Effect of Silicon on Resistance of St. Augustinegrass to Southern Chinch Bugs (Hemiptera: Blissidae) and Plant Disease[1]

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J. Entomol. Sci. 47(1): 17-26 (January 2012)

Abstract Silicate slag was applied to soil of Captiva, Floratam, and Raleigh varieties of St. Augustinegrass to measure the effect of plant silicon on resistance of the varieties to southern chinch bugs, *Blissus insularis* Barber, and plant disease. In general, silicate slag addition increased Si and Cu content in leaves but tended to decrease P and Mg concentrations. Tissue nutrient contents were generally lowest for Floratam; this trend occurred both with and without silicate slag amendment, indicating a lower nutrient requirement than with other varieties. Chinch bug survival was lowest and development slowest on Captiva which was the only variety with resistance to the insects. There were no significant differences in survival or developmental rates of chinch bugs between silicon treatments within any of the 3 varieties. In disease assessments, Raleigh was more susceptible to gray leaf spot than Captiva or Floratam. However, the addition of Si resulted in significant disease reduction in Raleigh. The addition of Si resulted in disease reduction in Floratam as measured by disease incidence, but not severity. The addition of Si slag caused significant increases in stolon number, stolon length, and leaf blade width in 1 - 2 varieties. Varieties varied in response to Si fertilization among 6 growth characters measured.

Key Words silicon, St. Augustinegrass, chinch bugs, disease

St. Augustinegrass, *Stenotaphrum secundatum* (Walt.) Kuntze, is used for lawns throughout the southern United States due to its wide adaptation to varying environmental conditions. The southern chinch bug, *Blissus insularis* Barber, is the plant's most damaging insect pest. Prior to the release of resistant Floratam St. Augustinegrass in 1973 (Horn et al. 1973), control of southern chinch bug was primarily through insecticidal applications. Host plant resistance in Floratam lasted until 1985 when southern chinch bug damage on Floratam was reported in Florida (Busey and Center 1987) and later confirmed by Cherry and Nagata (1997).

Silicon (Si) is the second most common element on earth, but it is not considered to be an essential element for plant growth (Arnon and Stout 1939). However, there is a growing body of evidence that Si can enhance plant resistance to insect pests. The solid silica that is associated with the plant cell walls may constitute a mechanical barrier to penetration of the mandibles of insects (Jones and Handreck 1967). Applied Si and higher available soil Si have improved the resistance of rice to several economically- important rice insect pests (Savant et al. 1997). Recently, Carvalho et al. (1999)

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reported that Si reduced the feeding and reproduction of greenbug (*Schizaphis graminum* Rondani), a sorghum herbivore. Also, Saigusa et al. (1999) reported reduced insect feeding in turf treated with calcium silicate. However, the insect-plant-silicon response is complex and not always predictable as evidenced by studies in which insects showed no response to silicon (Korndorfer et al. 2004).

Similarly, silicon was shown to suppress a range of diseases caused by fungi and fungal-like organisms on several turfgrass species. Suppression of Rhizoctonia Brown Patch (*Thanatephorus cucumeris* (A.B. Frank) Donk) on Zoysiagrass (*Zoysia* species), *Pythium aphanidermatum* (Edson) Fitz. on creeping bentgrass *Agrotis palustris* Hudson, and powdery mildew caused by *Blumeria graminis* (DC) E.O. Speer on Kentucy bluegrass *Poa pratensis* L. was reported by Si (Datnoff and Nagata 1999, Datnoff and Rutherford 2004, Hamel and Heckman 1999, Uriarte et al. 2004). The silicon enhances physical resistance of the plant cell by depositing in the cuticle or epidermal cells that may impede penetration by the pathogen (Datnoff et al. 2001). Gray leaf spot, caused by the fungal pathogen *Magnaporthe grisea* (T.T. Hebert) occurs on St. Augustinegrass in Florida where warm temperatures and wet weather favor the disease. Previous studies indicated that silicon was effective in reducing damage from this disease on certain varieties of St. Augustinegrass (Datnoff and Nagata 1999, Brecht et al. 2004).

Effect of silicon on growth of plants has been evaluated in a variety of crop species. Korndorfer et al. (2001) reported that Si fertilizer application to soil had a positive effect on yield of rice in 19 of 28 field experiments conducted in the Everglades Agricultural Area (Histosol) over a 5-year period (1992 - 1996). Yield increase due to the application of Si fertilizer in sugarcane was documented in many sugarcane growing areas of the world (Alvarez and Gascho 1979, Ayres 1966, Franco and Korndorfer 1995, Samuels 1969). Foliar sprays of potassium silicate on strawberry plants resulted in increased growth of leaves, petioles, crowns, and roots (Wang and Galletta 1998). However, information on the role of Si in growth of St. Augustinegrass is limited.

The objective of this study was to determine if silicon applications to St. Augustinegrass varieties increase the silicon in the plants and affect development and survival of southern chinch bugs and development of plant diseases. The effect of silicon on plant growth is also noted.

Materials and Methods

Silicon tests. Three grass varieties used in our tests were Captiva, Floratam, and Raleigh. These varieties are in commercial production in Florida and range in resistance to southern chinch bugs from Captiva (resistant), Floratam (once resistant, now susceptible), to Raleigh (susceptible). Plants were sprigged into 13-cm diam pots filled with a mixture of 50% sand and 50% Fafard #2 mix. Effects of silicon on resistance to gray leaf spot and chinchbugs were assayed by amending one set of pots with calcium silicate slag at a rate of 10,000 kg/ha, which has been previously shown to result in significant plant uptake of Si (Brecht et al. 2004). The other set of pots was not amended with silicon slag. The slag applied to the planting mix contained approx. 3,880 mg extractable Si/kg and was homogeneously mixed into the entire soil volume. All treatments received 3 g of Osmocote slow-release fertilizer (14 - 14 - 14) per pot surface applied at sprigging, and at 2-month intervals thereafter. All essential nutrients were added at rates deemed to be nonlimiting to plant growth. Plants were allowed to establish at least 2 months before exposure to chinch bugs. Pots received direct sunlight during establishment and natural precipitation with supplemental daily irrigation as needed.

At the end of each chinch bug, disease, or plant growth test, leaf tissue samples were collected from both Si-amended and unamended treatments and analyzed for total Si, N, P, K, S, Ca, Mg, Fe, Cu, Mn, and Zn. Leaves were collected, rinsed in distilled water to remove surface residues and contaminants, and then dried at 70°C for 3 d. Leaf tissue was then ground and subjected to high-temperature acid digestion for analysis of all nutrients except Si. In short, 0.3 g tissue was digested with 2 mL H_2SO_4 and 2 mL 30% H_2O_2 for 2 h at 350°C. Digestates were diluted to 50 mL final volume, then analyzed colorimetrically for N and P as described in Wright (2009) and for other nutrients using methods described in Wright and Mylavarapu (2010). Leaf Si content was analyzed by digestion of 0.1 g tissue with 2 mL of 30% H_2O_2 and 30 mL of 50% NaOH at 250°C for 30 min. The digestates were then analyzed colorimetrically using the method described by Gascho and Elwali (1978). Extractable Si content in soil was measured after Mehlich 3 extraction (Wright and Mylavarapu 2010), and then following the same colorimetric methods as used for leaf tissue. A Least Significant Difference (LSD) test was used to determine significant differences ($\alpha = 0.05$) among means of the 6 treatments using SAS (2010).

