Research Reports

Effects of Rolling and Sand Topdressing on Dollar Spot Severity in Fairway Turfgrass

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Additional index words. *Agrostis stolonifera*, annual bluegrass, *Clarireedia jacksonii*, creeping bentgrass, disease, golf course, *Poa annua*

Summary. **Results suggest that sand topdressing was more consistent at reducing dollar spot (*Clarireedia jacksonii*) in fairway turfgrass more so than rolling. This practice could be an effective cost-saving alternative to reduce frequent fungicide applications. Research was conducted from 2011 to 2014 on a simulated golf fairway and examined dollar spot severity responses in a mixed-stand of creeping bentgrass (*Agrostis stolonifera*) and annual bluegrass (*Poa annua* ssp. *reptans*) to sand topdressing and rolling. Treatments consisted of biweekly sand topdressing, rolling at three frequencies (one, three, or five times weekly), a control, and three replications. Infection was visually estimated. Sand topdressing significantly ($P < 0.05$) reduced disease up to 50% at the peak of the dollar spot activity in 2011, 2013, and 2014. Results on the effects of rolling on dollar spot were inconsistent.**

Turfgrass health is a major concern for golf course managers. Dollar spot (Salgado-Salazar et al., 2018; Smiley et al., 1992) is the most common foliar disease in the upper Midwest affecting turfgrass quality and playability resulting in the expenditure of millions of dollars for frequent fungicide applications (Goodman and Burpee, 1991; Vargas, 2005). Although infections can occur in both warm and cool season grasses worldwide, turfgrass managers commonly limit fungicide use due to economic, environmental, and fungicide resistance concerns (Delvalle et al., 2011; Detweiler et al., 1983; Golembiewski et al., 1995; Warren et al., 1974). The increasing cost and probable ban of certain chemical pesticides by the U.S. Environmental Protection Agency (2011) are causing turf managers to seek effective yet inexpensive means to control turf diseases. Research on alternative management strategies has given credence to cultural practices that not only promote plant health, but also are antagonistic to the pathogens (Giordano et al., 2012). Primary cultural practices that optimize fertilization, irrigation, and mowing have been shown to decrease dollar spot (Bennett, 1937; Couch 1962, 1966; Couch and Bloom, 1960; Endo, 1963; Landschoot and McNitt, 1997; Liu et al., 1995; Markland et al., 1969; Williams et al., 1996). Supplementary cultural practices such as sand topdressing effectively reduce dollar spot as well (Skorulski et al., 2010). Perhaps other supplementary cultural practices (cultivation and rolling) could be viable alternatives to chemical pesticide applications, thus decreasing the necessity, extending the efficacy, and reducing possible human exposure to these chemicals (Giordano et al., 2012), so that instead of applying eight to nine fungicide treatments per season at a cost of $16,000 to $27,000 annually on fairways (Turfgrass Producers International, 2011), sand topdressing may alleviate this annual expenditure, and possibly decrease cost per application by 25% to 50%. Although perhaps not as effective as conventional, chemical pest management systems, certain culture practices have proven to be acceptable disease management strategies in terms of playing conditions (Rossi and Grant, 2009).

One of the earliest turf mechanical practices was rolling of the green. It was typically used to smooth surface imperfections, and predated mechanical mowing (Beard et al., 2014). The practice of rolling became routine on sport turfgrass by the turn of the 20th century

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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
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
48.8243	lb/1000 ft^2	kg·ha^{-1}	0.0205
1	meq/100 g	cmol·kg^{-1}	1
1.7300	oz/inch^3	g·cm^{-3}	0.5780
6.8948	psi	kPa	0.1450
82.2960	yard^3/1000 ft^2	m^3·ha^{-1}	0.0122
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

