on 28 June, 5, 12, 19 and 27 July; and 2 10 and 17 August; 12 kg N ha^{-1} on 26 August, 4, 13 and 30 September; 21 October 2002; and 12 kg N ha^{-1} on 29 April, 14 and 30 May, 12 and 26 June, and 11 July; 5 kg N ha^{-1} on 18 and 28 July; 12 kg N ha^{-1} on 13 and 27 September; and 24 kg N ha^{-1} on 19 November 2003.

‡ Measurements of pH were made at the 0-2.5 cm depth (mat) and 2.6-5.0 cm depth (soil).

§ Means in a column followed by the same letter are not significantly different (P=0.05) according to Tukey's protected least significant difference test (P<0.0001).

in most plots throughout the year. Between 19 May and 7 August, plots treated with $(NH_4)_2SO_4$ generally exhibited the greatest bentgrass recovery (Table 4; all data not shown). On five out of eight rating dates (19 and 30 May, 6 and 12 June, and 12 July), $Ca(NO_3)_2$-treated plots had significantly less bentgrass regrowth, when compared to dead spots in plots treated with $(NH_4)_2SO_4$. Based on a playability threshold for a creeping bentgrass green, acceptable dead spot levels ($\leq$1.0 spot per plot) were observed in $(NH_4)_2SO_4$ -treated plots by 30 May; KNO_3 and 20-20-20 plots by 26 June; urea + Mn-treated plots by 12 July; and $Ca(NO_3)_2$ and urea plots by 29 July 2003. Little or no recovery was observed in unfertilized (unfertilized control and Mn alone) plots on any rating date.

pH. Approximately one month after treatment initiation (26 July 2002), significant pH differences ($P<0.0001$) were observed among the various fertilizer treatments in the 0 to 2.5 cm organic matter zone (i.e., mat). Plots receiving $Ca(NO_3)_2$ or KNO_3 generally exhibited the highest mat pH (pH=6.58 to 6.59) (Table 5). The mat pH in plots receiving urea+Mn (pH=6.49), however, were not significantly ($P\leq0.05$) different than mat pH in the aforementioned plots. The lowest mat pH (6.24) was observed in plots receiving $(NH_4)_2SO_4$. Mat pH for the remaining fertilizer-treated plots was similar, and ranged from an average pH of 6.41 to 6.46.

On 29 August 2003, mat pH again was lowest in plots receiving $(NH_4)_2SO_4$ (pH=5.57) and was greatest in

Table 6. Impact of various nitrogen-sources and manganese on various disorders in a 'L-93' creeping bentgrass putting green, 2003.

Treatment†	Yellow patch 26 Mar	Sod webworm 2 May	Algae 29 July	7 Aug	29 Aug	13 Sept
	%	No. spots per plot	% area blackened			
Calcium nitrate	21 c‡	46 a	0.2 b	0.0 b	1.4 b	5.6 b
Potassium nitrate	44 b	45 ab	0.0 b	0.0 b	0.8 b	1.1 b
Ammonium sulfate	4 d	17 cd	0.0 b	0.0 b	0.0 b	0.0 b
Urea	25 b	25 bcd	0.2 b	1.0 b	1.4 b	2.5 b
Urea + manganese	25 b	21 cd	0.5 b	0.1 b	2.6 b	3.1 b
Manganese	18 cd	4 d	0.9 b	2.0 b	13.0 a	17.5 a
20-20-20	75 a	31 abc	7.3 a	7.3 a	21.0 a	17.5 a
Unfertilized	22 b	4 d	0.3 b	0.3 b	14.0 a	21.3 a

† Nitrogen treatments were applied as follows: 12 kg N ha^{-1} on 29 April, 14 and 30 May, 12 and 26 June, 11 July; 5 kg N ha^{-1} on 18 and 28 July; 12 kg N ha^{-1} on 13 and 27 September; and 24 kg N ha^{-1} on 19 November 2003.

‡ Means in a column followed by the same letter are not significantly different (P<0.05) according to Tukey's protected least significant difference test.

plots receiving NO_3-N (pH=6.61 to 6.76) (Table 5). Except for $(NH_4)_2SO_4$-treated plots, all treatments had mat pH levels similar to the untreated control. Soil sampled at the 2.5 to 5.0 cm depth had pH levels higher than in the mat. In 2003, new dead spot infection centers began to develop on 21 August. Based on pH measurements on 29 August 2003 and dead spot infection centers at the time of peak disease activity (27 September 2003), there was a significant correlation between the number of new infection centers and mat (r=0.71, P<0.0001) and soil (r=0.78, P=0.0001) pH in plots receiving N. Among the N-fertilized plots, dead spot did not recur in plots with a pH below 5.91 and 6.54 in the mat and soil layer, respectively. Plots in which dead spot recurred, however, had pH values greater than 6.17 and 6.62 in the mat and soil layer, respectively. Smiley and Cook (1973) attributed the suppression of wheat take-all to acidification of the root zone through active plant uptake of NH_4 and subsequent release of $[H^+]$ from plant roots. Similarly, Hill et al. (2001) found a linear positive relationship between soil pH (0 to 2.5 and 2.5 to 5.0 cm depth) and summer patch severity in Kentucky bluegrass (*Poa pratensis* L.). It is likely that nitrification of NH_4-N by soil microbes as well as release of $[H^+]$ due to the plant uptake of NH_4 played a significant role in the acidification of mat and soil in this study.