Chinch bug tests. Chinch bugs were collected by vacuuming from natural chinch bug infestations in Palm Beach Co., FL. Chinch bugs and collected debris were stored in buckets with fresh St. Augustinegrass clippings at 18°C until testing. Each replicate consisted of testing chinch bugs against one potted plant from each of 2 silicon treatments in each variety. One runner/plant was inserted into a 15 cm long, 4-cm diam clear plastic tube. Thereafter, a sponge was cut to size so that it wrapped around the runner and was wedged into the tube end nearest the plant, thus preventing chinch bug escapes at that end. Ten first instars were placed into each tube, which contained moistened filter paper to maintain a high relative humidity. The other tube end was closed with a fine mesh cloth held in place with rubber bands to prevent chinch bug escape. Potted plants with tubes attached were held 21 d at 28°C at 12D/12L photoperiod. First instars and this time period and temperature were used because they produced both nymphs and adults after 21 days, thus allowing both survival and rate of development to be measured. Plants were irrigated every 2 - 3 d as needed. Also, water was lightly sprayed into tubes every 2 - 3 d to provide moisture for the chinch bugs. After 21 d, tubes were opened and survival and developmental stages determined. Chinch bugs were not observed on plants before tests, and < 10 chinch bugs were found per tube at the 3-wk termination. This highly suggests that the development and survival of chinch bugs in the tubes does represent the 10 first instars being held and not cryptic and/or migration of chinch bugs into tubes. Five replicates were conducted over an 8-month period and data pooled for analysis. LSD was used to determine significant differences ($\alpha = 0.05$) among means of the treatments using SAS (2010).

Disease assessment. Disease assessments were taken on the terminal node of one randomly selected runner from each of 10 pots per treatment. The disease incidence was calculated as the percentage from the number of leaflets with lesions of gray leaf spot divided by the total number of leaflets counted. The disease severity was visually estimated as a percentage of foliage exhibiting symptoms of gray leaf spot per plant. Each pot was a replicate with assessments made on 14 Dec 10. Gray leaf spot means were compared using a LSD test in SAS (2010).

Plant growth tests. To investigate the effect of silicon on growth of St. Augustinegrass, 8 plants grown in soil with Si fertilizer and 8 grown in untreated soil were selected from each of the 3 varieties for measurement of morphological traits. The leaf blade length, leaf width, and sheath length of each plant were determined based on the leaf on the first fully-expanded internode from the tip of the longest stolon. Length of internode was calculated as stolon length divided by number of internodes. To evaluate rates of stolon growth and new stolon formation, all but the longest stolon of each plant were trimmed on 27 January and the plants were placed outside at the Everglades Research and Education Center. After 6 wks (10 March), the length of the longest stolon of each plant was measured and new stolons were counted. Data for each trait were subject to statistical analysis as described previously.

Results and Discussion

Silicon tests. Silicate slag addition significantly increased the Si content of leaf tissue for all varieties (Table 1). However, varieties differed significantly in their ability to accumulate the applied Si in tissues, as Raleigh had also twice the Si content as Floratam, and approx. 1/3 more than Captiva. Similar trends among varieties were observed for treatments not receiving slag, indicating that some varieties, such as Raleigh, have an inherent mechanism for taking up Si from soil and storing it in their tissues better than varieties such as Floratam.

Phosphorus concentrations in tissue did not vary among varieties. Phosphorus content in tissue was significantly affected by Si content for 2 varieties. Addition of slag and accumulation of Si in tissue significantly decreased the tissue P content for Floratam and Captiva by an average of 26%. Overall, tissue Si was significantly negatively correlated ($r = -0.46$) with tissue P. This result may indicate that Si fertilization may lower the P requirement of these varieties. In light of potential P losses as leacheate or runoff from over-fertilized fields and lawns, this finding may indicate a potential for decreasing P fertilization rates for St. Augustinegrass. Additional research may be warranted to directly determine links between Si and P dynamics in turf.

Nitrogen tissue concentrations were not affected by slag addition. With slag addition, tissue N was higher for Raleigh than other varieties. Tissue N was significantly correlated with tissue P, K, Mg, and Mn. Similar to N, Raleigh receiving silicate slag had higher tissue K than other varieties that received slag, and tissue K was significantly increased (20%) for Raleigh by slag addition. However, Si addition did not increase tissue K for other varieties.

