Scientists Start to Recognize Silicon's Beneficial Effects

By Richard J. Hull

In the first articles of this series on beneficial elements (Hull, 2004), we discussed the general distinctions between essential and beneficial nutrients. The beneficial element under consideration here, silicon (Si), could justify being applied to turf. In fact, there are more published reports on the beneficial effects of applying Si to turf than there are for most essential micronutrient elements.

In his review article on Si, Emanuel Epstein concluded that Si is unquestionably an important requirement for the normal growth of many plants, and it should be viewed as "quasi-essential" (Epstein, 1999).

Si in soils and soil solutions

Silicon is the second-most abundant element in the earth's crust at 31 percent. Only oxygen is more plentiful at 49 percent.

Many of our most common minerals are various combinations of aluminum and iron silicates. These minerals are highly insoluble, so while the mineral matter of most soils is literally made of Si, its concentration in the soil solution is relatively low. As Si minerals weather, some of the Si slowly hydrates and solubilizes as orthosilicic acid (H_4SiO_4).

Because the Bordwell acidity measurement (pK_a) of silicic acid is 9.82 at 77 degrees Fahrenheit, it loses none of its positive hydrogen ions (H^+) at the pH of most soils and remains in the soil solution as uncharged silicic acid. The pK_{a1} is that solution pH at which an acid will lose to the solution 50 percent of its least tightly held H^+ such that half of the acid molecules are then present as a monovalent anion.

Salicic acid is weakly soluble; a saturated solution being about 2 millimoles (mM), which is equivalent to 56 milligrams (mg) Si/liter (Si/l). Therefore, soil solutions generally have a Si concentration of .1 mM to .6 mM (3-17 mg Si/l), which is low but still is 100 times greater than soil solution phosphate. Because there are so many silicate minerals in most soils, this low silicic acid concentration is well-maintained at the .1 mM to .6 mM level. This is the form and concentration of Si available to plant roots.

Si absorption and transport

Plants differ in their ability to absorb Si from the soil solution. Marschner (1995) identifies three types of plants based on their capacity for Si absorption: Si accumulators, