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Evaluation of Calcium Silicate for Brown Patch and Dollar Spot Suppression on Turfgrasses

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ABSTRACT

Nonfungicide alternatives for control of brown patch (caused by *Rhizoctonia solani* Kühn) and dollar spot (caused by *Sclerotinia homoeocarpa* F.T. Bennett) diseases are needed. Calcium silicate ($CaSiO_3$) was applied as a topdressing (2440 or 4880 kg ha^{-1}) to evaluate brown patch suppression in 'Bonsai 2000' and 'Tar Heel' tall fescue (*Festuca arundinacea* Schreb.) and 'L-93' creeping bentgrass (*Agrostis palustris* Huds.) in the field, or amended into soil at 7325 or 14 650 kg ha^{-1} to evaluate dollar spot on 'Penncross' creeping bentgrass in a growth chamber. The Chase silty clay loam (fine, montmorillonitic, mesic Aquic Argiudoll) under tall fescue had a pH of 6.4, a high initial Si content (173 mg kg^{-1}), and Si accumulation in leaves was minimal (one of five observations). Calcium silicate applied at 2440 kg ha^{-1} increased the area under disease progress curves (AUDPC) for brown patch by 26% in 2002 and 30% (both rates) in 2003. Tall fescue leaf P and K concentrations were reduced by $CaSiO_3$ and were negatively correlated ($r = -0.41$ for P; -0.44 for K; $P < 0.02$) with brown patch. Calcium silicate topdressing increased Si in creeping bentgrass leaf tissue as well as the sand root zone, which initially contained <12 mg kg^{-1} Si. A positive correlation ($r = 0.81$; $P < 0.001$) occurred between creeping bentgrass leaf Si concentration and brown patch severity in one of three years, which may have resulted from reduced leaf P and K after $CaSiO_3$ application. The silty clay loam (170 mg kg^{-1} Si) amended with $CaSiO_3$ before planting creeping bentgrass had no effect on leaf Si concentrations or dollar spot incidence. Thus, $CaSiO_3$ application to soil containing adequate Si should not be recommended for control of brown patch on tall fescue, nor should $CaSiO_3$ be recommended to control brown patch on creeping bentgrass grown on low Si soil or dollar spot on high Si soil. In fact, $CaSiO_3$ application may exacerbate brown patch disease incidence possibly because of nutrient imbalances, particularly in tall fescue.

Tall fescue is widely used for home lawns, sport fields, golf course roughs, and utility areas, because of its heat and drought resistance and ease of establishment. Some of the improved turf-type tall fescue cultivars are more susceptible to brown patch than pasture-type cultivars are (Yuen et al., 1994). Preventive fungicide regimes for brown patch suppression in tall fescue home lawns often cost more than customers are willing to spend. Curative control strategies are somewhat ineffective because significant damage is evident before an application can be made (Settle et al., 2001). In addition, frequent labor-intensive scouting is also necessary for a curative brown patch control program to be effective. Therefore, alternatives to traditional fungicide applications would be useful.

Creeping bentgrass is the primary turfgrass used for golf course putting greens. However, it is highly susceptible to dollar spot and brown patch and fungicides are commonly used for preventive control. As environmental stewards, golf course superintendents are interested in identifying potential avenues for reducing creeping bentgrass fungicide requirements.

One potential tool for reducing fungicide requirements in tall fescue and creeping bentgrass may be the use of Si fertilizers. Silicon has been reported to suppress some diseases on various crops in the last decade (Raid et al., 1992; Chérif et al., 1994; Deren et al., 1994; Seebold et al., 2000, 2001). Only recently has work been done to evaluate the potential efficacy of Si on turfgrass disease control. Researchers in North Carolina found that brown patch and dollar spot on creeping bentgrass were reduced approximately 20 and 30%, respectively, when soluble potassium silicate (20.7% SiO_2) at 25 kg ha^{-1} was applied (Uriarte et al., 2004). Gray leaf spot [*Pyricularia grisea* (Cooke) Sacc.] on St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze.] was reduced 9 to 28% by Si applied alone at 1000 kg ha^{-1} and was reduced 59 to 68% by the combination of Si and the fungicide chlorothalonil (2,4,5,6-tetrachloroisophthalonitrile) at 1.3 kg ha^{-1} (Brecht et al., 2004).

Mechanisms by which Si confers disease suppression have not been well defined. A common hypothesis regarding Si efficacy is that it creates a physical barrier to restrict fungal hyphae penetration (Kim et al., 2002). As an alternative, Si may induce accumulation of antifungal compounds (Chérif et al., 1992a, 1992b), such as flavonoid and diterpenoid phytoalexins (Rodrigues et al., 2003, 2004) that degrade fungal and bacterial cell walls.

The objective of this experiment was to evaluate the efficacy of $CaSiO_3$ for brown patch reduction on creeping bentgrass and tall fescue and dollar spot suppression on creeping bentgrass.

MATERIALS AND METHODS

Tall Fescue

Field Experiment

Tar Heel (relatively brown patch resistant) and Bonsai 2000 (relatively brown patch susceptible) (National Turfgrass Evaluation Program [NTEP], 2002) tall fescue were seeded at 342 kg ha^{-1} in September 2001 at the Rocky Ford Turfgrass Research Center in Manhattan, KS. The soil contained 41 mg

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Abbreviations: AUDPC, area under disease progress curves.

kg^{-1} of P (HCl–ammonium fluoride extractant) and 367 mg kg^{-1} of K (ammonium acetate extractant) using standard procedures for the north central region of the United States (Brown, 1998). Turf was mowed at 7.5 cm twice weekly and watered as needed. Urea (46–0–0) was applied to provide N at 49 kg ha^{-1} on 17 Apr., 3 May, and 18 Sept., 2002; and on 5 and 29 May and 22 Sept., 2003.