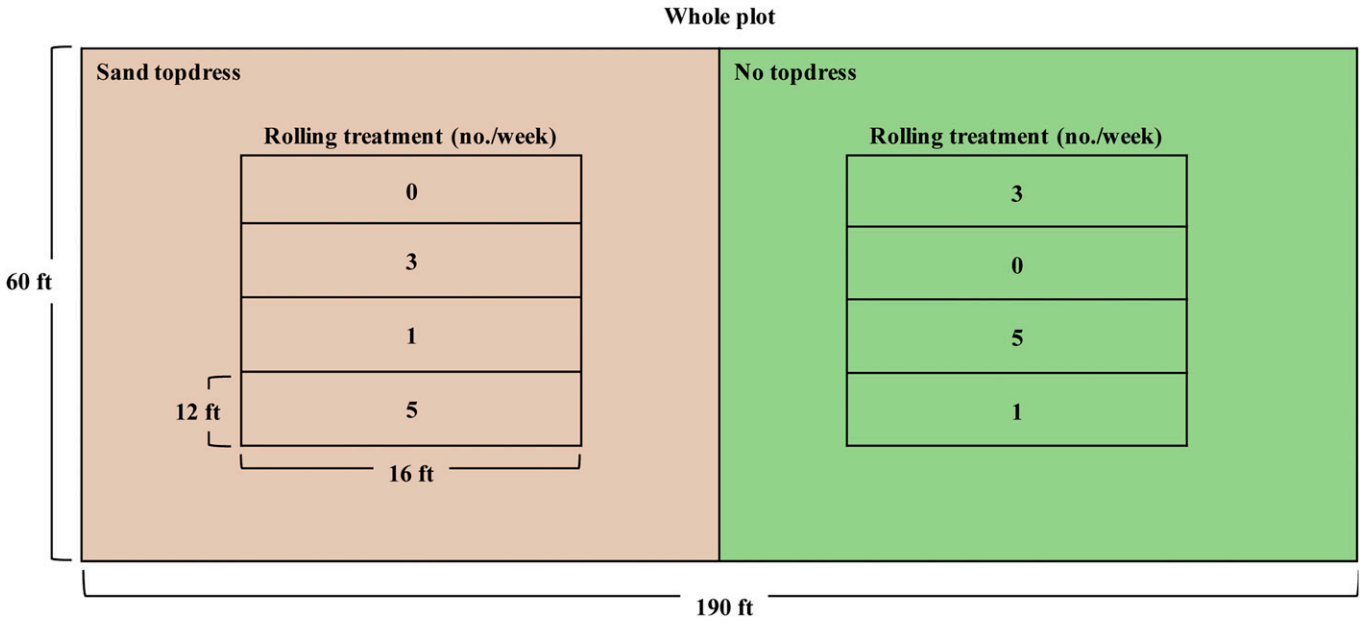

Fig. 1. Diagram of experimental plot used to study the effects of sand topdressing × rolling frequency on dollar spot severity in creeping bentgrass and annual bluegrass (not to scale). A two-way factorial, split-plot randomized complete block was replicated three times. Four subplots were randomized within each whole plot factor and assigned rolling treatments of one, three, and five times weekly plus control. A triplex mower with vibratory rollers [1298 lb (588.8 kg)] and vertical force value of 4.5 psi (31.03 kPa) was used for the rolling treatments. A sand layer of 1.4 inches (3.56 cm) was accumulated over a 4-year period with biweekly sand topdress applications from May to September at 0.14 yard^3/1000 ft^2 (11.521 m^3·ha^{-1}); 1 ft = 0.3048 m.

Table 1. Particle size distribution of sand used to topdress creeping bentgrass and annual bluegrass in 2015.

Particle size [sieve no. (mm)][z]	Distribution (%)
Gravel [10 (2.00)]	0.0
Very coarse sand [18 (1.00)]	5.0
Coarse sand [35 (0.50)]	16.5
Medium sand [60 (0.25)]	44.8
Fine sand [140 (0.105)]	33.3
Very fine sand [270 (0.053)]	0.3
Silt	0.0
Clay	0.1

[z]U.S. standard; silt and clay particle sizes measured by hydrometer method (Soil and Plant Nutrient Laboratory Michigan State University, East Lansing, MI); 1 mm = 0.0394 inch.

(Beard et al., 2014), yet the advent of new mowers in the late 1920s and the fear of compaction led to the decline of rollers and was almost nonexistent until the 1990s for tournament play (Beard et al., 2014). From a modern golf perspective, lightweight rolling has been used to increase ball roll distance (Nikolai et al., 2001) by smoothing the putting green surface. Whether rolling is applied daily or weekly, a device of varying force per unit area (from 6.5 to 14.2 psi) and design configuration (this includes rollers on mowers) is often used on a putting green. In the mid-1990s, researchers discovered that rolling at a frequency of three times weekly reduced dollar spot, and localized dry spot, moss, and broadleaf weeds in creeping bentgrass (Nikolai et al., 2001). Inguagiato et al. (2009) observed that rolling decreased the severity of anthracnose (*Colletotrichum cereale*), whereas Roberts et al. (2012) reported that rolling not only increased ball roll distance, but also reduced anthracnose in annual bluegrass putting greens. These experiments demonstrated that turfgrass edaphic environment and pathogen activity could be affected by rolling practices. However, the mechanisms surrounding the effects of rolling on disease suppression remain unknown.

The objective of the study was to evaluate the efficacy of sand topdressing and rolling on dollar spot severity in a mixed-sward creeping bentgrass and annual bluegrass fairway. Different rolling frequency and sand topdressing treatments were used to garner data that would help validate that dollar spot severity would be decreased by sand topdressing and by rolling.

Materials and methods

Field research on the effects of sand topdressing and rolling on dollar spot severity in fairway turfgrass was conducted May through Oct. 2011 to 2014 at the Hancock Turfgrass Research Center, East Lansing, MI. The experimental site was a mixed-stand simulated golf fairway of 60% creeping bentgrass and 40% annual bluegrass seeded in 2009. The native soil of this site is Capac loam (fine loamy, mixed, mesic Aquic Glossudalfs) with a cation exchange capacity of 15 meq/100 g, pH of 7.8, bulk density of 1.5 g·cm^{-3}, and particle analysis of 50% sand, 24% silt, and 26% clay

The experiment was a two-way factorial, split-plot randomized complete block design with three replications (Fig. 1). The whole plot factor was sand topdressing. Six plots (60 × 95 ft) were either sand topdressed or not topdressed (native soil) with biweekly applications May through September at 0.14 yard^3/1000 ft^2. A sand layer of 1.4 inches

Table 2. Effects of sand topdressing and rolling frequency on dollar spot severity in creeping bentgrass and annual bluegrass in 2011 at East Lansing, MI.

