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PURPOSE

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Silicon Fertilization Does Not Enhance Creeping Bentgrass Resistance to Cutworms and White Grubs

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SUMMARY

High plant silicon (Si) content, which makes grasses more difficult for herbivores to chew and digest, is associated with insect resistance in several Poaceous crops. University of Kentucky researchers evaluated if fertilization with Si enhances resistance of 'Penncross' creeping bentgrass to two major insect pests: foliage-feeding black cutworms, and root-feeding masked chafer grubs. The study's findings include:

- Prilled calcium silicate fertilizer (Excellerator) applied to fairway-height turf on silt loam soil elevated leaf Si by as much as 40% without reducing palatability or suitability for cutworms.
- Rates as high as 3,363 kg of product per ha also did not reduce density or weight of naturally-occurring chafer grubs.
- Sodium silicate drenches that elevated leaf Si content of greenhouse-grown bentgrass from 0.5 to 2.5% did not reduce cutworm feeding or survival, caused no inordinate erosion of mandibular teeth, and had only small effects on larval growth rates.
- Results suggest that Si fertilization is unlikely to enhance creeping bentgrass resistance to key insect pests.

There is a recent growing interest in silicon (Si) fertilization of turfgrasses to enhance plant performance and resistance to diseases and abiotic stress (3,9). Silicon is plentiful in most soils but is combined with other elements, forming insoluble silicates, so most of it is not in plant-available form (5). Silicon deficiency adversely affects plant growth and viability (5). Plant-available Si may be limiting in highly organic soils having little mineral matter and in soils that are heavily leached or that have high quartz sand content, conditions that may occur on golf course greens, tees, and other turfgrass sites (3).

Silicon is absorbed as silicic acid by plant roots and transported via xylem to stems and leaves (5). Silica polymers deposited in cell walls strengthen stems and present a barrier to fungal penetration. Silicon may also elicit production of compounds involved in induced disease resistance (5). Silicon fertilization may benefit turfgrasses by reducing water use, enhancing heat and drought tolerance, producing more erect growth with increased photosynthetic efficiency, promoting cleaner mowing cuts, and rendering foliage less susceptible to fungal pathogens (3,9).

Plant tissues high in Si may be difficult for herbivores to chew and digest (12,15). In some cases, insects' mandibular teeth may be so eroded by the abrasiveness of Si in plant cell walls that feeding ability is compromised and impaired growth or starvation ensues (7,14). Fertilizing with Si enhances insect resistance in several Poaceous crops including rice, wheat, and sugar cane (15).

In contrast, applications of calcium silicate slag that increased Si content of five species of potted warm-season turfgrasses did not affect growth and development of tropical sod webworms, *Herpetogramma phaeopteralis* (10). No

Capacity for creeping bentgrass to accumulate Si was evaluated by applying a prilled calcium silicate fertilizer (Excellerator, Excell Minerals, Sarver, PA) plus micronutrients, to plots on a Maury silt loam soil at the University of Kentucky Turfgrass Research Facility, Lexington.

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Root-feeding white grubs of masked chafer (*Cyclocephala spp.*) are serious pests of turfgrasses.

published studies have examined if augmenting Si enhances insect resistance in cool-season turfgrasses. We tested that hypothesis in field and greenhouse trials using 'Penncross' creeping bentgrass (*Agrostis stolonifera*) and the black cutworm [BCW], *Agrotis ipsilon*, a caterpillar that chews blades and stems. We also evaluated Si fertilization effects on field densities of root-feeding masked chafer (*Cyclocephala spp.*) grubs.

Does field-applied Si fertilizer elevate Si content of creeping bentgrass?

Capacity for creeping bentgrass to accumulate Si was evaluated by applying a prilled calcium silicate fertilizer (Excellerator, Excell Minerals, Sarver, PA) containing 39.3% total available Si (5.8% $CaMgSiO_4$, 17.9% $Ca_3Mg(SiO_4)_2$, 8.0% Ca_2MgSiO_7, and 7.6% Ca_2SiO_4), plus micronutrients, to plots on a Maury silt loam soil at the University of Kentucky Turfgrass Research Facility, Lexington. The turf was fertilized twice per year with 73 kg of N per ha from urea in October and December, irrigated about 2.5 cm per week, and mowed at 16 mm three times per week. Treatments included the label rate (2,242 kg of product per ha or 2000 lb/acre) and 1.5, 0.5, and 0.25× label rate, plus untreated controls, applied to 0.91-m × 0.91-m plots in a randomized complete block with six replicates on April 19, 2005.