This experiment was set up as a split-plot design with four replications. Whole-plot (3.1 by 12.2 m) treatments consisted of the two cultivars, and subplots (2.1 by 3.0 m) consisted of untreated tall fescue, turf treated with $CaSiO_3$ at 2440 or 4880 kg ha^{-1}, and turf receiving flutolanil [*N*-(3-(1-methylethoxy)phenyl)-2-(trifuoromethyl)benzamide] at 4.8 kg a.i. ha^{-1}. Calcium silicate was applied at label rates, 0.35 and 0.7 times the common elemental Si application rate for rice (*Oryza sativa* L.) grown on soil with Si $\leq$ 19 mg kg^{-1} (Korndörfer et al., 2001). Calcium silicate (31% SiO_2, 22% Ca, 3% Mg, and 4% S) (Calcium Silicate Corporation, Inc., Lake Harbor, FL) was uniformly applied by using a hand-held shaker bottle on 29 May and 10 Oct. 2002, and on 14 May and 29 Sept. 2003. Flutolanil was applied on a 21-d interval with a CO_2–pressurized sprayer at 207 kPa in water equivalent to 794 L ha^{-1} from 29 May to 30 Sept. 2002 and from 1 June to 30 Sept. 2003.

Data were collected on turfgrass visual quality; leaf N, P, K, and Ca concentrations; and Si concentration in leaves and soil. Turfgrass visual quality was rated once weekly on a 0-to-9 scale, where 0 = dead turf; 6 = acceptable quality for a home lawn; and 9 = optimum color, density, and uniformity. The percentage of each plot infected with brown patch was rated visually each week on a 0-to-100% scale. The seasonal data for disease were also analyzed using the AUDPC (Campbell and Madden, 1991).

Leaf nutrient concentration was determined by collecting clippings with a rotary mower on 2 Aug. and 10 Oct. 2002 and on 14 May, 20 Aug., and 5 Oct. 2003. Nitrogen, P, and K in plant tissue were measured using the method described by Linder and Harley (1942) and Thomas et al. (1967). Ammonia and P were analyzed with a Technicon Auto Analyzer II (TechniCon Systems, Inc., Tarrytown, NY.). Potassium was determined by using a Flame AA Spectrophotometer (Perkin-Elmer, Inc., Norwalk, CT). Calcium was measured according to the method described by Gieseking et al. (1935) and analyzed by using an inductively coupled plasma (ICP) spectrometer (Fisons-ARL Accuris, Ecublens, Switzerland). Foliar Si concentration was determined following the method described by Elliott and Snyder (1991).

Four soil cores (1.5-cm diam. and 7 cm deep) were randomly sampled in each plot on the same dates as leaf tissue sampling in 2003 with a soil sampler and mixed in a plastic container for Si analysis. Soil Si concentration was determined according to the method described by Korndörfer et al. (2001).

Creeping Bentgrass

Field Experiment

This experiment was conducted on a L-93 creeping bentgrass nursery putting green at the Kansas City Country Club in Mission Hills, KS. L-93 creeping bentgrass was seeded at 74 kg ha^{-1} in March 2002 on a sand-based putting green constructed to USGA specifications. Soil pH was 6.9 and P and K concentrations were 20 and 25 mg kg^{-1}, respectively (Brown, 1998). Nitrogen from a granular fertilizer composed primarily of urea was applied at 25 kg N ha^{-1} on 29 Mar., 15 and 24 Apr., 14 May, 5 July, 26 Aug., and 17 Sept. 2002; on 12 May, 16 June, and 10 Sept. 2003; and on 8 Apr., 18 May, and 2 Sept. 2004. A soluble 10–1–4 (N–P–K) fertilizer (Daniels Plant Food, Inc., Sherman, TX) was applied at 5 kg N ha^{-1} on 26 Mar., 7 and 22 Apr., and 5 Sept. 2003. A soluble 18–0–2 (N–P–K, Primos Products, Inc., Medford, NJ) was applied at the same rate on 30 Apr., 22 May, 27 June, 11 and 23 July, 20 Aug., and 5 and 15 Sept. 2003; and on 25 Mar., 1 and 21 Apr., 7 and 24 May, 7 and 21 June, 9 and 22 July, and 12 and 20 Aug. 2004. Turf was mowed at 3 mm every other day and watered as needed. The research area was spiked to an 8-mm depth on 17 June, 15 July, 5 Aug., and 5 Sept. 2002; 21 May, 4 and 23 June, 21 July, and 11 Aug. 2003; and on 28 June, 19 July, and 10 Aug. 2004.

Experimental design was a randomized complete block with four replications. Treatments consisted of untreated plots and $CaSiO_3$, as described previously, applied at 2440 or 4880 kg ha^{-1} uniformly by using a hand-held shaker bottle on 24 May and 26 Sept. 2002; 4 Apr. and 15 Aug. 2003; and 4 May 2004. Before $CaSiO_3$ application, the study area was core aerified (2-cm diam., 8 cm deep) with a Greens 09120 aerator (The Toro Company, Bloomington, MN).

Data were collected on turfgrass visual quality; brown patch and dollar spot severity; amounts of N, P, K, Ca, and Si in

Table 1. Brown patch disease as influenced by $CaSiO_3$ topdressing and the fungicide flutolanil in Bonsai 2000 and Tar Heel tall fescue at Manhattan, KS, in 2002.

