Silvery-thread Moss Control in Creeping Bentgrass Putting Greens with Mancozeb Plus Copper Hydroxide and Carfentrazone Applied in Conjunction with Cultural Practices

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SUMMARY. Carfentrazone is a broadleaf weed control herbicide that is also used for control of silvery-thread moss (*Bryum argenteum*) in creeping bentgrass (*Agrostis stolonifera*) putting greens. Field studies were initiated in June 2006 and May 2007 to evaluate silvery-thread moss control with carfentrazone alone, carfentrazone applied with nitrogen (N) and/or topdressing (TD), N alone, TD alone, and mancozeb plus copper hydroxide. All treatments except for mancozeb plus copper hydroxide and the non-treated control reduced silvery-thread moss populations 16 weeks after initial treatment. Carfentrazone applied alone and carfentrazone followed by N decreased silvery-thread moss populations by 39%. Carfentrazone followed by TD and carfentrazone followed by N + TD decreased silvery-thread moss populations by 73% and 66%, respectively. These data indicate the importance of using cultural practices to control silvery-thread moss on creeping bentgrass putting greens.

Silvery-thread moss encroachment is an increasing problem on creeping bentgrass putting greens across the United States (Burnell et al., 2004; Danneberger and Taylor, 1996; Happ, 1998). Silvery-thread moss can be found in many environments such as concrete surfaces, tree roots, compacted soils, cool damp soils, and golf course putting greens (Boesch and Mitkowski, 2005). Once established on a golf course putting green, silvery-thread moss can be difficult to control due to its reproductive nature and anatomy. Silvery-thread mosses are able to reproduce sexually via spores or asexually from displaced fragments (Boesch and Mitkowski, 2005; Nelson, 2007; Yelverton, 2005). These spores and fragments can spread through golf spikes, mowers, or other turf managing equipment.

A demand for a faster, more competitive playing surface has forced turf managers to reduce fertility and to lower mowing heights, thus adding increased stress to creeping bentgrass putting greens (Aylward, 2007; Boesch and Mitkowski, 2005; Danneberger and Taylor, 1996; Happ, 1998; Yelverton, 2005). However, if over-fertilized or not properly maintained, excessive thatch buildup can occur on creeping bentgrass putting greens. Common cultural practices used to control thatch buildup are aerification, vertical mowing, and sand topdressing (TD) (McCarty et al., 2007; Turgeon, 2008). These cultural practices can disrupt golf course play and are often not used repeatedly, increasing the potential for thatch accumulation. Excessive thatch accumulation can disrupt water infiltration and air movement in a golf course putting green, making it more favorable to silvery-thread moss encroachment (Happ, 1998). These stresses and the

restriction of mercury-based fungicides have been attributed to the increase in silvery-thread moss infestations observed recently on golf course putting greens (Nelson, 2007; Yelverton, 2005).

Golf course superintendents have tried numerous commercial products and homemade treatments to control silvery-thread moss. Some of these products have been evaluated and numerous trade journals have reviewed their efficacy. Such products include chlorothalonil fungicide, ferrous and ferric sulfates, sodium carbonates such as baking soda, sodium carbonate peroxyhytests, and even dish detergent (Ultra Dawn®; Procter & Gamble, Cincinnati). These treatments are highly variable and often ineffective compared with the use of carfentrazone and mancozeb plus copper hydroxide, both labeled for the control of silvery-thread moss.

Although silvery-thread moss persists on a broad range of soils and surfaces, it does not persist on metal-contaminated sites (Weber and McAvoy, 2003). The sequence of metal toxicity for silvery thread moss has been identified as: mercury > copper > lead > nickel > cadmium > zinc > magnesium (Weber and McAvoy, 2003). With the loss of Hg, Cu-containing pesticides became the focus for silvery-thread moss control.

