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Silicon in the Life and Performance of Turfgrass

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Over the past few years there has been a growing interest in the element silicon and its effects on the life and performance of plants. Many turfgrass managers want more information regarding its role in plant function. This article attempts to address that issue by first presenting general information about silicon in soil, silicon in plants, and silicon effects on abiotic (i.e., heat stress, drought stress, mineral toxicities, and wear tolerance) and biotic (plant diseases and insects) stress. Then, the currently-known role of silicon in turfgrass is explained along with mechanism(s) of silicon-mediated resistance to plant diseases. Finally, an outlook section on the future for silicon in turfgrass performance is presented.

Silicon in Soil

Silicon (Si) is the second most abundant mineral element in soil after oxygen and comprises approximately 28% of the earth's crust (11,12). Despite the abundance of Si in most mineral soils worldwide, Si deficiency can still occur due to Si depletion from continuous planting of crops that demand high amounts of this element, such as rice (11). Rice can uptake roughly 230 to 470 kg of Si per ha and intensive cropping results in the removal of Si from the soil solution at a rate faster than it can be replenished naturally (11,33). Silicon deficiency occurs more often in highly-weathered, low-base-saturation, and low-pH soils such as Oxisols and Ultisols which are used to cultivate upland rice in Asia, Africa, and Latin America (32).

Heavy rainfall in regions where these two types of soils occur can cause high degrees of weathering, leaching, and desilification (33). Organic soils (Histosols) are also deficient in plant-available Si because of the greater content of organic matter (» 80%) and low content of minerals. Those Entisols having a high content of quartz sand (SiO_2) are also low in plant-available Si (6). Such Si-deficient conditions may be prevalent on USGA-based quartz sand greens and tees.

Soil solutions generally have a Si concentration of 3 to 17 mg of Si per liter (19). This is considered low, but nevertheless it is 100 times greater than phosphorus in most soil solutions.

Silicon in Plants

Many plants are able to uptake Si. Plants absorb Si from the soil solution in the form of monosilicic acid, $Si(OH)_4$, which is carried by the transpiration stream and deposited in plant tissues as amorphous silica gel, SiO_2nH_2O, also known as opal (33,35). Depending upon the species, the content of Si accumulated in the biomass can range from 1% to greater than 10% by weight (11,12). Plant species are considered Si accumulators when the concentration of Si (dry weight basis) is greater than 1% (13). Relative to monocots, dicots such as tomato and soybean are considered poor accumulators of Si with values less that 0.1% of Si in their biomass. Terrestrial grasses such as wheat, oat, rye, barley, sorghum, corn, sugarcane, and turfgrass contain about 1% of Si in their biomass, while aquatic grasses have Si content up to 5% (12,13,20,25). On a weight basis, Si is taken up at levels equal to or greater than essential nutrients such as nitrogen and potassium in plant species belonging to the families Poaceae, Equisetaceae, and Cyperaceae (33). Although Si has not been considered an essential element for crop plants for lack of supportive data, species such as *Equisetum* and some diatomaceaes cannot survive without an adequate level of Si in their environment (12,13). Currently, 21 plant families have been identified as being Si accumulators (26).