	Brown patch (%)†															
	June	July				August					September				October	
Treatment	28	5	12	19	26	2	9	16	23	30	6	13	20	27	4	AUDPC‡
Whole plot																
Bonsai 2000	0	7	8	6	6	4	4	6	5	8	8	3 a	2	2	0	68
Tar Heel	0	6	8	6	5	4	5	5	5	6	7	2 b	1	2	0	60
Subplot																
Untreated	0	7 b¶	10 a	8 a	5 b	5 a	5 b	7 ab	6 a	8 b	10 a	3 a	2 a	2 a	0	77 b
$CaSiO_3$, 2440 kg ha^{-1}§	0	8 b	11 a	8 a	7 ab	5 a	5 b	4 bc	6 a	11 a	10 a	3 a	2 a	2 a	0	81 b
$CaSiO_3$, 4880 kg ha^{-1}§	0	11 a	12 a	8 a	8 a	5 a	7 a	10 a	7 a	9 ab	10 a	3 a	2 a	3 a	0	96 a
Flutolanil, 4.8 kg a.i. ha^{-1}	0	0 c	0 b	0 b	0 c	0 b	0 c	1 c	0 b	0 c	0 b	0 b	0 b	0 b	0	3 c
ANOVA																
Whole plot	NS#	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
Subplot	NS	*	*	*	*	*	*	*	*	*	*	*	*	*	NS	*
Whole plot × Subplot	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS

* Significant at $P \leq 0.05$.
† Percentage of plot area infected with brown patch was rated visually on a 0-to-100% scale.
‡ Area Under the Disease Progression Curve (AUDPC) represents brown patch on 15 dates between 28 June and 4 Oct. 2002.
§ Calcium silicate was applied as topdressing at 2400 or 4880 kg ha^{-1} on 29 May and 10 Oct. 2002.
¶ Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).
\# NS, not significant.

Table 2. Brown patch disease as influenced by $CaSiO_3$ topdressing and the fungicide flutolanil in Bonsai 2000 and Tar Heel tall fescue at Manhattan, KS, in 2003.

	Brown patch (%)†													
	July					August				September				
Treatment	4	11	18	25	31	8	15	22	29	5	12	19	26	AUDPC‡
Whole plot														
Bonsai 2000	0	19	27	31	29	25 a	30 a	34 a	37 a	32 a	23	4	0	286 a
Tar Heel	0	15	22	24	27	17 b	19 b	23 b	29 b	22 b	16	3	0	214 b
Subplot														
Untreated	0	20 a¶	29 a	35 a	31 a	22 a	25 b	30 b	33 b	28 b	15 ab	4	0	263 b
$CaSiO_3$, 2440 kg ha^{-1}§	0	23 a	34 a	37 a	35 a	29 a	35 a	39 a	46 a	38 a	26 a	5	0	342 a
$CaSiO_3$, 4880 kg ha^{-1}§	0	21 a	31 a	38 a	39 a	28 a	33 ab	38 ab	44 a	36 a	26 a	6	0	332 a
Flutolanil, 4.8 kg a.i. ha^{-1}	0	4 b	5 b	3 b	8 b	4 b	7 c	7 c	9 c	7 c	9 b	1	0	64 c
ANOVA														
Whole plot	NS#	NS	NS	NS	NS	*	*	*	*	*	NS	NS	NS	*
Subplot	NS	*	*	*	*	*	*	*	*	*	*	NS	NS	*
Whole plot × Subplot	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at $P \leq 0.05$.
† Percentage of plot area infected with brown patch was rated visually on a 0-to-100% scale.
‡ Area Under the Disease Progression Curve (AUDPC) represents over 13 dates between 4 July and 26 Sept. 2003.
§ Calcium silicate was applied as topdressing at 2400 or 4880 kg ha^{-1} on 29 May and 10 Oct. 2002 and 14 May and 29 Sept. 2003.
¶ Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).
# NS, not significant.

leaves; and Si concentrations in soil. Turfgrass visual quality was rated on a 0-to-9 scale, where 0 = dead turf; 7 = acceptable quality for a putting green; and 9 = optimum color, density, and uniformity. Percentage of brown patch–infected plot area was rated visually on a 0-to-100% scale. Visual quality and brown patch infection were measured once in August in 2002 and 2003 and in July 2004 when brown patch was most active in the field. Dollar spot was observed only in July 2004; on that occasion, the number of *S. homoeocarpa* infection centers in each plot was counted and converted to number per square meter. Clippings were collected for tissue testing by using a walk-behind reel mower on 19 July and 26 Sept. 2002; on 4 April, 15 Aug., and 29 Sept. 2003; and on 4 May and 19 July 2004. Soil was sampled on the same dates in 2003 and 2004 as described in the tall fescue experiment, and nutrient contents in tissue and soil were measured as described previously. Soil was sampled in November 2003 at a 1-cm depth to determine effects of $CaSiO_3$ application on surface pH.

Growth Chamber Experiment

A silty clay loam soil with a pH of 7.0, 141 mg kg^{-1} of P, and 545 mg kg^{-1} of K was collected from the Rocky Ford Turfgrass Research Center in Manhattan, KS. Soil was air dried for about 4 wk, uniformly amended with $CaSiO_3$ at 0, 7325, and 14 650 kg ha^{-1}, and used to fill 10-cm diam. by 20-cm deep PVC containers (1.9 kg of the mixture was put in each container). Penncross creeping bentgrass was seeded at 49 kg ha^{-1} in the greenhouse on 8 Jan. 2003. Temperature in the greenhouse averaged 20°C. Turf was mowed at 1.4 cm and watered every other day. Water-soluble N (8% ammoniacal and 12% NO_3–N) was applied at 25 kg N ha^{-1} on 8 Jan. and 27 Feb. 2003. On 25 Mar. 2003, turf was transferred into a growth chamber set to provide 12 h light/dark cycles, a temperature of 25°C, and 60% humidity 4 d before *S. homoeocarpa* inoculation. Experimental units were arranged in a randomized complete block design with five replications.

Oats infested with *S. homoeocarpa*, isolated from creeping bentgrass at Manhattan, KS, were air dried in a flow hood for 8 h and ground in a blender to pass an 850-μm sieve. Creeping bentgrass leaves were misted with distilled water, uniformly dusted with 0.1 g infested oat particles, and placed in the growth chamber at a constant 25°C and 100% humidity in the dark for 24 h. After gently washing off the remaining oat inoculum with distilled water, containers were moved into a greenhouse and air dried for 48 h. Measurements were taken

Table 3. Bonsai 2000 and Tar Heel tall fescue visual quality as influenced by $CaSiO_3$ topdressing and the fungicide flutolanil at Manhattan, KS, in 2002 and 2003.†

	2002			2003		
Treatment	July	August	September	July	August	September
Whole plot						
Bonsai 2000	6.3	5.9	7.3	5.6	5.3 b	7.0
Tar Heel	6.3	6.0	7.3	5.8	5.8 a	7.0
Subplot						
Untreated	6.0	5.9 b§	7.0	5.4 b	5.4 b	7.0
$CaSiO_3$, 2440 kg ha^{-1}‡	6.0	5.6 b	7.0	5.1 b	4.9 c	6.5
$CaSiO_3$, 4880 kg ha^{-1}‡	6.0	5.3 b	7.0	5.1 b	4.9 c	6.5
Flutolanil, 4.8 kg a.i. ha^{-1}	7.0	7.1 a	8.0	7.3 a	6.9 a	7.0
ANOVA						
Whole plot	NS¶	NS	NS	NS	*	NS
Subplot	NS	*	NS	*	*	NS
Whole plot × subplot	NS	NS	NS	NS	*	NS

* Significant at $P \leq 0.05$.
† Tall fescue visual quality was rated on a scale of 0 to 9, where 0 = dead, 6 = acceptable quality for home lawn, and 9 = optimum color, density, and uniformity.
‡ Calcium silicate was applied at 2400 or 4880 kg ha^{-1} on 29 May and 10 Oct. 2002 and on 14 May and 29 Sept. 2003.
§ Means (an average of four weekly ratings in each month) within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).
¶ NS, not significant.

Table 4. Calcium and Si concentrations in Bonsai 2000 and Tar Heel tall fescue leaves as influenced by $CaSiO_3$ topdressing and the fungicide flutolanil at Manhattan, KS, in 2002.

	2 August		10 October	
Treatment	Ca	Si	Ca	Si
	mg kg^{-1}			
Whole plot				
Bonsai 2000	7610	23500	5900	18200
Tar Heel	8300	25100	6200	18500
Subplot				
Untreated	8100 a‡	25500	5000 b	18600
$CaSiO_3$, 2440 kg ha^{-1}†	8200 a	22900	7900 a	18900
$CaSiO_3$, 4880 kg ha^{-1}†	8000 a	24700	6300 ab	18400
Flutolanil, 4.8 kg a.i. ha^{-1}	7500 b	24100	4900 b	17300
ANOVA				
Whole plot	NS§	NS	NS	NS
Subplot	*	NS	*	NS
Whole plot*subplot	NS	*	NS	NS

* Significant at $P \leq 0.05$.
† Calcium silicate was applied at 2400 or 4880 kg ha^{-1} on 29 May and 10 Oct. 2002.
‡ Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).
§ NS, not significant.

once after the pots were air dried in the greenhouse. The pots were then put back into the growth chamber at 25°C and 100% humidity in the dark for another 24 h and air dried for 48 h in the greenhouse.

Data were collected on the percentage of dollar spot damage after air-drying procedures on 1 and 5 Apr. 2003. Percentage dollar spot damage was measured by counting the number of leaves that exhibited dollar spot symptoms out of 50 randomly selected tillers (each tiller had two or three leaves). Silicon concentration in plant tissue and soil were determined as described in the tall fescue field experiment.

Data Analysis

Data from tall fescue and creeping bentgrass experiments were subjected to analysis of variance (ANOVA) with PROC MIXED procedure of Statistical Analysis System (1999–2000). Means were separated with Fisher's least significant difference (LSD) test at $P \leq 0.05$. Correlation analysis was run among concentrations of all leaf nutrients and between leaf nutrient levels and disease ratings using PROC CORR.

RESULTS AND DISCUSSION

Tall Fescue

Maximum brown patch infection was <10% of the plot area in 2002, and differences between cultivars were detected on 13 September when Bonsai 2000 had a slightly higher level of infection than Tar Heel (Table 1). In 2003, brown patch levels exceeded 30% in August (Table 2). Tar Heel had lower brown patch levels than Bonsai 2000 from 8 Aug. to 5 Sept. 2003, and a lower brown patch AUDPC level at the end of the season, supporting observations in NTEP reports (2002).

Less brown patch in Tar Heel was also reflected in better turf quality in August 2003 (Table 3). An interaction was observed in tall fescue visual quality between whole-plot and subplot treatments in August 2003 (Table 3). Subplots in Tar Heel had better quality (quality = 5.3–5.8) than those in Bonsai 2000 (quality = 4.3–5.0) when no fungicide was applied. In flutolanil-treated plots, however, Bonsai 2000 had better quality (quality = 7.0) than Tar Heel (quality = 6.8).