Junction® (SePRO, Meridian, IN) is a mancozeb-based fungicide labeled for the control of silvery-thread moss (SePRO Corp., 2006). It is a coordination product of zinc ion, manganese ethylenebisdithiocarbamate, and copper hydroxide. Copper hydroxide comprises 46.1% (30% metal equivalent) of the total Junction® (mancozeb plus copper hydroxide) chemistry. The highest labeled rate of 4 oz/1000 ft² (12.2 kg·ha⁻¹) product weekly would apply copper (Cu) at an equivalent of 5 lb/acre (5.6 kg·ha⁻¹) (SePRO Corp., 2006). Previous research has indicated that five or more applications

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.0929	ft ²	m ²	10.7639
0.0700	ft ³ /acre	m ³ ·ha ⁻¹	14.2913
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
3.0515	oz/1000 ft ²	kg·ha ⁻¹	0.3277

of copper hydroxide could potentially induce iron deficiency or Cu phytotoxicity in turfgrass plants (Boesch and Mitkowski, 2005; Landschoot et al., 2004). A buildup of Cu within the root profile can also be detrimental to turfgrass roots. Cook et al. (2002) observed root stunting after applying an equivalent of 293 kg·ha⁻¹ Cu over a 1-year period.

Landschoot et al. (2004) concluded that mancozeb plus copper hydroxide summer treatments did not control silvery-thread moss, but five biweekly fall applications of 7.04 kg·ha⁻¹ Cu provided 100% silvery-thread moss control when plots were re-evaluated in the spring. Similarly, Cook et al. (2002) found that five to seven biweekly applications of copper hydroxide applied at 4.85 to 7.27 kg·ha⁻¹ Cu during cool wet weather between October and March effectively controlled silvery-thread moss.

In 2005, carfentrazone, a protoporphyrinogen oxidase inhibitor used for the control of a wide range of broadleaf weeds, was labeled for the control of silvery-thread moss on creeping bentgrass putting greens (FMC Corp., 2005; Senseman, 2007). It quickly became the industry standard for silvery-thread moss control on creeping bentgrass putting greens due to its fast, effective, visual control. Numerous trade journal reports concluded that carfentrazone provides efficient control of silvery-thread moss over a broad temperature spectrum (Aylward, 2007; Boesch and Mitkowski, 2005; FMC Corp., 2005; Nelson, 2007; Settle et al., 2006; Yelverton, 2005). Despite all of these reports, no peer-reviewed publications are currently available evaluating carfentrazone control of silvery-thread moss on creeping bentgrass putting greens.

Research was initiated to evaluate silvery-thread moss control on creeping bentgrass putting greens with carfentrazone alone, carfentrazone applied with nitrogen (N) and/or TD, N alone, TD alone, and mancozeb plus copper hydroxide. Increased N and TD treatments were added to this evaluation, as the lack of these practices is often linked with an increase in silvery-thread moss infestations.

Materials and methods

Field studies were initiated on 20 June 2006 at the Honors Course

(HC), Ootlewah, TN, and on 21 May 2007 at The Crossings Golf Club (CC), Jonesborough, TN. Studies evaluated silvery-thread moss control with carfentrazone, carfentrazone applied with cultural practices, cultural practices alone, and mancozeb plus copper hydroxide. Putting greens at HC were built to the U.S. Golf Association (USGA) specifications with a pH of 6.7 (USGA, 2004). Putting greens at CC were constructed as California greens with a pH of 6.8 (Davis et al., 1990). Creeping bentgrass putting greens at HC and CC were mowed daily to a height of 1/8 inch. Total annual N applied to putting greens at HC and CC was 235 and 171 kg·ha⁻¹ N, respectively. Research was conducted on naturalized populations of silvery-thread moss contaminating creeping bentgrass putting greens at each location.

Research was conducted in a randomized complete block design and was replicated three times. Treatments included carfentrazone alone at 0.12 kg·ha⁻¹, carfentrazone followed by TD at 6.5 m³·ha⁻¹, carfentrazone followed by N at 12.2 kg·ha⁻¹, carfentrazone followed by N + TD, mancozeb plus copper hydroxide alone at 1.8 kg·ha⁻¹, N alone, TD alone, and N plus TD. A total of two carfentrazone treatments was applied, at trial initiation and 2 weeks after initial treatment (WAIT). Cultural measures, N, and/or TD were applied at 4 WAIT (2 weeks after the last carfentrazone treatment) and were continued biweekly until 10 WAIT, totaling four applications. Nitrogen applications were made with a 24N-1.7P-9.9K granular greens-grade fertilizer (Pro Source One, Memphis, TN) in addition to the total annual inputs of each location. Six mancozeb plus copper hydroxide treatments were applied, beginning at trial initiation, and were continued biweekly until 10 WAIT. Spray applications were applied with a carbon dioxide pressurized backpack sprayer calibrated to 30 gal/acre and equipped with 8002 XR TeeJet® (Spraying Systems, Wheaton, IL) flat-fan nozzles. Granular N and TD treatments were applied over each individual plot by hand. Topdressing treatments were brushed into the turf canopy with a push broom. Overhead irrigation was then used to water granular N and TD treatments into the soil profile.