	Dollar spot severity (0% to 100%)							
	19 Aug.	22 Aug.	2 Sept.	10 Sept.	24 Sept.	1 Oct.	8 Oct.	17 Oct.
Topdressing[z]								
Sand topdress	9.5	17.1	21.4	28.8	26.0	19.3	20.5	16.4
Non-topdress	22.8	27.9	37.2	43.2	39.9	40.8	40.1	28.5
Rolling frequency (no./week)[y]								
0	16.0	21.3	34.0 a[x]	39.8	34.0	29.3	31.2	20.3
1	16.5	22.7	31.5 ab	38.2	36.5	32.3	33.7	24.3
3	16.2	24.0	28.3 bc	34.0	33.0	29.8	27.7	24.3
5	15.8	22.0	23.3 c	31.8	28.3	28.7	28.7	20.8
ANOVA[w]								
Topdress (S)	0.0197	0.0243	0.0148	0.0214	0.0980	0.0247	0.0496	0.1170
Rolling frequency (R)	0.7237	0.7811	0.0064	0.0602	0.0773	0.4096	0.0921	0.2417
S × R	0.1114	0.1985	0.0315	0.4361	0.5447	0.5592	0.2942	0.2894

[z]Sand applied biweekly May to September at 0.14 yard^3/1000 ft^2 (11.521 m^3·ha^{-1}); Capac loam (non-topdress): 50% sand, 24% silt, and 26% clay.
[y]Vibratory rollers on triplex mower [1298 lb (588.8 kg)]; vertical force value of 4.5 psi (31.03 kPa).
[x]Mean values within columns separated according to Fisher's protected least significant difference at $P \leq 0.05$.
[w]Mixed factor effects analysis of variance (ANOVA) model in SAS (version 9.4; SAS Institute, Cary, NC) at $P \leq 0.05$.

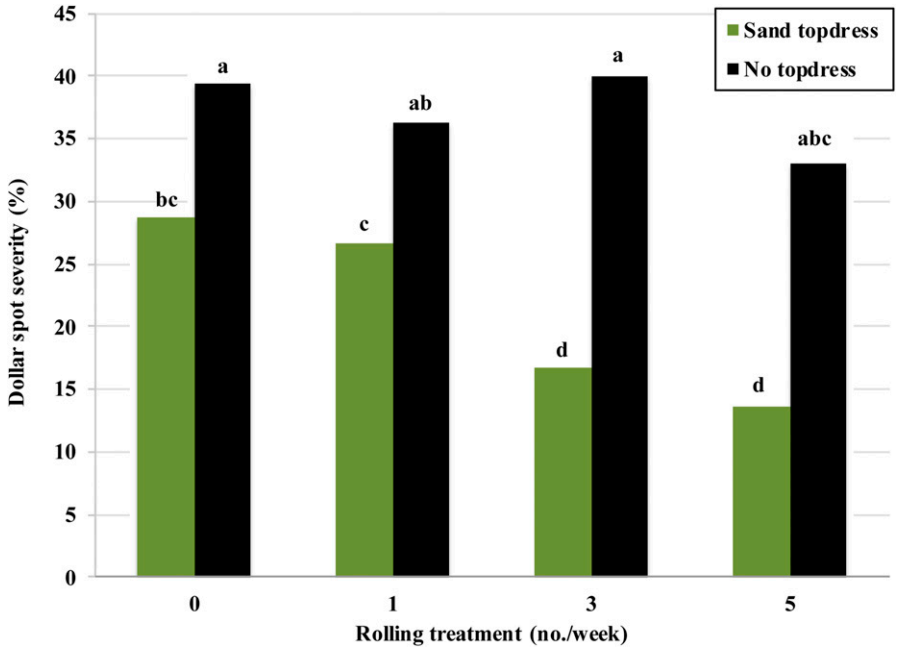

Fig. 2. Effects of sand topdressing × rolling frequency on dollar spot severity in creeping bentgrass and annual bluegrass on 2 Sept. 2011 at East Lansing, MI. A triplex mower with vibratory rollers [1298 lb (588.8 kg)] and vertical force value of 4.5 psi (31.03 kPa) was used for the rolling treatments. A sand layer of 1.4 inches (3.56 cm) was accumulated over a 4-year period with biweekly sand topdress applications from May to September at 0.14 yard^3/1000 ft^2 (11.521 m^3·ha^{-1}). The native soil of the site was Capac loam (non-topdress): 50% sand, 24% silt, and 26% clay. Mean values were separated according to Fisher's protected least significant difference at $P \leq 0.05$.

was accumulated over a 4-year period (Table 1). Four subplots measuring 12 × 16 ft were randomized within each whole plot and assigned rolling treatments of one, three, and five times weekly plus control. A triplex mower (model 2500A; Deere & Co., Moline, IL) with vibratory rollers (Turfline, Moscow, MO) was used in this experiment. This unit had a 5.0-ft swath, vertical force value of 4.5 psi (31.03 kPa), and weighed 1298 lb.

The site was maintained as a typical Michigan golf course fairway, mowed (clippings not collected) three times weekly at 0.5 inch, and if no rain events occurred, 0.15 inch of water was applied in a single irrigation period May through October. Herbicides and insecticides were applied as needed, but fungicides were not applied for the duration of the study. Azoxystrobin was applied only to discourage gray snow mold (*Typhula incarnata*) at the end of each growing season. The site was not core cultivated for the duration of the study to minimize surface disruption and soil displacement.

Liquid and granular fertilizer formulations were used to supply nitrogen (N) and elemental phosphorus (P) and potassium (K) to the site. In 2011, urea fertilizer 46N–0P–0K (3.0 lb/1000 ft^2 N) was used; however, the formulation was substituted for a urea-ammonium nitrate 28N–0P–0K (1.6 lb/1000 ft^2 N) the following season, remaining as such for the duration of this study. Applications of polymer-coated urea (PCU) fertilizer 29N–0P–8.3K (1.25 lb/1000 ft^2 N) were included on 20 July 2013 and 7 June 2014. In addition, a PCU fertilizer 29N–0.9P–7.5K (1.1 lb/1000 ft^2 N) was applied on 29 Aug. 2014.

During the first two seasons of the study, in 2011 and 2012, naturally occurring dollar spot was prevalent, but in 2013 and 2014, the site was artificially inoculated to encourage uniform disease coverage using the Goodman and Burpee (1991) technique. After a 10-d incubation period, this concoction of silica sand, cornmeal, potato dextrose agar, and

Table 3. Effects of sand topdressing and rolling frequency on dollar spot severity in creeping bentgrass and annual bluegrass in 2012 at East Lansing, MI.

	Dollar spot severity (0% to 100%)											
	24 June	6 July	13 July	20 July	28 July	3 Aug.	10 Aug.	18 Aug.	25 Aug.	3 Sept.	8 Sept.	16 Sept.
Topdressing[z]												
Sand topdress	5.9	5.8	5.2	5.7	20.6	16.0	17.1	29.0	15.9	19.1	40.7	17.8
Non-topdress	2.3	2.8	5.4	4.5	16.2	12.8	17.7	23.2	13.8	22.2	39.8	28.8
Rolling frequency (no./week)[y]												
0	1.8	3.8	5.0	3.8	14.8	10.5	13.5 a[x]	22.3	10.7 a	16.7	38.5	22.8
1	5.8	4.5	5.5	6.7	16.8	12.2	14.8 a	25.3	10.8 ab	18.0	39.2	22.0
3	3.8	3.8	5.8	4.5	17.7	16.3	19.3 ab	25.3	16.7 bc	21.8	40.8	25.2
5	4.8	5.0	4.8	5.3	24.2	18.7	21.8 b	31.3	21.3 c	26.0	42.3	23.3
ANOVA[w]												
Topdress (S)	0.0996	0.0711	0.7777	0.4831	0.2892	0.2679	0.8352	0.2161	0.7921	0.5231	0.8201	0.0487
Rolling frequency (R)	0.1986	0.9262	0.8569	0.5567	0.0580	0.0583	0.0373	0.2802	0.0100	0.1081	0.8526	0.6075
S × R	0.5828	0.6350	0.8420	0.8940	0.0892	0.5508	0.6331	0.5444	0.2019	0.6456	0.5283	0.3131

[z]Sand applied biweekly May to September at 0.14 yard^3/1000 ft^2 (11.521 m^3·ha^{-1}); Capac loam (non-topdress): 50% sand, 24% silt, and 26% clay.
[y]Vibratory rollers on triplex mower [1298 lb (588.8 kg)]; vertical force value of 4.5 psi (31.03 kPa).
[x]Mean values within columns separated according to Fisher's protected least significant difference at $P \leq 0.05$.
[w]Mixed factor effects analysis of variance (ANOVA) model in SAS (version 9.4; SAS Institute, Cary, NC) at $P \leq 0.05$.

Table 4. Seasonal precipitation amounts received June to September at the Hancock Turfgrass Research Center, East Lansing, MI.[z]

Yr	Precipitation (inches)[y]
2011	9.76
2012	4.61
2013	11.0
2014	11.3

[z]Lat. 42.7110°N, long. 84.4760°W, elevation 841.8 ft (256.58 m).
[y]Data provided by the Michigan Automated Weather Network and Enviro-weather Program, Michigan State University, East Lansing; 1 inch = 2.54 cm.

dollar spot VCG-B (Powell and Vargas, 2001) inoculum was applied at a rate of 9.0 lb/1000 ft^2 using a drop-spreader (model 36H13; Gandy Co, Owatonna, MN).

Plots were visually rated for dollar spot severity on a 0% (no dollar spot observed) to 100% (entire plot area blighted) scale. Area under the disease progress curve (AUDPC) values were assessed by the following: $\Sigma_{i-1}^{n-1}\left(\frac{y_i+y_i+1}{2}\right)(t_{i+1}-t_i)$, where i = 1, 2, 3…n-1, t is time in days of each reading, y is the percentage of affected foliage at each reading, and n is the number of readings (Campbell and Madden, 1990). Data analysis was conducted using PROC GLIMMIX in SAS software (version 9.4; SAS Institute, Cary, NC). Statistical model for analysis of dollar spot severity data consisted of the fixed effects of sand topdressing and rolling treatments along with their interactions. Normality and equal variance assumptions have been checked using normal probability plots and side-by-side box plots, respectively. When the interaction effects were found to be statistically significant, the interactions were examined using slicing (simple effect tests), and mean separations among the cell means. When the interactions appeared to be spurious or representing differences in magnitude of the studied effects, marginal means were reported and compared. Statistical tests were conducted at 0.05 level of probability. Mean separations were performed based on Fisher's protected least significant difference (Westfall et al., 1999).

Results

Significant main effects of sand topdressing and rolling on dollar spot severity were observed. In 2011, sand topdressing treatment significantly reduced dollar spot severity compared with the non-topdress plots (Table 2). High-frequency rolling reduced dollar spot when compared with the control on 2 Sept. A sand topdressing × rolling frequency interaction was observed in which three and five times weekly rolling treatments in combination with sand topdressing significantly reduced dollar spot (Fig. 2) compared with the once per week rolling treatment.

Main effects of topdressing and rolling frequency were significant in 2012 (Table 3). Sand topdressing reduced dollar spot compared with non-topdress plots on 16 Sept. Contrary to the overall trend observed in 2011, dollar spot was most severe on the plots that received the high-frequency rolling treatments. More so dollar spot pressure was considerably lower in 2012, in part due to high air temperatures and below average precipitation (Table 4) that adversely affected both the fungus and turfgrass despite efforts to supply adequate irrigation amounts to the research site.

Main effects of sand topdressing and rolling frequency were observed on several collection dates in 2013 as well as a significant sand topdressing × rolling frequency interactions (Table 5). When compared with the control, the sand topdressing treatment notably reduced dollar spot severity by 34% and 66% on 21 and 30 Aug., respectively. During this period, ideal climatic conditions for an epidemic of dollar spot were experienced (Table 6). Thus, rolling five times per week resulted in lower dollar spot severity

Table 5. Effects of sand topdressing and rolling frequency on dollar spot severity in creeping bentgrass and annual bluegrass in 2013 at East Lansing, MI.

	Dollar spot severity (0% to 100%)									
	17 June	27 June	12 July	22 July	9 Aug.	21 Aug.	30 Aug.	10 Sept.	20 Sept.	27 Sept.
Topdressing[z]										
Sand topdress	2.5	5.2	29.2	23.8	18.8	11.8	4.3	2.6	3.9	5.6
Non-topdress	1.1	3.9	26.7	24.2	26.3	17.8	12.7	4.7	4.3	8.8
Rolling frequency (no./week)[y]										
0	1.7	3.8	23.3	26.7 a[x]	25.8	20.8 a	12.2 a	4.5	5.0	9.5
1	2.0	4.5	32.5	26.7 a	22.0	14.2 b	8.3 ab	2.8	3.2	5.3
3	2.2	5.3	27.5	24.2 a	22.5	14.7 b	7.8 ab	3.8	5.3	8.3
5	1.3	4.5	23.3	18.3 b	19.7	9.7 c	5.7 b	3.3	3.0	5.7
ANOVA[w]										
Topdress (S)	0.1349	0.2806	0.6089	0.7457	0.0822	0.0432	0.0250	0.1095	0.5846	0.1819
Rolling frequency (R)	0.8466	0.6742	0.0616	0.0163	0.3486	0.0010	0.0532	0.4013	0.1384	0.0688
S × R	0.8985	0.8667	0.3735	0.5596	0.4625	0.0528	0.9839	0.7076	0.8650	0.6860

[z]Sand applied biweekly May to September at 0.14 yard^3/1000 ft^2 (11.521 m^3·ha^{-1}); Capac loam (non-topdress): 50% sand, 24% silt, and 26% clay.
[y]Vibratory rollers on triplex mower [1298 lb (588.8 kg)]; vertical force value of 4.5 psi (31.03 kPa).
[x]Mean values within columns separated according to Fisher's protected least significant difference at $P \leq 0.05$.
[w]Mixed factor effects analysis of variance (ANOVA) model in SAS (version 9.4; SAS Institute, Cary, NC) at $P \leq 0.05$.