Only tall fescue treated with flutolanil exhibited less brown patch than untreated turf and had acceptable quality throughout both years (Tables 1, 2, and 3). Seebold et al. (2000, 2001) reported that Si suppression of blast [caused by *Magnaporthe grisea* (Herbert) Barr.] in rice was more obviously observed in the disease-susceptible cultivars. Nevertheless, we observed no $CaSiO_3$ reduction of brown patch in Bonsai 2000. Tall fescue treated with $CaSiO_3$ at 4880 kg ha^{-1} exhibited 25 and 26% more brown patch (AUDPC) than untreated turf in 2002 and 2003, respectively (Tables 1 and 2). Tall fescue receiving $CaSiO_3$ at 2440 kg ha^{-1} had 30% more brown patch (AUDPC) than untreated turf in 2003 (Table 2).

Calcium concentrations in tall fescue leaves were higher in $CaSiO_3$–treated (2400 kg ha^{-1}) turf in October, 2002, but leaf Si concentrations were not affected by cultivar or $CaSiO_3$ topdressing main effects (Table 4). Calcium deficiencies in turfgrasses have been associated with increased susceptibility to a range of diseases (Couch, 1966); how-

Table 5. Calcium in Bonsai 2000 and Tar Heel tall fescue leaves and Si in soil and leaves as influenced by $CaSiO_3$ topdressing and the fungicide flutolanil at Manhattan, KS, in 2003.

	Soil			Leaves					
	14 May	20 August	5 October	14 May		20 August		5 October	
Treatment	Si	Si	Si	Ca	Si	Ca	Si	Ca	Si
	mg kg^{-1}								
Whole plot									
Bonsai 2000	208	208	263	4600	29300	9700	25900	5300	19600
Tar Heel	199	216	275	5000	29500	8100	23500	5500	18400
Subplot									
Untreated	173 b‡	149 c	187 c	4900	30500	8000	24500	5200	17100 b
$CaSiO_3$, 2440 kg ha^{-1}†	210 ab	257 b	296 b	4700	28300	8600	27200	5400	20800 a
$CaSiO_3$, 4880 kg ha^{-1}†	255 a	303 a	402 a	4800	30100	9000	24100	5500	19900 a
Flutolanil, 4.8 kg a.i. ha^{-1}	176 b	137 c	189 c	4800	28500	10000	23000	5500	18100 ab
ANOVA									
Whole plot	NS§	NS	NS	NS	NS	NS	NS	NS	NS
Subplot	*	*	*	NS	NS	NS	NS	NS	*
Whole plot*subplot	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at $P \leq 0.05$.
† Calcium silicate was applied at 2400 or 4880 kg ha^{-1} on 29 May and 10 Oct. 2002 and on 14 May and 29 Sept. 2003.
‡ Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).
§ NS, not significant.

Table 6. Silicon and Ca leaf levels as affected by $CaSiO_3$ topdressing on L-93 creeping bentgrass at the Kansas City Country Club in Mission Hills, KS, in 2002.

Treatment	19 July		26 September	
	Ca	Si	Ca	Si
	mg kg^{-1}			
Untreated	7800	7400 b‡	6000	6800 c
$CaSiO_3$, 2440 kg ha^{-1}†	7200	8900 a	5700	12 800 b
$CaSiO_3$, 4880 kg ha^{-1}†	7200	9500 a	5400	15 100 a
ANOVA	NS§	*	NS	*

* Significant at $P \leq 0.05$.
† Calcium silicate was applied at 2400 or 4880 kg ha^{-1} on 24 May and 26 Sept. 2002.
‡ Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).
§ NS, not significant.

ever, increased foliar concentrations have not been reported to increase brown patch infection.

An interaction in tissue Si content between whole-plot and subplot treatments was observed in August 2002 (Table 4). Subplots in Tar Heel had higher Si leaf concentrations (>26 300 mg kg^{-1}) than those in Bonsai 2000 (<23 700 mg kg^{-1}) when no CaSi was applied. In CaSi-treated plots, however, Bonsai 2000 had higher Si tissue levels (23 700–24 900 mg kg^{-1}) than Tar Heel did (22 160–24 500 mg kg^{-1}). Winslow (1992) and Deren et al. (1994) reported that Si accumulation differed in rice genotypes.

In 2003, soil Si concentrations were higher under $CaSiO_3$–treated turf in May (4880 kg ha^{-1}) and in August and October (2440 and 4880 kg ha^{-1}) (Table 5). Despite these soil differences, $CaSiO_3$ increased tall fescue leaf Si relative to untreated turf only in October 2003 (Table 5). The lack of leaf Si accumulation after 2 yr of $CaSiO_3$ topdressing was probably due to the high initial soil Si level (170 mg kg^{-1}), which was nine times higher than the reported critical soil Si level of 19 mg kg^{-1}, above which no tissue Si accumulation in rice would be expected (Korndörfer et al., 2001).

Phosphorus leaf concentrations were lower in tall fescue treated with $CaSiO_3$ (3.1 and 3.2 g kg^{-1} at the low and high $CaSiO_3$ levels, respectively) than untreated turf (3.4 g kg^{-1}) in August 2002; there were no differences in P leaf concentrations among treatments in October 2002, nor in N or K concentrations in August or October. Phosphorus level in leaves in August was negatively correlated ($r = -0.41$; $P = 0.0198$) with level of brown patch infection.

Table 8. Silicon soil and leaf concentrations and Ca leaf concentrations as affected by $CaSiO_3$ topdressing on L-93 creeping bentgrass at the Kansas City Country Club in Mission Hills, KS, in 2004.

Treatment	Soil		Leaf tissue			
	4 May	19 July	4 May		19 July	
	Si	Si	Ca	Si	Ca	Si
	mg kg^{-1}					
Untreated	12.2	10.6 b‡	6300	6800 c	4600 b	8500 b
$CaSiO_3$, 2440 kg ha^{-1}†	52.5	64.2 a	6500	19 800 b	5700 a	18 100 a
$CaSiO_3$, 4880 kg ha^{-1}†	74.7	67.7 a	6900	26 900 a	5700 a	18 700 a
ANOVA	NS§	*	NS	*	*	*

* Significant at $P \leq 0.05$.
† Calcium silicate was applied at 2400 or 4880 kg ha^{-1} on 24 May and 26 Sept. 2002, 4 Apr. and 15 Aug. 2003, and 4 May 2004.
‡ Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).
§ NS, not significant.