Silicon Effects on Abiotic and Biotic Stress

The beneficial effects of Si, direct or indirect, to plants under abiotic and/or biotic stress have been reported to occur in a wide variety of crops such as rice (*Oryza sativa*), oat (*Avena sativa*), barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), cucumber (*Cucumis sativus*), sugarcane (*Saccharum officinarum*), ornamentals (such as paper daisy, *Banksia gardneri*), and turfgrass (such as St. Augustinegrass, *Stenotaphrum secundatum*) (10,12,13). Leaves, stems, and culms of plants grown in the presence of Si show an erect growth, especially for rice. This suggests that the distribution of light within the canopy is greatly improved (11,12,33). Silicon increases rice resistance to lodging and drought, and dry matter accumulation in cucumber and rice (1,12,22). Silicon can positively affect the activity of some enzymes involved in the photosynthesis in rice and turfgrass (33,34) as well as reduce rice leaf senescence (21). Silicon can lower the electrolyte leakage of rice leaves, promoting greater photosynthetic activity in plants grown under water deficit or heat stress (2). Silicon increases the oxidation power of rice roots, decreases injury caused by climate stress such as typhoons and cool summer damage in rice, alleviate frost damage in sugarcane and other plants, and favors supercooling of palm leaves (17,33). Silicon reduces the availability of toxic elements such as manganese (Mn), iron (Fe), and aluminum (Al) to roots of plants such as rice and sugarcane and increases rice and barley resistance to salt stress (23,33). Moreover, the most significant effect of Si to plants, besides improving their fitness in nature and increasing plant productivity, is the suppression of insect feeding and plant diseases (3,6,8,33).

Role of Silicon in Turfgrass

Fertilization with Si has shown positive effects in alleviating abiotic stress as well as improving plant growth and development in several turfgrass species. Since Si improves leaf and stem strength through deposition in the cuticle and by maintaining cell wall polysaccharide and lignin polymers (19,35), the possibility exists that Si could improve wear tolerance. Saiguisa and his colleagues (31) demonstrated significant improved wear resistance in the Zoysiagrass cultivar 'Miyako.' Foliar spraying potassium silicate at 1.1 or 2.2 kg of Si per ha, or applying 22.4 kg/ha as a soil drench, also significantly reduced by around 20% the injury caused by wear to seashore paspalum (36). However, K alone or together with Si provided the same effect. In another study, several cultivars of creeping bentgrass and Zoysiagrass had improved turf quality, growth, and resistance to traffic and heat stress (24). Under severe drought stress, Si-fertilized St. Augustinegrass plants had a better response than those non-fertilized (36). Leaf firing and density were significantly greater by 13 and 23.5%, respectively, in Si-fertilized plants. Quality, color, and density also were significantly enhanced when fertilized with Si over the controls by 19, 13.6, and 8.5%, respectively. However, under these test conditions, visual scores were all below what would be considered acceptable for turfgrass use. Nevertheless, this demonstrates that Si may improve these turfgrass qualitative factors under extreme drought stress. Schmidt and his associates (34) also showed that foliar applications of Si significantly enhanced photosynthetic capacity increasing chlorophyll content especially during the summer when plants were influenced by environmental stress.

Gussak and his associates (15) demonstrated increased growth and establishment of creeping bentgrass (*Agrostis palustris* Huds.) fertilized with Si. Brecht et al. (4) and Datnoff et al. (5) also demonstrated similar results in St. Augustinegrass. A percent bare ground coverage (vertical prostrate growth) rating was recorded 11 to 12 weeks after sprigging a field with St. Augustinegrass by estimating a visual percent area of bare ground covered by grass in a 2-m^2

area (4). They demonstrated that the final percent bare ground coverage was significantly increased by using Si by 17 to 24% over the control. Ten months after sprigging, one pallet containing 46 m^2 of St.Augustinegrass was harvested from each treatment-silicon and a control (5). Sod pieces (mat), 30 × 61 cm, were washed to remove soil, dried for 48 h, and weighed. In addition, fresh, intact sod pieces (mats) from each treatment were transplanted to a sand site and monitored for turf quality and root length development for 21 days. At harvest, the treatment that had been fertilized with Si had a dry sod mat weight that was 13% significantly higher than the control. Sod pieces amended with Si also had improved turf quality ratings, 7.1 to 7.6 versus 6.6 to 7.1 in comparison to the non-fertilized control, 14 and 21 days after being transplanted to the field. In addition, Si treatments had a significantly greater increase in newly-generated roots, 0.8 to 1 cm in root length, in comparison to the non-fertilized control.