Tissue Ca was generally not influenced by Si amendment, and few differences among varieties were evident. Silicon addition tended to decrease tissue Mg, as Mg was 23% higher for treatments not receiving slag. Raleigh also had higher tissue Mg than all other varieties either with or without slag. Similar to Mg, tissue Mn was generally higher for Raleigh than other varieties, although Si did not influence tissue Mn. Likewise, tissue Fe was not influenced by Si addition, and few variety differences were detected. In contrast, tissue Cu was significantly influenced by Si for all varieties. Silicate slag addition increased tissue Cu by an average of 37%. Tissue Si was significantly correlated with tissue Cu ($r = 0.85$). Tissue Zn content was generally not influenced by Si, and there were no variety differences. Tissue Zn content was generally not influenced by Si, and there were no variety differences.

Chinch bug tests. Survival and development of chinch bugs held on different varieties and silicon treatments are shown in Table 2. Mean survival was lower in the 2

Table 1. Leaf tissue analysis for three St. Augustinegrass varieties*.

Variety	Si Fertilization	Si g/kg	TP g/kg	TN g/kg	K g/kg	Ca g/kg	Mg g/kg	Mn mg/kg	Fe mg/kg	Cu mg/kg	Zn mg/kg
Captiva	-	1.8 c	4.6 a	26.7 ab	23.8 b	3.0 a	1.5 b	225 a	37 b	27 bc	162 b
Captiva	+	7.3 b	3.0 bc	23.7 c	18.3 c	2.9 a	1.0 c	206 a	47 b	48 a	135 b
Floratam	-	1.0 c	3.9 ab	25.0 abc	20.6 bc	2.1 b	1.5 b	194 ab	55 ab	21 c	280 a
Floratam	+	5.3 b	3.0 c	21.9 bc	17.0 c	2.1 b	1.0 c	150 b	64 a	42 ab	154 b
Raleigh	-	2.1 c	3.9 ab	26.7 ab	23.9 b	2.2 b	1.9 a	221 a	48 ab	46 ab	198 ab
Raleigh	+	10.4 a	3.9 abc	29.5 a	28.6 a	2.7 ab	1.7 ab	230 a	48 ab	59 a	151 b

* Means in the column followed by the same letter are not significantly different (alpha = 0.05) using a Least Significant Difference test (SAS 2010).

Table 2. Survival* and development of southern chinch bugs held 21 days on different varieties and silicon treatments.

Variety	Survival		% adults of total survivors
	$\overline{X}$ ± SD	Range	
Captiva - Si	2.2 ± 2.3 B	0 - 6	36
Captiva + Si	1.8 ± 1.8 B	0 - 4	33
Floratam - Si	5.2 ± 1.9 A	3 - 8	57
Floratam + Si	3.6 ± 2.1 AB	2 - 7	67
Raleigh - Si	4.2 ± 1.5 AB	2 - 6	66
Raleigh + Si	6.0 ± 3.2 A	2 - 9	74

* Ten first instars were used at start of test. Means in the column followed by the same letter are not significantly different (alpha = 0.05) using a Least Significant Difference test (SAS 2010).

Captiva treatments than the other 4 treatments of Floratam and Raleigh. The percentage of chinch bug adults of all survivors (nymphs + adults) was also lower in Captiva with silicon (33%) and without (36%) than the other 4 treatments (range = 57 - 74%). These latter data indicate that, besides causing direct mortality, Captiva reduced the developmental rate of the chinch bugs during the test. The preceding data are expected because Captiva was the only variety of the 3 tested which is currently resistant to southern chinch bugs in Florida (Nagata and Cherry 2003, Trenholm et al. 2006).

There were no significant differences in chinch bug survival among silicon treatments in any of the 3 varieties. The percentage of adults of total live nymphs and adults was similar (range = 12%) among silicon treatments in each of the 3 varieties. These latter data indicate that, besides not causing direct mortality, the silica treatments did little, if anything, to reduce developmental rates of the chinch bugs. As noted earlier, increased Si in plant tissue has been shown to reduce feeding damage in some studies. However, the insect-plant-silicon response is complex and not always predictable. For example, Peterson et al. (1988) showed that high levels of silica decreased digestibility in *Spodoptera eridania* (Cramer) and promoted increased consumption rates. However, larval growth rates were not different from the control even at the highest level of silica (20% dry weight). More recently, Korndorfer et al. (2004) found that higher concentrations of silicon found in 5 turfgrass species treated with calcium silicate slag did not affect tropical sod webworm *Herpetogramma phaeopteralis* Guenee feeding or development. Also, it has been shown that certain plant genotypes are more efficient that others in their accumulation of Si, thus making them more resistant (Savant et al. 1997). Our study, like other studies, shows application of elements to plants may affect insects in different and not always predictable ways.