Potassium leaf content was lower in $CaSiO_3$–treated (4880 kg ha^{-1}) turf (17.8 g kg^{-1}) compared to untreated turf (19.8 g kg^{-1}) in August 2003, and K leaf level was negatively correlated ($r = -0.44$; $P = 0.0122$) with brown patch infection. No differences in leaf N or P level were observed among treatments in August 2003. In May and October 2003, tissue levels of N, P, and K were similar among all treatments.

Leaf concentrations of N, P, and K in tall fescue fell within the reported sufficiency range (Turner and Hummel, 1992) on all sampling dates. Street et al. (1974) reported that leaf N decreased with increasing Si application in 'K-31' tall fescue and 'Pennstar' Kentucky bluegrass (*Poa pratensis* L.). The consequences of leaf nutrient imbalances created by Si are unknown. It seems that the $CaSiO_3$–induced imbalances of other nutrients, including P or K, may have increased the level of brown patch infection in tall fescue, since there were no significant differences in Si leaf content among treatments. Micronutrients, not measured herein, could also have been affected by $CaSiO_3$ application as was reported in St. Augustinegrass (Brecht et al., 2004).

Creeping Bentgrass

Field Experiment

In July 2002, leaf Si concentrations in L-93 creeping bentgrass topdressed with $CaSiO_3$ were higher than those

Table 7. Silicon (Si) soil and leaf levels and Ca leaf levels as affected by $CaSiO_3$ topdressing on L-93 creeping bentgrass at Kansas City Country Club in Mission Hills, KS, in 2003.

Treatment	Soil concentrations			Leaf concentrations					
	4 April	15 August	29 September	4 April		15 August		29 September	
	Si	Si	Si	Ca	Si	Ca	Si	Ca	Si
	mg kg^{-1}								
Untreated	2.9 b‡	10.9 b	10.4 b	5100 b	13 200 c	3600 b	6800 c	3000	6400 b
$CaSiO_3$, 2440 kg ha^{-1}†	5.4 b	19.3 b	43.5 b	5900 b	20 100 b	3900 a	15 600 b	3300	18 900 a
$CaSiO_3$, 4880 kg ha^{-1}†	19.2 a	51.6 a	126.0 a	7300 a	25 500 a	4100 a	18 600 a	3400	20 800 a
ANOVA	*	*	*	*	*	*	*	NS	*

* Significant at $P \leq 0.05$.
† Calcium silicate was applied at 2400 or 4880 kg ha^{-1} on 24 May and 26 Sept. 2002, 4 Apr. and 15 Aug. 2003.
‡ Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).
§ NS, not significant.

Table 9. Calcium silicate topdressing effects on visual quality, brown patch, and number of *S. homoeocarpa* infection centers on L-93 creeping bentgrass at the Kansas City Country Club in Mission Hills, KS, in August 2002, 2003, and 2004.

	8 Aug. 2002		15 Aug. 2003		19 July 2004		
Treatment	Quality	Brown patch	Quality	Brown patch	Quality	Brown patch	*S. homoeocarpa*
		%		%		%	no. m^{-2}
Untreated	3.8	6	4.8	3.8 a‡	4.8	18	8.8
$CaSiO_3$, 2440 kg ha^{-1}†	4.3	3	4.5	9.5 b	4.5	23	9.5
$CaSiO_3$, 4880 kg ha^{-1}†	4.3	4	4.3	16.3 c	4.5	23	9.8
ANOVA	NS§	NS	NS	*	NS	NS	NS

* Significant at $P \leq 0.05$.
† Calcium silicate was applied at 2400 or 4880 kg ha^{-1} on 24 May and 26 Sept. 2002, 4 Apr. and 15 Aug. 2003, and 4 May 2004.
‡ Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).
§ NS, not significant.

in untreated turf (Table 6). By September, there were also differences in leaf Si content between the $CaSiO_3$ application rates; turf receiving the higher $CaSiO_3$ topdressing rate exhibited greater tissue Si accumulation. Nevertheless, leaf Si levels in all treatments were within a range that would be considered low in rice (<17 000 mg kg^{-1}) (Korndörfer et al., 2001).

Soil topdressed with $CaSiO_3$ at 4480 kg ha^{-1} had higher Si levels than soil under untreated turf in 2003 (Table 7). In July 2004, higher Si soil contents were observed in $CaSiO_3$–treated creeping bentgrass at both application rates (Table 8). In April 2003, Ca tissue contents were higher in creeping bentgrass topdressed with $CaSiO_3$ at 4480 kg ha^{-1} than those in untreated turf or that topdressed at 2240 kg ha^{-1}. In August 2003 and July 2004, Ca leaf accumulation was observed in turf treated with $CaSiO_3$ at both rates.

Brown patch was observed in all 3 yr, with the greatest pressure occurring on 19 July 2004 when infection was >18% (Table 9). Despite higher soil and leaf Si concentrations, no reduction in brown patch severity occurred. Brown patch severity increased with $CaSiO_3$ topdressing level on 16 August 2003, with over 16% infection at the higher $CaSiO_3$ application level. There was a positive correlation ($r = 0.86$; $P < 0.001$) between brown patch severity and Si tissue level on this date (Fig. 1).