Silicon also has been effective in suppressing diseases in a number of warm- and cool-season turfgrass species (Table 1). Silicon has increased the resistance of zoysiagrass to *Rhizoctonia solani* (31); creeping bentgrass to *Pythium aphanidermatum*, *Sclerotinia homoeocarpa*, and *R. solani* (15,28,30,34,37); and in Kentucky bluegrass to powdery mildew (*Sphaerotheca fuliginea*) (16). Gray leaf spot development was reduced by Si over a range of 19 to 78% on several cultivars of St. Augustinegrass under greenhouse conditions (7) (Fig. 1). In field experiments, Si alone was compared to foliar sprays of chlorothalonil and of Si plus chlorothalonil for managing gray leaf spot development (4). Gray leaf spot was reduced by 17 to 27%, 31 to 63%, and 56 to 64% for Si alone, chlorothalonil alone, and Si plus chlorothalonil, respectively, compared to a non-treated control. Recently, Nanayakkara et al. (27) demonstrated similar results in perennial ryegrass turf. They showed that gray leaf spot severity was reduced from 11 to 24%.

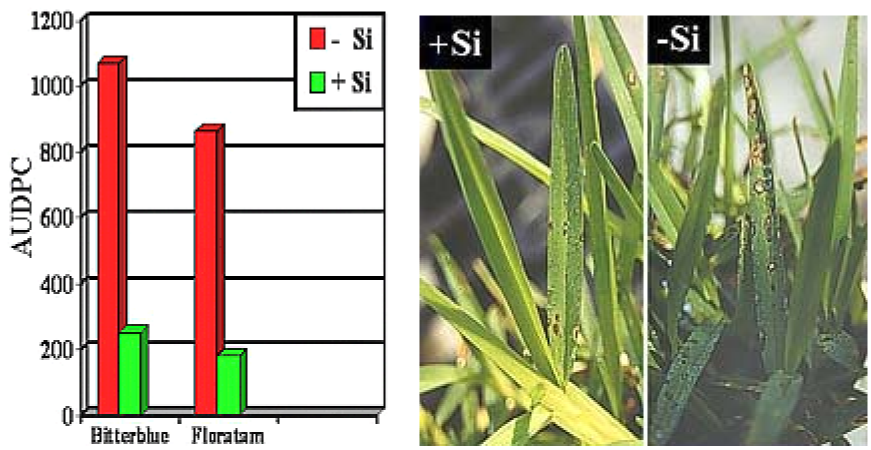

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Fig. 1. Influence of silicon on gray leaf spot development in St. Augustinegrass.

Datnoff and Rutherford (9) recently evaluated the ability of Si to enhance disease resistance in 'Tifway' bermudagrass to *Bipolaris cynodontis*, the cause of leaf spot and melting out. They found that plants fertilized with Si had 39% fewer lesions than plants non-fertilized (Fig. 2). This was also the first experiment to demonstrate that bermudagrass accumulates Si. Silicon increased in leaf tissues 38 to 105% over the control.

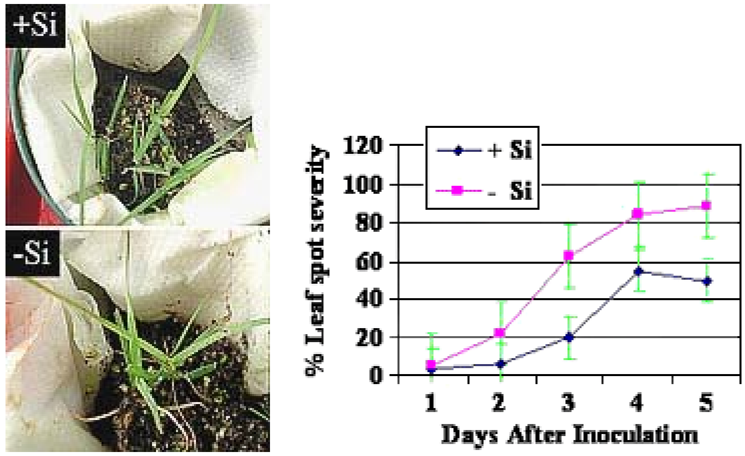

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Fig. 2. Influence of silicon on Bipolaris leaf spot development in bermudagrass.