The percentage of silvery-thread moss control was evaluated visually on a 0% (no control) to 100% (complete control) scale and was evaluated 3, 5, 11, and 16 WAIT. A grid system was used to evaluate total silvery-thread moss population change within the 1 × 1-m plots. Grids contained 100 intersecting points, if silvery-thread moss persisted within an intersecting point it would be counted, giving an accurate silvery-thread moss population percentage and eliminating human bias. Grid counts were made at study initiation and at 16 WAIT. Percentage of silvery-thread moss reduction was calculated using the following equation: Percentage of silvery-thread moss population change = [(b/a) × 100] - 100, where a is the percentage of silvery-thread moss cover at trial initiation and b is the percentage of silvery-thread moss cover at 16 WAIT. A negative moss population value indicates a silvery-thread moss population reduction where a positive value indicates a silvery-thread moss population increase.

Data were subjected to analysis of variance (ANOVA) at $\alpha = 0.05$ using the general linear model procedure in SAS (version 8; SAS Institute, Cary, NC). Variance homogeneity was inspected by plotting residuals and evaluating them for skewing and general disuniformity (Zar, 1999). Neither arcsine nor log transformation improved variance homogeneity; therefore, non-transformed data were used for analysis. Rating dates within a given year were analyzed separately and were not included as a factor in ANOVA. Fisher's protected least significant difference at $\alpha = 0.05$ was applied for mean comparisons. Treatment by location interaction was non-significant for all data; therefore, data were pooled over location.

Results and discussion

VISUAL ASSESSMENT OF SILVERY-THREAD MOSS CONTROL. At no time was creeping bentgrass injury observed with any treatment. No difference was observed among carfentrazone treatments at 3 and 5 WAIT (Table 1). Carfentrazone alone controlled silvery-thread moss 77% at 3 WAIT. In comparison, mancozeb plus copper hydroxide controlled silvery-thread moss 11% at 3 WAIT. We observed that carfentrazone applications affected

surface silvery-thread moss tissue, but would leave a residual silvery-thread moss layer that resembled turfgrass thatch. Given that silvery-thread moss lacks a true vascular system (Crum and Anderson, 1981), contact herbicides such as carfentrazone do not progress throughout the plant (Yelverton, 2005). Therefore, injury is foliar in nature and residual silvery-thread moss can sustain regrowth. Continual carfentrazone applications applied at $0.12 \text{ kg} \cdot \text{ha}^{-1}$ could potentially increase silvery-thread moss suppression, allowing creeping bentgrass to regrow.

Carfentrazone-containing treatments applied with or without N and/or TD controlled silvery-thread moss 43% to 67% at 5 WAIT. At 5 WAIT, only one N and/or TD application had been made. Mancozeb plus copper hydroxide, N, TD, and N + TD treatments controlled silvery-thread moss 3% to 13% at 5 WAIT.

At 11 WAIT, carfentrazone applied with N and/or TD controlled silvery-thread moss greater than carfentrazone alone. Carfentrazone alone controlled silvery-thread moss 36%, while carfentrazone plus TD, N, and N + TD controlled silvery-thread moss 77%, 69%, and 77%, respectively at 11 WAIT. No difference was observed between carfentrazone alone, N, TD, N + TD, or mancozeb plus copper

hydroxide at 11 WAIT. Carfentrazone applied with N and/or TD controlled silvery-thread moss greater than all other treatments at this rating date, including carfentrazone applied alone.