Grass clippings (1 cm long; 10 g total wet weight) were harvested from the inner 0.5 m^2 of each plot 30 days after treatment, dried at 40°C, and ground to pass a 40-mesh screen. Sub-samples (100 mg) were digested in an autoclave with sodium hydroxide and hydrogen peroxide and analyzed for Si by inductively coupled plasma spectrometry (4).

Leaf Si content was significantly elevated by the Si fertilizer. Mean percentage foliar Si was 0.57, 0.72, 0.68, 0.78, and 0.80 at the 0, 0.25, 0.5, 1.0, and 1.5× rates of fertilizer, respectively, representing increases of 36.4 and 40.3% at 1.0× and 1.5× label rates, respectively.

Does field-applied Si fertilizer enhance bentgrass resistance to black cutworms or masked chafer grubs?

Eight pairs of 1.83-m × 1.83-m plots were marked adjacent to the aforementioned rate study in the same stand. One plot of each pair was treated with Excellerator at label rate on April 19, 2005. Tillers were sampled 30 days after treatment and presented to first-instar BCW in choice tests to determine if larvae would avoid feeding on Si-fertilized grass.

For each replicate, six tillers, three each from treated and control plots, were arranged in an alternating, spoke-like pattern on moist filter paper in 9-cm diameter Petri dishes. Ten larvae were then added to each dish. Assays were run in

Silicon fertilization had little or no effect on grass suitability for black cutworm.

Parameter		Treated	Control	t-value^{x}	P
Larval wt (mg) attained by	7 days	15.9	16.2	-0.50	0.31
	14 days	446	484	-1.65	0.07
Larval instar attained by	7 days	3.9	3.8	0.69	0.74
	14 days	6.6	6.7	-1.98	0.04
Days to reach	Pupa	21.5	21.4	0.66	0.27
	Adult	34.4	34.2	0.57	0.29
Pupal wt (mg)	Females	519	527	-0.78	0.23
	Males	476	479	-0.18	0.43
% survival	(to pupa)	87.5	90.0	-0.61	0.28

^{x} One-tailed paired t-test, 7 degrees of freedom.

Table 1. Mean larval weights (mg) and instar stage attained at 7 and 14 days after treatment; mean number of days to reach pupa and adult stages, mean weigts (mg) of female and male pupae, and % survival of black cutworms reared on clippings from Si-fertilized or non-treated (control) creeping bentgrass field plots. Also shown are t-values for treated versus control t-test comparisons for each variable, and well as the probability (P) values that the differences between the treated and non-treated control values were a result of random chance. P values need to be equal or less than 0.05 to denote significant treatment effects. There were no differences between groups of larvae fed silicon-treated or untreated grass, except for the parameter larval instar attained by 14 days.

a growth chamber at 25 °C (day) and 22 °C (night) and a photoperiod of 14:10 (light:dark) hours. Numbers of BCW feeding on tillers were recorded after 24 hours. Data were analyzed by one-tailed paired t-tests (H1: treated < control). First instars did not discriminate between tillers from treated or untreated plots. Mean numbers feeding on treated versus untreated tillers were 4.8 and 4.3 , respectively.

Newly-hatched BCW were reared on clippings from the field plots used for choice tests, starting 30 days after treatment, to determine if Si fertilization reduced bentgrass suitability for growth and development. Initially there were 10 larvae per plot (160 total) individually held in Petri dishes at 27 °C and 18:6 (light:dark) hour photoperiod and provided fresh clippings on moist paper every 48 hours.

Parameters measured were 7-day and 14-day larval weight and instar, pupal weight, days to pupation and moth emergence, and survival. Values for individuals reared on grass from a given plot were averaged; then cohorts fed grass from treated versus control plots were compared by paired t-tests using plots as replicates. There were no gender differences except for pupal weight, so males and females were pooled except for that parameter. Silicon fertilization had little or no effect on grass suitability for BCW (Table 1).