Table 6. Seasonal climatic conditions at the Hancock Turfgrass Research Center in 2013 at East Lansing, MI.[z]

	Air temp (°F)[y]		Precipitation	Relative humidity (%)	
Date	Maximum	Minimum	(inches)[y]	Maximum	Minimum
20 Aug.	83.5	58.6	—	91.5	22.9
21 Aug.	84.6	63.5	—	89.7	42.8
22 Aug.	79.0	64.2	0.22	90.0	56.9
23 Aug.	80.6	59.0	—	88.1	21.4
24 Aug.	81.3	52.7	—	92.8	33.8
25 Aug.	83.8	56.7	—	91.5	47.5
26 Aug.	83.5	68.0	—	86.4	57.7
27 Aug.	89.4	69.6	1.70	92.5	62.1
28 Aug.	82.2	66.7	1.40	92.8	58.0
29 Aug.	88.3	61.5	—	94.1	42.0
30 Aug.	85.1	66.4	0.13	90.7	54.0

[z]Lat. 42.7110°N, long. 84.4760°W, elevation 841.8 ft (256.58 m).
[y]Data provided by the Michigan Automated Weather Network and Enviro-weather Program, Michigan State University, East Lansing; (°F – 32) ÷ 1.8 = °C, 1 inch = 2.54 cm.

in comparison with the control and the one and three time weekly rolling treatments on 22 July and 21 Aug. Furthermore, as rolling frequency increased on the sand topdressed plots, dollar spot severity was drastically reduced compared with the non-topdressed plots that received similar rolling treatments (Fig. 3).

Significant main effects of sand topdressing were observed in 2014; however, rolling frequency results were not significant. Only one collection date was observed in which sand topdressing reduced disease by 46% compared with the control (Table 7).

The AUDPC was calculated for 2011 to 2014 (Table 8). Main and interaction effects of sand topdress and rolling frequency were significant in 2011. Plots that were sand topdressed and rolled either three or five times weekly had less dollar spot compared with non-topdress plots with similar rolling treatments (Fig. 4). Sand topdressing decreased dollar spot when compared with the non-topdress plots. Subsequent seasons did not result in significant treatment effects.

Discussion

Results from our study were similar to Skorulski et al. (2010), in which sand topdressing reduced dollar spot severity and increased turfgrass quality, color, and density in a fairway turf. Others have observed significant reductions of anthracnose in annual bluegrass fairway plots with regular sand topdressing (Hempfling et al., 2015). Some researchers have speculated that the sand particle shape and topdressing incorporation method exacerbate turf disease severity response, but Inguagiato et al. (2013) found that neither the sand shape nor the method of incorporation enhanced anthracnose severity. More so they noticed that routine sand topdressing reduced anthracnose severity in annual bluegrass putting greens. In another study, Inguagiato et al. (2012) found that comparatively low sand rates applied at short intervals substantially reduced anthracnose. Perhaps these seasonal accumulations of sand topdressing not only dilute thatch (Beard, 1973; Ledeboer and Skogley, 1967), but also dilute the fungal stroma of dollar spot, the primary means of pathogen survival and dissemination (Vargas, 2005). Some speculate that sand topdressing produces a favorable microclimate for thatch decomposition within the turf canopy and upper rhizosphere (Ledeboer and Skogley, 1967). Dilution of this thatch layer (McCarty et al., 2005) also has been shown to be an important aspect in dealing with the accumulation of this substance (Couillard et al., 1997), in which excessive amounts have been attributed to numerous turfgrass deficiencies such as increased localized dry spot (Cornman, 1952), intensified disease incidence (Beard, 1973; Murray and Juska, 1977), and adversely affected water infiltration rates (Murray and Juska, 1977).

Despite claims that rolling and sand topdressing significantly reduce

turf disease severity (Inguagiato et al., 2009; Nikolai et al., 2001; Skorulski et al., 2010), the effects of rolling on dollar spot severity were inconsistent in this study. Nevertheless, sand topdressing was more consistent at reducing dollar spot severity in turf plots. There is a dearth of research addressing lightweight rolling effects on fairway turf, particularly the mechanism involved in dollar spot suppression. Major differences between turf found in fairways and putting greens include the height and frequency of cut, and the intensity of cultural practices that affect thatch accumulations. In most circumstances, a putting green will have less thatch. Therefore, rolling intensity and/or the mechanical forces involved in rolling fairways might have to be greater to affect this edaphic environment. Many people believe leaf exudate (guttation) and dew that accumulate on the leaf surface provide sustenance for diseases such as brown patch and dollar spot (Monteith and Dahl, 1932; Williams et al., 1996). Consequently, most golf course superintendents regularly remove dew from the turf surface using many different techniques, such as dragging, whipping, rolling, or irrigation (Vargas, 2005). Nevertheless, researchers have reported that displacement of leaf surface moisture has some effect on disease incidence, and dew removal by mechanical wiping of foliage, and morning mowing not only reduces brown patch in perennial ryegrass [*Lolium perenne* (Settle et al., 2001)], but also reduces dollar spot in creeping bentgrass (Delvalle et al., 2011; Williams et al., 1996).

Perhaps rolling affects soil porosity (Ball et al., 1988; Beard, 1973) and matric potential (Hillel, 1998) with sand-based root zones benefiting from these compaction

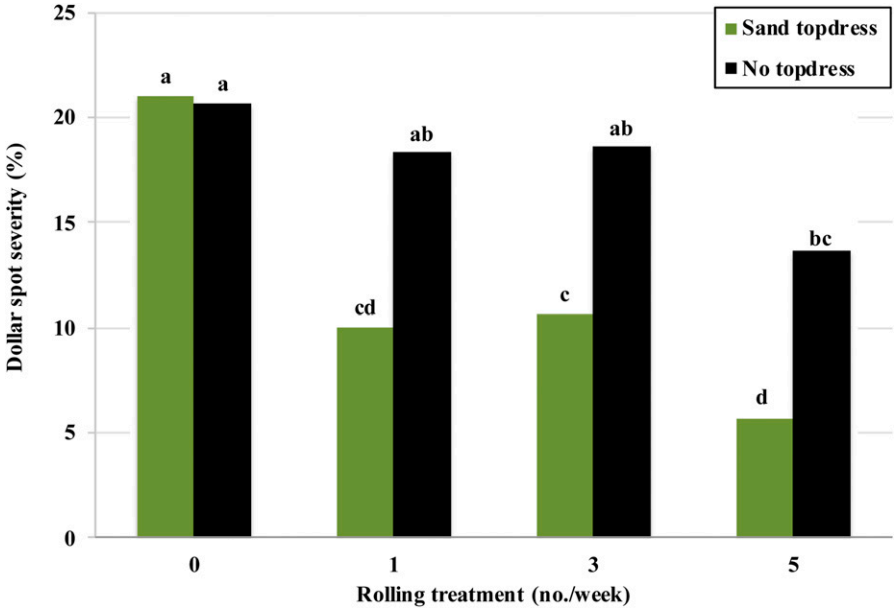

Fig. 3. Effects of sand topdressing × rolling frequency on dollar spot severity in creeping bentgrass and annual bluegrass on 21 Aug. 2013 at East Lansing, MI. A triplex mower with vibratory rollers [1298 lb (588.8 kg)] and vertical force value of 4.5 psi (31.03 kPa) was used for the rolling treatments. A sand layer of 1.4 inches (3.56 cm) was accumulated over a 4-year period with biweekly sand topdress applications from May to September at 0.14 yard^3/1000 ft^2 (11.521 m^3·ha^{-1}). The native soil of the site was Capac loam (non-topdress): 50% sand, 24% silt, and 26% clay. Mean values were separated according to Fisher's protected least significant difference at $P \leq 0.05$.

Table 7. Effects of sand topdressing and rolling frequency on dollar spot severity in creeping bentgrass and annual bluegrass in 2014 at East Lansing, MI.

	Dollar spot severity (0% to 100%)											
	26 June	4 July	11 July	17 July	28 July	4 Aug.	11 Aug.	18 Aug.	25 Aug.	2 Sept.	9 Sept.	19 Sept.
Topdressing[z]												
Sand topdress	4.8	18.3	15.0	14.3	3.3	6.0	5.7	10.3	5.8	7.6	9.1	1.2
Non-topdress	2.5	10.8	9.2	10.3	4.9	7.7	11.1	11.1	10.8	7.7	8.9	1.3
Rolling frequency (no./week)[y]												
0	3.2	17.5	12.5	13.2	4.8	8.5	10.0	12.5	9.7	8.3	9.5	1.7
1	5.5	13.3	10.0	10.3	3.3	6.0	7.5	10.0	7.2	7.8	9.0	1.0
3	3.0	14.2	15.0	15.8	5.7	8.2	9.7	11.7	9.3	7.8	9.5	1.3
5	2.8	13.3	10.8	9.7	2.7	4.7	6.3	8.5	6.8	6.5	8.0	1.0
ANOVA[x]												
Topdress (S)	0.2620	0.0946	0.1102	0.1624	0.2009	0.2881	0.0719	0.4714	0.0481	0.9241	0.9070	0.7651
Rolling frequency (R)	0.2217	0.7050	0.4904	0.0810	0.0626	0.0967	0.1165	0.1521	0.2333	0.6711	0.8012	0.7012
S × R	0.5326	0.6898	0.5627	0.1229	0.2137	0.4519	0.2095	0.4524	0.6667	0.8188	0.5690	0.9446

[z]Sand applied biweekly May to September at 0.14 yard^3/1000 ft^2 (11.521 m^3·ha^{-1}); Capac loam (non-topdress): 50% sand, 24% silt, and 26% clay.
[y]Vibratory rollers on triplex mower [1298 lb (588.8 kg)]; vertical force value of 4.5 psi (31.03 kPa).
[x]Mixed factor effects analysis of variance (ANOVA) model in SAS (version 9.4; SAS Institute, Cary, NC) at $P \leq 0.05$. Mean values within columns, if shown with letters, separated according to Fisher's protected least significant difference at $P \leq 0.05$.

Table 8. Effects of sand topdressing and rolling frequency on the area under the disease progress curve (AUDPC) for the severity of dollar spot in creeping bentgrass and annual bluegrass at East Lansing, MI.