Topdressing is used on golf greens to control thatch by diluting the organic matter that is generated by decaying leaf matter, stolons, and rhizomes (Turgeon and Vargas, 2006). Visual assessment of the TD plots indicated that along with dilution, abrasion from sand particles also potentially broke up and separated the silvery-thread moss residual tissue. This potentially would allow carfentrazone to contact more surface area of the moss, increasing carfentrazone efficacy. Increased N could also promote creeping bentgrass competitiveness, thus leading to greater silvery-thread moss control. Nitrogen treatments increased yearly nitrogen rates at CC from 171 to $219.8 \text{ kg} \cdot \text{ha}^{-1}$ N and HC from 235 to $283.8 \text{ kg} \cdot \text{ha}^{-1}$ N. Lower mowing heights and reduced fertility are considered beneficial for increasing putting green speed, but they decrease turfgrass vigor (Nikolai, 2005). Allowing dead silvery-thread moss patches to remain without promoting bentgrass growth increases the chance of silvery-thread moss recovery.

Carfentrazone alone controlled silvery-thread moss treatments 54%

at 16 WAIT. Carfentrazone applied with N, TD, and N + TD controlled silvery-thread moss 76%, 68%, and 78%, respectively, at 16 WAIT. In contrast to 11 WAIT, no statistical difference was observed between carfentrazone applied alone and carfentrazone applied with N and/or TD. Nitrogen, TD, and N + TD controlled silvery-thread moss 32%, 34%, and 29%, correspondingly, at 16 WAIT. Carfentrazone applied alone did not differ statistically from N and/or TD applied alone; however, when these treatments were applied as a combination, silvery-thread moss control increased.

On the final rating date, mancozeb plus copper hydroxide controlled silvery-thread moss 7%. Mancozeb plus copper hydroxide could potentially have been more effective if applied during fall conditions rather than early summer as it was applied in this research. Landschoot et al. (2004) observed minimal silvery-thread moss control with mancozeb plus copper hydroxide when applied during summer months; however, applications made in fall provided excellent silvery-thread moss control in the following spring. Previous research has reported the potential for creeping bentgrass chlorosis from five or more mancozeb plus copper hydroxide plus copper hydroxide applications (Landschoot et al., 2004); however, no creeping bentgrass chlorosis was observed at anytime during this study.

SILVER-THREAD MOSS POPULATION CHANGE. Changes in silvery-thread moss populations were assessed to provide quantitative supplemental data to visual control ratings. All treatments except mancozeb plus copper hydroxide and non-treated control plots decreased silvery-thread moss populations at 16 WAIT (Table 2). Carfentrazone applied alone or with N, TD, and N + TD reduced silvery-thread moss populations by 39%, 73%, 39%, and 66%, respectively. Nitrogen, TD, and N + TD reduced silvery-thread moss populations similar to applications of carfentrazone alone (by 22%, 36%, and 23%, respectively). According to Aylward et al. (2007), fertilization and cultural practices are vital for long-term silvery-thread moss suppression.

Silvery-thread moss is a difficult weed species to evaluate visually on

Table 1. Percentage of visual silvery-thread moss control on creeping bentgrass putting greens using carfentrazone, carfentrazone followed by (fb) nitrogen (N) and/or topdressing (TD), N and/or TD alone, and mancozeb plus copper hydroxide at 3, 5, 11, and 16 weeks after initial treatment (WAIT).

Treatment ^z	Rate ($\text{kg} \cdot \text{ha}^{-1}$ or $\text{m}^3 \cdot \text{ha}^{-1}$) ^y	Visual silvery-thread moss control (%) ^x			
		3 WAIT	5 WAIT	11 WAIT	16 WAIT
Carfentrazone	0.12	77	43	36	54
Carfentrazone fb TD	0.12 fb 6.5	—	63	77	76
Carfentrazone fb N	0.12 fb 12.2	—	54	69	68
Carfentrazone fb N + TD	0.12 fb 12.2 + 6.5	—	67	77	78
Mancozeb plus copper hydroxide	1.8	11	13	4	7
N	12.2	—	3	23	32
TD	6.5	—	9	25	34
N + TD	12.2 + 6.5	—	10	20	29
LSD _{0.05} ^w		15	25	32	31

^zAll carfentrazone treatments with or without N and/or TD were applied twice (trial initiation and 2 WAIT), six mancozeb plus copper hydroxide treatments were applied (trial initiation and 2, 4, 6, and 8 WAIT), and four N and/or TD treatments were applied (4, 6, 8, and 10 WAIT).