Negative correlations ($r = -0.6$ to -0.7; $P < 0.033$) were observed between leaf macronutrient levels in September 2002 (N, P, and K) and July 2004 (N and K) and leaf Si (Fig. 2 and 3), which was consistent with observations in the tall fescue experiment.

Adequate soil and leaf tissue levels of N, P, and K are prescribed to minimize brown patch and other diseases in creeping bentgrass (Dernoeden, 2000). Despite reductions in leaf N, P, and K content after $CaSiO_3$ application (Table 10), concentrations of all three were within, or greater than, the sufficiency range as reported by Turner and Hummel (1992), with the exceptions of

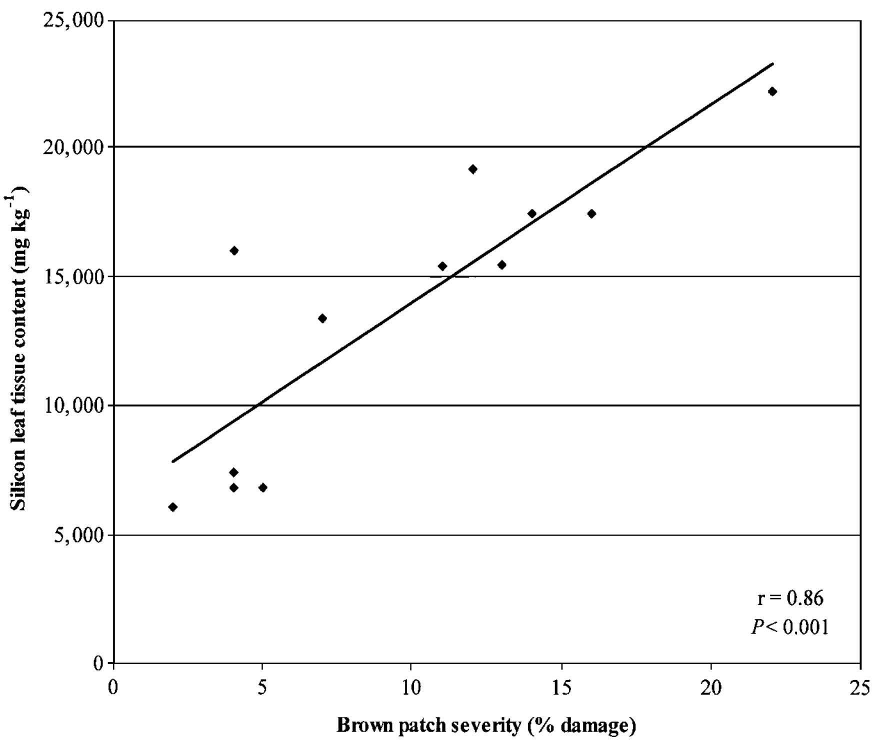

Fig. 1. Correlation between Si leaf content in L-93 creeping bentgrass and brown patch severity on 15 Aug. 2003 at the Kansas City Country Club in Mission Hills, KS.

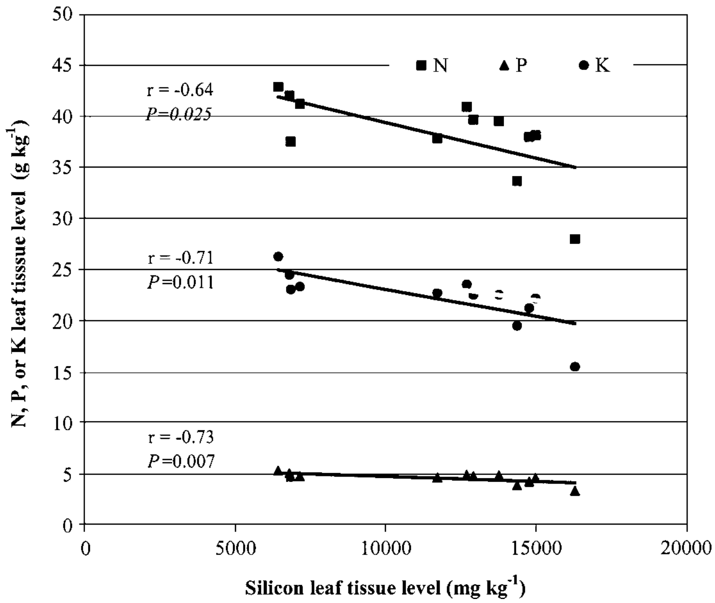

Fig. 2. Correlation between Si and N, P, or K leaf tissue level in L-93 creeping bentgrass on 26 Sept. 2002 at the Kansas City Country Club in Mission Hills, KS.

N and P in April 2003. No differences were observed in tissue N, P, and K levels among treatments in August 2003 when brown patch level increased with tissue Si content. Furthermore, there was no correlation between levels of any element except Si with brown patch severity in August 2003. Turf quality was unacceptable in all 3 yr (quality < 5) due mainly to the presence of brown patch (Table 9).

Soil pH to a 1-cm depth was higher under $CaSiO_3$–treated (pH 7.9) than untreated (pH 7.2) turf in November 2003. There is no information in the literature indicating that an increase in soil surface pH could encourage brown patch; this deserves further investigation.

Dollar spot was observed in July 2004, but there were no differences in the number of *S. homoeocarpa* infection centers among $CaSiO_3$–treated and untreated turf (Table 9).