	AUDPC[z]			
	2011	2012	2013	2014
Topdressing[y]				
Sand topdress	1228	1406	1255	725
Non-topdress	2088	1306	1515	698
Rolling frequency (no./week)[x]				
0	1736 a[w]	1141	1605	805
1	1790 a	1265	1410	649
3	1623 ab	1403	1406	808
5	1484 b	1615	1118	586
ANOVA[v]				
Topdress (S)	0.0166	0.7854	*[u]	0.8194
Rolling frequency (R)	0.0136	0.1076	*	0.1201
S × R	0.0178	0.5124	*	0.4287

[z]AUDPC = Σ {[(rating$_1$ + rating$_2$) ÷ 2] × [difference of days between rating$_2$ and rating$_1$]} for the total rating period.
[y]Sand applied biweekly May to September at 0.14 yard^3/1000 ft^2 (11.521 m^3·ha^{-1}); Capac loam (non-topdress): 50% sand, 24% silt, and 26% clay.
[x]Vibratory rollers on triplex mower [1298 lb (588.8 kg)]; vertical force value of 4.5 psi (31.03 kPa).
[w]Mean values within column separated according to Fisher's protected least significant difference at $P \leq 0.05$.
[v]Mixed factor effects analysis of variance (ANOVA) model in SAS (version 9.4; SAS Institute, Cary, NC) at $P \leq 0.05$.
[u]Data did not converge in mixed factor ANOVA model.

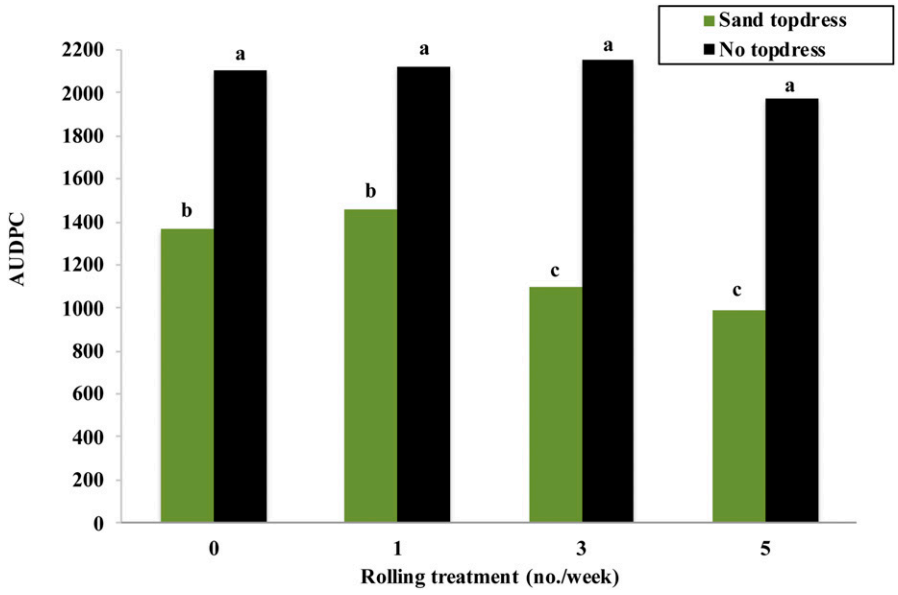

Fig. 4. Effects of sand topdressing × rolling frequency on the area under the disease progress curve (AUDPC) for the severity of dollar spot in creeping bentgrass and annual bluegrass in 2011 at East Lansing, MI. A triplex mower with vibratory rollers [1298 lb (588.8 kg)] and vertical force value of 4.5 psi (31.03 kPa) was used for the rolling treatments. A sand layer of 1.4 inches (3.56 cm) was accumulated over a 4-year period with biweekly sand topdress applications from May to September at 0.14 yard^3/1000 ft^2 (11.521 m^3·ha^{-1}). The native soil of the site was Capac loam (non-topdress): 50% sand, 24% silt, and 26% clay. Mean values were separated according to Fisher's protected least significant difference at $P \leq 0.05$.

operations (Giordano et al., 2012; Nikolai et al., 2001). Studies have shown that sand textured (80% sand, 10% peat, 10% soil) plots that were rolled had increased percentage of water retention in comparison with the nonrolled plots (Nikolai et al., 2001). Therefore, mechanisms by which rolling is suppressive to the dollar spot pathogen could be the effect of soil moisture levels mitigating drought-stress–related disease epidemics (Couch, 1966; Couch and Bloom, 1960; Dykema, 2014), or the effect of beneficial microorganisms that proliferate in the turfgrass edaphic environment, as proposed by Giordano et al. (2012). Moreover, our observations support earlier statements that drought-stressed turf is more susceptible to a variety of turf diseases that, in effect, cause a noticeable decrease of turfgrass quality (Couch, 1966; Couch and Bloom, 1960). It is still arguable as to how certain cultural practices affect turfgrass diseases. In an unpublished research study, we combined sand topdressing and rolling with a fungicide to investigate probable decreases in annual fungicide usage and deduced that sand topdressing alone or in combination with a fungicide could be a viable alternative for controlling dollar spot in a golf course fairway. Although it may not be prudent to compare the cost and control equivalent of synthetic fungicides to that of sand topdressing, in regions with pesticide restrictions, any degree of disease suppression is better than none.

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