^yTopdressing rates are expressed in cubic meters per hectare. All other treatments are expressed in kilograms per hectare; $1 \text{ kg} \cdot \text{ha}^{-1} = 0.8922 \text{ lb/acre}$, $1 \text{ m}^3 \cdot \text{ha}^{-1} = 14.2913 \text{ ft}^3/\text{acre}$.

^xSilvery-thread moss visual control was evaluated for each plot at each timing relative to the non-treated. Numbers were pooled between locations. No cultural practices were applied 3 WAIT, therefore, carfentrazone treatments were displayed as a single mean. All carfentrazone treatments significantly differed from mancozeb plus copper hydroxide treatments.

^wFisher's protected least significant difference at $P \leq 0.05$.

Table 2. Percentage of silvery-thread moss population change from carfentrazone alone, carfentrazone followed by (fb) nitrogen (N) and/or topdressing (TD), N and/or TD alone, and mancozeb plus copper hydroxide at the study completion, 16 weeks after initial treatment (WAIT).

Treatment ^z	Rate (kg·ha ⁻¹ or m ³ ·ha ⁻¹) ^y	Population change (%) ^x
Carfentrazone	0.12	-39 ^w
Carfentrazone fb TD	0.12 fb 6.5	-73
Carfentrazone fb N	0.12 fb 12.2	-39
Carfentrazone fb N + TD	0.12 fb 12.2 + 6.5	-66
Mancozeb plus copper hydroxide	1.8	35
N	12.2	-22
TD	6.5	-36
N + TD	12.2 + 6.5	-23
Non-treated		53
LSD _{0.05} ^v		43

^zAll carfentrazone treatments with or without cultural practices were applied twice (trial initiation and 2 WAIT), six mancozeb plus copper hydroxide treatments were applied (trial initiation and 2, 4, 6, and 8 WAIT), and four N and/or TD treatments were applied (4, 6, 8, and 10 WAIT).

^yTopdressing rates are expressed in cubic meters per hectare. All other treatments are expressed in kilograms per hectare; 1 kg·ha⁻¹ = 0.8922 lb/acre, 1 m³·ha⁻¹ = 14.2913 ft³/acre.

^xPercentage of silvery-thread moss population change was calculated by comparing silvery-thread moss populations at the beginning and end of each study. Percentage of silvery-thread moss population change = [(b/a) × 100] - 100, where a is the percentage of silvery-thread moss cover at trial initiation and b is the percentage of silvery-thread moss cover at 16 WAIT. Numbers were pooled between locations.

^wA negative value indicates a silvery-thread moss population reduction where a positive value indicates a silvery-thread moss population increase.

^vFisher's protected least significant difference at $P \leq 0.05$.

creeping bentgrass putting greens. Changes can be observed in populations with changing environmental conditions. Burnell et al. (2004) observed fluctuations in non-treated plots and attributed it to the ephemeral nature of silvery-thread moss. We observed a 53% population increase with the non-treated plots. Despite mancozeb plus copper hydroxide applications, silvery-thread moss populations increased 35%. While there seem to be discrepancies between visual control evaluations and population change evaluations, visual control measurements were rated relative to the non-treated control, and the dynamic nature of silvery-thread moss populations explains these discrepancies. However, as previously mentioned, though treatments appear to injure silvery-thread moss surface tissue, residual tissue was able to sustain regrowth. Therefore, population percentages were better indicators of treatment efficacy.

A healthy turf stand is one of the best ways to prevent silvery-thread moss invasion (Cook et al., 2002). Previous research has attributed increased encroachment to lower mowing heights, reduced fertility, and the elimination of mercury-based fungicides (Burnell et al., 2004; Hummel, 1994; Nelson, 2007; Yelverton, 2005). Any stress applied to the turf

resulting in a reduction in stand density and decreased plant vigor can add to the risk of silvery-thread moss encroachment. These data suggest that cultural practices such as N and TD can aid in the control of silvery-thread moss on creeping bentgrass putting greens and can provide as much long-term control as carfentrazone applied alone.

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