Yellow Patch, Sod Webworm and Algae. Various disorders were monitored in 2003. In March, a severe outbreak of yellow patch was observed in the study site. In plots treated with 20-20-20 and KNO_3, 75% and 44% of the bentgrass was blighted by the pathogen, respectively (Table 6). Moderate disease levels were observed in plots treated with $Ca(NO_3)_2$, urea, urea + Mn and in the untreated control. Very low levels of yellow patch were observed in plots treated with $(NH_4)_2SO_4$.

All fertilizer-treated plots had severe sod webworm damage, while little damage was observed in plots receiving no fertilizer on 2 May 2003 (Table 6). The greatest insect damage (45 to 46 spots per plot) occurred in plots treated with KNO_3 or $Ca(NO_3)_2$. A similar level of insect damage occurred in plots treated with 20-20-20. Among fertilized plots, $(NH_4)_2SO_4$-treated plots sustained the least webworm damage (17 spots per plot), however, there were no significant differences among plots treated with $(NH_4)_2SO_4$, urea, urea + Mn and the unfertilized plots.

An unidentified blue-green, filamentous algae began to develop in the study site in early to mid-May 2003 following extended periods of overcast and rainy weather. Between 19 May and 13 September, percent of the plot area blackened by algae generally was greatest in plots treated with 20-20-20 (Table 6). By late August and into September, the level of algae blackening was similar in plots treated with $MnSO_4$ alone, 20-20-20 and the unfertilized control. On all rating dates, no blackening was observed in $(NH_4)_2SO_4$-treated plots. A low level of algae was present in plots treated with KNO_3, $Ca(NO_3)_2$, urea, and urea + Mn. There were, however, no algal blackening differences among the aforementioned N-sources and plots treated with $(NH_4)_2SO_4$.

CONCLUSIONS

Study I

Data revealed few differences in the ability of water soluble and water insoluble N-sources to enhance recovery of bentgrass in the autumn following heavy summer disease pressure. All N-sources aided in the recovery and healing of dead spot, but none provided for complete recovery before winter. Plots treated with $(NH_4)_2SO_4$ and IBDU, however, were among the fastest and slowest to recover, respectively. Iprodione failed to improve dead spot recovery when applications were initiated in late summer after most injury was evident. In this study, dead spot severity had peaked prior to the application of iprodione and few new infection centers appeared after early to mid-September. While fungicides may prevent infection, they likely have little impact on the recovery of existing dead spot patches. Therefore, this study indicated that iprodione, and perhaps other fungicides, only are likely to be effective when applied preventively or just after the initial symptoms are observed. In the mid-Atlantic region, a preventive fungicide program for new putting green constructions would begin in May, prior to the time when symptoms are most likely to appear. Initiating fungicide applications during the period of increasing patch diameter and pseudothecia development (i.e., June through August), likely would result in reduced or poor dead spot control. Hence, in an early curative fungicide program, chemicals need to be applied early enough to prevent new infections and nitrogen should be tank-mixed with fungicides to aid in the recovery of existing dead spots. Therefore, it appears more important to apply water-soluble N-sources to promote recovery rather than fungicides during the autumn months following peak dead spot activity.

Study II

This study was initiated to assess the impact of five water soluble N-sources and Mn on reducing severity or preventing new *O. agrostis* infection centers after the disease had appeared. When applied during the early stages of symptom development, none of the water soluble N-sources prevented new infection centers from occurring and the number of *O. agrostis* infection centers increased in all plots until mid-August 2002. Although new infection centers were minimal in late August and September, the percent of plot area diseased continued to increase in plots not receiving N. When compared to unfertilized plots, significantly less dead spot (percent and no. infection centers per plot) was observed in all plots receiving N by early to mid-September 2002. In the second year (2003), reactivation of previously infected dead spot patches was minimal. In August 2003, however, plots treated with KNO_3, $Ca(NO_3)_2$, and urea exhibited a recurrence of new *O. agrostis* infection centers. The application of 20-20-20 delayed, but did not prevent new dead spot symptoms. Conversely, dead spot did not recur in unfertilized plots or plots receiving $(NH_4)_2SO_4$ in 2003. The number of dead spot infection centers per plot in 2003 was positively correlated with pH and disease incidence appeared to be favored at a pH greater than 6.0 and 6.6 in the mat and soil, respectively. Furthermore, $(NH_4)_2SO_4$ generally was most effective in reducing yellow patch severity, and sod webworm damage as well as algal growth.

Applications of N-alone were not very effective in reducing the severity of active dead spot. In study I, plots treated with $(NH_4)_2SO_4$ were fastest to completely recover. Ammonium sulfate also was the only N-source to prevent dead spot recurrence in the second year of study II. Because both studies were initiated after dead spot developed, it is unknown if any N-source would have reduced or enhanced the damage when applied preventively. Regardless, it would appear prudent to utilize $(NH_4)_2SO_4$ as the primary N-source during establishment. Due to the potential of $(NH_4)_2SO_4$ to lower pH to detrimental levels, soil tests should be conducted routinely and appropriate measures taken to correct pH extremes.

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