Disease assessments. The results of the disease assessments for the 3 varieties either amended or nonamended with Si are presented in Table 3. By both rating systems, Raleigh without Si had significantly higher disease incidence and severity compared with all other varieties and Si treatments. Raleigh with Si fertilization had significantly less disease incidence (47%) than Raleigh without Si (92%) but was also

Table 3. Disease incidence and severity ratings for gray leaf spot on three varieties of St. Augustinegrass.

		Disease Ratings*	
Variety	Si Fertilization	Disease Incidence (% of affected leaflet/runner)	Disease Severity (% affected foliage)
Captiva	-	6.0 d	1.11 c
Captiva	+	7.0 d	0.4 c
Floratam	-	26.0 c	2.6 c
Floratam	+	9.0 d	0.75 c
Raleigh	-	92.0 a	43.0 a
Raleigh	+	47.0 b	17.4 b

* Means in the column followed by the same letter are not significantly different ($P < 0.0001$) using a Least Significant Difference test (SAS 2010).

significantly higher compared with Floratam and Captiva regardless of Si treatment (Table 3). Only Floratam without Si had significantly higher disease incidence compared with the other Floratam and Captiva treatments. However, overall, gray leaf spot disease was very low on Captiva regardless of Si treatment and on Floratam with Si. These results indicate that Raleigh overall was more susceptible to gray leaf spot; however, the addition of Si resulted in significant disease reduction for this variety. Floratam and Captiva had considerably less disease but the addition of Si assisted in disease suppression on Floratam as measured by disease incidence but not severity.

This trial was very successful for disease evaluation of the targeted pathogen. The disease severity in this trial was very high and differences between the cultivars and application or no application of silicon were readily apparent. It would be useful to examine seasonal effects on this and other diseases over time to see if silicon helps under different environmental conditions and disease pressure.

Plant growth tests. Results of morphological measurements of the 3 St. Augustinegrass varieties with or without silicate slag application to the potting soil are presented in Table 4. During a 6-wk period of time, lengths of the longest stolons on average increased by 25.6 cm in Floratam, 27.4 cm in Captiva, and 12.5 cm in Raleigh. All plants of Floratam and Captiva were healthy but the Raleigh plants had gray leaf spot disease (Table 3), which may explain why the Raleigh plants grew poorly and slowly. Addition of Silicate slag significantly increased the length of the longest stolons in Floratam but had no effects on growth of the longest stolons of Captiva or Raleigh, suggesting that varieties responded differently to Si addition to soil. Similarly, formation of the new stolons of Floratam and Captiva was significantly promoted by Si fertilization. Floratam plants grown in Si slag-added soil had 1.5 more stolons than the plants in unamended soil and Captiva plants in Si slag-added soil produced 3.5 more stolons than the plants in unamended soil. Si fertilization did not significantly affect the number of stolons in Raleigh. There were no significant differences in internode lengths between plants grown in Si-added soil and unamended soil for all 3 varieties.

Table 4. Growth characteristics* of three St. Augustinegrass varieties with (+) and without (-) silicon fertilization.

Variety	Si Fertilization	Stolon growth (cm)	Number of stolons	Leaf blade length (cm)	Leaf blade width (cm)	Sheath length (cm)	Internode length (cm)
Captiva	-	27.4 ab	7.6 b	1.8 d	0.5 d	1.7 b	3.2 b
Captiva	+	27.8 ab	11.1 a	2.0 cd	0.6 c	1.6 b	3.5 b
Floratam	-	25.6 b	4.4 c	3.0 ab	0.9 a	2.4 a	4.4 a
Floratam	+	32.1 a	6.1 b	3.2 a	0.9 a	2.5 a	4.5 a
Raleigh	-	12.5 c	1.5 d	2.3 cd	0.6 c	1.6 b	2.9 b
Raleigh	+	12.4 c	2.0 d	2.5 bc	0.7 b	1.8 b	3.3 b

* Means in the column followed by the same letter are not significantly different (alpha = 0.05) using a Least Significant Difference test (SAS 2010).

Among the 3 leaf characteristics (leaf blade length, width, and sheath length), Si fertilization resulted in increase of leaf blade width in Captiva and Raleigh but did not significantly influence leaf blade length or sheath length in any of varieties.

The present study showed that growth characteristics in St. Augustinegrass responded differently to Si fertilization. Si treatment had significantly positive effects on 3 of the 6 traits in 1 or 2 varieties. However, no trait was significantly influenced by Si slag in all 3 varieties. There were no significant effects of Si fertilization on leaf length, sheath length, and internode length in any of the 3 varieties. Secondly, varieties varied in their responses to Si treatment, Floratam responding to Si fertilization for stolon length and stolon number per plant, Captiva responding for stolon number and leaf blade width, and Raleigh responding for leaf width. Thirdly, all the effects of Si fertilization detected in this study were positive on the growth characteristics, which in general agrees with the observations made in jute by Khan and Roy (1964), in cucumber by Adatia and Besford (1986), and in cowpea by Mali and Aery (2008).

Data obtained in this study are relevant to our testing conditions. However, other variables may affect these test results. For example, testing was conducted in cooler weather from Jan. to Mar. Greater plant growth would be expected during warmer months. Also, disease incidence and severity of Raleigh was higher than Captiva and Floratam and may have affected plant growth of Raleigh. Under field conditions throughout the year, occurrence of different diseases on the three varieties may be different than observed in this study.

References Cited

Adatia, M. H. and R. T. Besford. 1986. The effects of silicon on cucumber plants grown in recirculating nutrient solution. Ann. Bot. (Lond.) 58: 343-351.

Alvarez, J. and G. J. Gascho. 1979. Calcium silicate slag for sugarcane in Florida. Part II-Economic response. Sugar y Azucar 74: 32-35.

Arnon, D. I. and P. R. Stout. 1939. The essentiality of certain elements in minute quantity for plants with special reference to copper. Plant Physiol. 14: 371-375.

Ayres, A. S. 1966. Calcium silicate slag as a growth stimulant for sugarcane on low-silicon soils. Soil Sci. 101: 216-227.

Brecht, M. O., L. E. Datnoff, T. A. Kucharek and R. T. Nagata. 2004. Influence of silicon and chlorothalonil on the suppression of gray leaf spot and increase plant growth in St. Augustinegrass. Plant Dis. 88: 338-344.

Busey, P. and B. Center. 1987. Southern chinch bug (Hemiptera: Heteroptera: Lygaeidae) overcomes resistance in St. Augustinegrass. J. Econ. Entomol. 80: 608-611.

Carvalho, S. P., J. C. Moraes and J. G. Carvalho. 1999. Silica effect on the resistance of *Sorghum bicolor* (L.) Moench to the greenbug *Schizaphis graminum* (Rond.) (Homoptera: Aphididae). Anais da Sociedade Entomologica do Brasil. 28: 505-510.

Cherry, R. and R. Nagata. 1997. Ovipositional preference and survival of southern chinch bugs (*Blissus insularis* Barber) on different grasses. Int. Turfgrass Soc. Res. J. 8: 981-986.

Datnoff, L. E. and R. T. Nagata. 1999. Influence of silicon on gray leaf spot development in St. Augustinegrass. Phytopathology 89: S19.

Datnoff, L. E. and B. A. Rutherford. 2004. Effects of silicon on leaf spot and melting out in bermudagrass. Golf Course Manage. 5: 89-92.

Datnoff, L. E., G. H. Snyder and G. H. Korndorfer. 2001. Silicon in agriculture. Elseveir Science, The Netherlands.

Franco, C. J. F. and G. H. Korndorfer. 1995. Aplicação de silício (Si) em cana-de-açucar: uma alternation para melhorar características químicas de solos de cerrado. Annual, II Semana de Ciências Agrárias-SECA, Uberlándia.

Gascho, G. J. and A. M. O. Elwali. 1978. Tissue testing of Florida sugarcane. Gainesville (FL): Univ. Florida Inst. Food and Agric. Sci. (IFAS). Belle Glade Agricultural Research and Education Center Research Report EV-1978-3.

Hamel, S. C. and J. R. Heckman. 1999. Impact of mineral silicon products on powdery mildew in greenhouse grown turf. Rutgers Turfgrass, vol. 31, Rutgers, NJ.

Horn, G., A. Dudeck and T. Toler. 1973. Floratam St. Augustinegrass: a fast growing new variety for ornamental turf resistant to St. Augustinegrass decline and chinch bugs. Florida Agric. Exp. Stn. Circ. S-224.

Jones, L. H. P. and K. A. Handreck. 1967. Silica in soils, plants, and animals. Adv. Agron. 19: 107-149.

Khan, D. H. and A. C. Roy. 1964. Growth, P-uptake and fiber cell dimensions of jute plants affected by silicate treatement. Plant Soil 20: 331-336.

Korndorfer, A., R. Cherry and R. Nagata. 2004. Effect of calcium silicate on feeding and development of tropical sod webworms (Lepidoptera: Pyralidae). Fla. Entomol. 87: 393-395.

Korndorfer, G. H., G. H. Snyder, M. Ulloa and L. E. Datnoff. 2001. Calibration of soil and plant silicon for ice production. J. Plant Nutr. 24: 1071-1084.

Mali, M. and N. C. Aery. 2008. Silicon effects on nodule growth, dry-matter production, and mineral nutrition of cowpea (*Vigna unguiculata*). J. Plant Nutr. Soil Sci. 171: 835-840.

Nagata, R. and R. Cherry. 2003. A new source of southern chinch bug (Hemiptera: Lygaeidae) resistance in a diploid selection of St. Augustinegrass. J. Entomol. Sci. 38: 654-659.

Peterson, S., J. Scriber and J. Coors. 1988. Silica, cellulose, and their interactive effects on the feeding performance of the southern armyworm, *Spodoptera eridania* (Cramer) (Lepidoptera: Noctuidae). J. Kans. Entomol. Soc. 61: 169-177.

Saigusa, M., K. Onozawa, H. Watanabe and K. Shibuya. 1999. Effects of porous hydrate calcium silicate on the wear resistance, insect resistance and disease tolerance of turf grass "Miyako". Grassland Sci. 45: 416-420.

Samuels, G. 1969. Silicon and sugar. Sugar y Azucar 66: 25-29.

SAS. 2010. SAS Institute. Cary, NC.

Savant, N. K., G. H. Snyder and L. E. Datnoff. 1997. Silicon management and sustainable rice production. Adv. Agron. 58: 151-199.

Trenholm, L., J. Cisar and J. Unruh. 2006. St. Augustinegrass for Florida lawns. U. of Florida Electronic Data and Information Source (EDIS) – ENH5.

Uriarte, R. F., H. D. Shew and D. C. Bowman. 2004. Effect of soluble silica on brown patch and dollar spot of creeping bentgrass. J. Plant Nutr. 27: 325-339.

Wang, S.Y. and G. J. Galletta. 1998. Foliar application and potassium silicon induces metabolic changes in strawberry plants. J. Plant Nutr. 21: 157-167.

Wright, A. L. 2009. Soil phosphorus stocks and distribution in chemical fractions for long-term cropping, pasture, turfgrass, and forest systems in Florida. Nutr. Cycl. Agroecosyst. 83: 223-231.

Wright, A. L. and R. S. Mylavarapu. 2010. Nutrient stratification in uncultivated and sugarcane-cultivated peatlands. Commun. Soil Sci. Plant Anal. 41: 2633-2643.