Mechanism(s) of Silicon-Mediated Resistance to Plant Diseases

The effect of Si on plant resistance to disease is considered to be due either to an accumulation of absorbed Si in the epidermal tissue, and/or expression of pathogensis-induced host defense responses. Accumulated monosilicic acid polymerizes into polysilicic acid and then transforms to amorphous silica, which forms a thickened Si-cellulose membrane (18). By this means, a double cuticular layer protects and mechanically strengthens plants. Silicon also might form complexes with organic compounds in the cell walls of epidermal cells, therefore increasing their resistance to degradation by enzymes released by fungi (8).

Research also points to the role of Si *in planta* as being active and this suggests that the element might amplify the response for inducing defense reactions to plant diseases. Silicon has been demonstrated to stimulate chitinase activity and rapid activation of peroxidases and polyphenoxidases after fungal infection (3). Glycosidically bound phenolics extracted from Si amended plants when subjected to acid or B-glucosidase hydrolysis displayed strong fungistatic activity. More recently, flavonoids and momilactone phytoalexins, low molecular weight compounds that have antifungal properties, were found to be produced in both dicots and monocots, respectively, fertilized with Si and challenge inoculated by the pathogen in comparison to non-fertilized plants also challenged inoculated by the pathogen. These antifungal compounds appear to be playing an active role in plant disease suppression (14,29).

Table 1. Turfgrass, disease, and plant pathogen response to silicon.

Turfgrass	Disease	Pathogen	Effect[x]	Reference(s)
Zoysiagrass	Leaf blight	*Rhizoctonia solani*	<	(31)
Creeping bentgrass	Root rot	*Pythium aphanidermatum*	<	(15,28,30,34,37)
	Brown patch	*Rhizoctonia solani*	<	
	Dollar spot	*Sclerotinia homoeocarpa*	<	
Kentucky bluegrass	Powdery mildew	*Sphaerotheca fuliginea*	<	(16)
Bermudagrass	Leaf spot	*Bipolaris cynodontis*	<	(9)
St. Augustine-grass	Gray leaf spot	*Magnaporthe grisea*	<	(4,7)
Perennial ryegrass	Gray leaf spot	*Magnaporthe grisea*	<	(27)

[x] Silicon applied as calcium silicate or potassium silicate decreased (<) disease intensity.

Outlook and Future for Silicon in Turfgrass Performance

That Si plays an important role in the mineral nutrition of plant species such as rice and sugarcane is not in doubt nor is its ability to enhance plant development and efficiently control plant diseases. Now evidence is accumulating that similar effects occur in certain turfgrasses. Effective, practical means of application, affordable sources of Si, and methods for identifying conditions under which Si fertilization will be beneficial are needed for use in turfgrass management. However, research on the use of Si for turfgrass is in its infancy. For example, no soil tests for gauging amounts of plant-available Si have been calibrated for turfgrass. Furthermore, most analytical laboratories do not routinely assay plant tissue for Si. In fact, the current standard tissue digestion procedures used in most laboratories would render Si insoluble, making an analysis of the digested tissue meaningless. Thus, the two analytical tools most often used for determining the need for fertilization with plant nutrients are not widely available for Si. While a number of beneficial responses of turfgrass to Si applications have been documented in controlled experiments, particularly in the laboratory, few large-scale field effects have been observed to date. Conditions under which beneficial responses to Si fertilization will occur are not well known for turfgrass.

Nevertheless, as the need for environmentally friendly strategies for management of abiotic and biotic stress increases, Si could provide a valuable tool for use in plants capable of its accumulation. The use of Si for improving plant performance while controlling plant diseases in turf would be well-suited for inclusion in integrated pest management strategies and would permit reductions in fungicide use. As researchers and turfgrass managers become aware of Si and its turf potential, it is likely that this often overlooked element will be recognized as a viable means of enhancing turfgrass health and performance.

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