Additional larvae concurrently reared on grass from the same plots were sacrificed on the last day they were second or sixth instars. Head capsules of 10 larvae per treatment, per instar, were split with a scalpel and mandibles were removed with fine forceps. Length (µm) of the third mandibular incisor was then measured with an ocular micrometer at 50× magnification. Mean lengths for second instars fed on treated or control grass were 23.6 and 20.0 µm, respectively. Values for sixth instars were 82.4 and 87.2, respectively. There was no inordinate wear associated with feeding on Si-fertilized grass.

Half of each treated plot was re-treated with Excellerator at 0.5 label rate on July 20, 2005 to determine if refreshing Si levels might augment resistance to masked chafer grubs. Natural grub densities were sampled on Sept. 8, 2005. Sod strips (0.91 m × 0.46 m, 6 cm deep) were cut from both halves of each plot and grubs were counted, identified, and weighed. Samples from halves of each control plot were averaged, whereas portions of treated plots that received one or two applications were considered separate treatments. Six core samples (5 cm diameter, 8 cm deep) were pulled from each plot concurrent with grub sampling and washed to remove soil. Roots were then cut off, dried, ground, and analyzed for Si content as described earlier.

Densities of masked chafers, the predominant grubs present, were unaffected by Si treatments. Mean numbers in 0.42 m^2 samples from untreated plots and portions of treated plots receiving one or two Si applications were 8.3, 11.7, and 10.2, respectively. Weight per grub also did not differ between treatments averaging 390, 367, and 379mg, respectively. Root Si content was not elevated by the treatments averaging 6.5, 7.0 , and 7.5% dry wt for control, once-treated, and twice-treated plots.

Does sodium silicate soil drench enhance bentgrass resistance to cutworms?

Additional trials evaluated if a Si soil drench (7) might be more effective than prilled calcium silicate for augmenting bentgrass resistance to BCW. 'Penncross' bentgrass cores (20 cm in diameter, 12 cm deep) pulled from research plots in early December 2005 were potted and grown in a greenhouse at 23 to 25°C and photoperiod of 16:8 (light:dark) hours under sodium vapor lights to stimulate growth. They were watered every third day and cut at 2- to 2.5-cm height. Granular mefonoxem (Subdue, Syngenta, Greensboro, NC) at 370 ml/93 m^2 was applied once to discourage fungal diseases. Treatment regimes (Table 2) were each replicated six times. Sodium silicate solution (14% NaOH, 27% SiO_2) was applied in 20 ml water per pot. All treatments were applied to the surface followed by 1.0 cm of irrigation.

Tillers harvested from each pot at 35 days after treatment were presented to neonate BCW in paired choice tests, as above. Each treatment was tested versus untreated grass. Damaged tillers and larvae feeding on each tiller were counted after 24 hours. A rearing trial, similar to above, was initiated at 35 days after treatment. Ten neonates were collectively reared on clippings from each pot. Survival, larval weight, and instar were recorded after 7 days. Because quantity of grass clippings was limited, three representative larvae from each cohort (ones whose weight deviated < 10% from the group mean) were individually reared on clippings from that pot for another 7 days, then weight and instar were recorded. Data were averaged to provide a single value per replicate pot and analyzed by paired t-tests (choice tests) or two-way

Treatment	Si rate (g/m^2)	No. of weekly applications[y]	Si per pot per application	Total Si per pot
Excellator	88.0	1	1.76g	1.76g
Sodium Si solution (low)[x]	10.0	4	0.05g	0.20g
Sodium Si solution (high)	100.0	4	0.50g	2.00g
Control	-	-	-	-

[x] Contains 14% NaOH, 27% SiO_2 (Sigma-Aldrich, St. Louis, MO).

[y] First application January 5, 2006; subsequent ones January 12, 19, and 26, 2006.

Table 2. Silicon (Si) sources and amounts applied to pots of creeping bentgrass in the greenhouse study

ANOVA (rearing trial). Clippings harvested during the bioassays were dried and analyzed for Si content as described earlier.

Low and high rates of sodium silicate resulted in 2.4- and 5-fold increases in Si content of bentgrass leaf blades (Table 3). Neonate BCW nevertheless did not discriminate between treated or control tillers. Mean numbers feeding on the respective choices were 3.7 and 4.8 for high SiO_2 versus control, 4.7 and 3.7 for low SiO_2 versus control, 4.0 and 5.3 for Excellerator versus control.

Numbers of tillers fed upon also did not differ.. BCW fed clippings from pots drenched with sodium silicate gained less weight than controls during the first week, but there was high survival in all treatments and differences were nonsignificant by 14 days (Table 3). Mandibles of larvae reared on Si-augmented grass showed no inordinate incisor wear. No phytotoxicity was apparent 3 days after treatment, but by 35 days after treatment, there was substantial yellowing and browning of some grass plants from the high-rate sodium silicate drench. We used only green, apparently healthy tillers in the bioassays.

Discussion and Recommendations

Leaf and stem silicification has been viewed as both a constitutive and quantitatively inducible anti-herbivore defense of grasses (13,17). High plant Si content may adversely affect herbivores by abrading dentition (1,7,14), reducing digestibility (15), or contributing to pathological conditions in livestock (12). Herbivores as diverse as voles (6), slugs (18), and insects (8) may in some cases discriminate between high- and low-Si plants, feeding preferentially on the latter. Other studies, however, including one with a caterpillar feeding on *Agrotis tenuis* (2), did not support the hypothesis that natural or grazing-induced variation in Si acts as a defense.

Fertilizing with prilled calcium silicate increased foliar Si content in our creeping bentgrass field plots by 36 to 40%, and sodium silicate soil drenches gave 2.5 to 5-fold increases in the greenhouse. Our results differ from Uriate et al. (16) who, finding no effect of spray-applied potassium silicate on leaf Si in USGA sand-based putting greens, suggested that creeping bentgrass may be a Si excluder. Foliar Si in their untreated plots averaged 85 mg/kg, compared to 57 mg/kg in our control plots on silt loam soil.

Black cutworms, a key pest of bentgrass putting greens and tees, nevertheless readily devoured foliage from our calcium silicate-fertilized field plots with no reduction in their growth or survival. There also was no effect on abundance or weight of masked chafer grubs. Initially-retarded growth of BCW observed on high-Si grass in our greenhouse trial could translate to higher mortality from invertebrate predators (e.g.,

	Larvae after 7 days				Larvae after 14 days	
Treatment	Foliar Si (%)[x]	Weight (mg)	Instar	survival (%)	Weight (mg)	Instar
High SiO_2	2.5 a	11.3 a	2.7 a	97 a	256 a	6.2 a
Low SiO_2	1.2 b	13.9 ab	2.9 b	98 a	278 a	6.4 a
Excellerator	0.7 c	17.1 bc	3.0 b	97 a	284 a	6.4 a
Control	0.5 c	20.4 c	3.0 b	98 a	320 a	6.4 a

[x] Means within columns followed by different letters are significantly different at P= 0.05.

Table 3. Mean weight, growth rate, and survival of black cutworms reared on clippings from creeping bentgrass treated with sodium silicate soil drenches or prilled calcium silicate (Excellerator) in the greenhouse

ants) that focus on early instars (11), but larvae had compensated by 14 days. Because the high sodium silicate rate caused some phytotoxicity, changes in leaf quality unrelated to Si may have occurred in the apparently healthy tillers provided to the larvae. Absence of measurable mandibular wear in our study contrasts with Goussain et al. (7) where incisors of fall armyworms fed leaves from Si-augmented corn plants became so eroded that feeding was impaired and mortality and cannibalism increased.

In conclusion, while Si doubtless contributes to general structural defense of turfgrasses by lowering food quality for insects and other herbivores, our data suggest that augmenting Si is unlikely to enhance resistance of creeping bentgrass to two of its major insect pests. Korndofer et al. (10) reached a similar conclusion for warm-season grasses and tropical sod webworms. Research concerning how Si affects other grass species and insect feeding guilds (e.g., stem-burrowers, sucking pests) is nevertheless warranted.

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