Growth Chamber Experiment

Soil Si concentrations increased with $CaSiO_3$ application rate, ranging from 170 mg kg^{-1} in untreated soil to

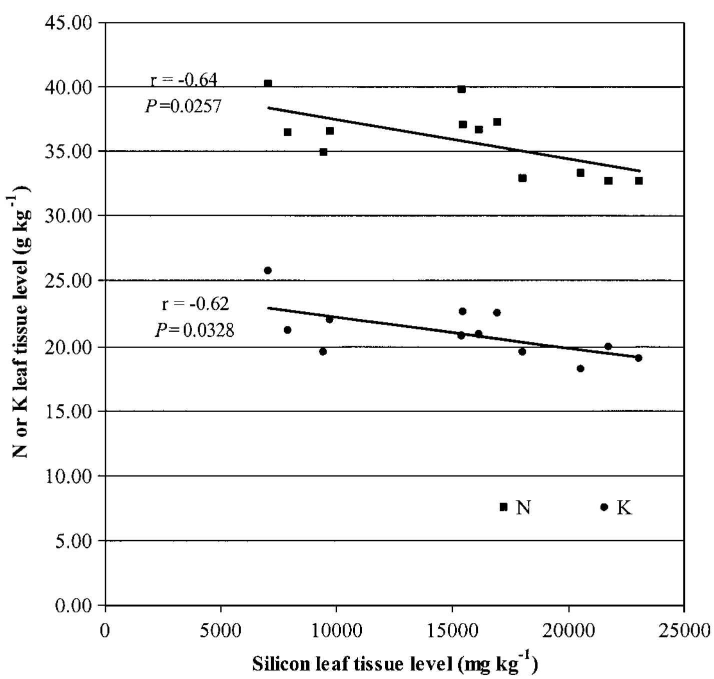

Fig. 3. Correlation between Si and N or K leaf leaf tissue level in L-93 creeping bentgrass on 19 July 2004 at the Kansas City Country Club in Mission Hills, KS.

Table 10. Calcium silicate soil amendment effects on leaf N, P, and K concentrations on L-93 creeping bentgrass in the Field Experiment at the Kansas City Country Club in Mission Hills, KS, in August 2002, 2003, and 2004.

	2002						2003									2004					
	19 July			26 September			4 April			15 August			29 September			4 May			19 July		
Treatment	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
	$g\ kg^{-1}$																				
Untreated	40.7	5.0	22.5	40.9 a‡	5.0 a	24.3 a	16.4	2.0	11.1	39.0	6.3	18.8	39.9	4.3	23.4	35.8 a	4.7 a	21.1 a	37.0	7.2	22.1
$CaSiO_3$, 2440 $kg\ ha^{-1}$†	41.8	4.9	22.7	39.4 a	4.8 a	22.8 a	16.1	1.9	10.0	39.0	6.2	17.9	36.7	4.4	22.1	32.9 b	4.0 b	18.8 b	35.1	7.1	20.8
$CaSiO_3$, 4880 $kg\ ha^{-1}$†	42.7	5.0	23.2	34.4 b	4.0 b	19.6 b	18.8	2.1	11.8	39.1	6.4	18.6	37.4	4.5	22.4	33.6 b	4.1 b	18.6 b	35.5	6.9	20.0
ANOVA	NS§	NS	NS	*	*	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*	*	NS	NS	NS

* Significant at $P \leq 0.05$.
† Calcium silicate was applied at 2400 or 4880 $kg\ ha^{-1}$ on 24 May and 26 Sept. 2002, 4 Apr. and 15 Aug. 2003, and 4 May 2004.
‡ Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).
§ NS, not significant.

295 $mg\ kg^{-1}$ in soil amended at 14650 $kg\ ha^{-1}$ (data not shown). Silicon levels in Penncross leaves were just over 34 000 $mg\ kg^{-1}$ and there were no differences among treatments. The percentage of leaves damaged by *S. homoeocarpa* ranged from 54 to 57% and there were no differences among treatments.

Initial soil Si concentrations seemed to play a primary role in whether differences in creeping bentgrass leaf Si concentrations were observed. In the Growth Chamber Experiment, soil Si content in an untreated silty clay loam was 170 $mg\ kg^{-1}$, and no tissue differences in Si were observed in creeping bentgrass growing on $CaSiO_3$–amended soil. In the Field Experiment, initial soil Si contents levels in this sandy medium were <12 $mg\ kg^{-1}$ and Si leaf accumulation occurred.

Others researchers have reported mixed results regarding the influence of Si on disease suppression in turfgrasses. Soluble Si applications helped to reduce leaf spot [caused by *Bipolaris cynodontis* (Marignoni) Shoemaker] in bermudagrass [*Cynodon dactylon* (L.) Pers.] and gray leaf spot in St. Augustinegrass on soil containing Si at ≤10 $mg\ kg^{-1}$ (Datnoff and Rutherford, 2003; Brecht et al., 2004). Pythium blight [caused by *Pythium aphanidermatum* (Edson) Fitzp.] severity was higher in creeping bentgrass treated with soluble Si at 55 $g\ m^{-2}$ than untreated turf or turf treated at 27 $g\ m^{-2}$ (Gussack et al., 1998). Uriarte et al. (2004) observed dollar spot and brown patch suppression in creeping bentgrass after foliar application of potassium silicate at 25 $kg\ ha^{-1}$. But, they observed an accumulation of K, not Si, in leaves after application. No work has demonstrated that an increase in leaf Si content provides a concomitant increase in creeping bentgrass dollar spot or brown patch resistance.

Our results indicate that despite increases in tissue Si levels following $CaSiO_3$ application on L-93 creeping bentgrass where soil Si content was low (≤12 $mg\ kg^{-1}$), no reduction in brown patch occurred in two of three years, and an increase in infection was observed in one year. Tall fescue growing in a silty clay loam with a high initial level of Si (170 $mg\ kg^{-1}$) exhibited an increase in brown patch after $CaSiO_3$ topdressing in consecutive years. Dollar spot incidence on creeping bentgrass growing on the same soil in a growth chamber was not affected by soil incorporation of $CaSiO_3$.

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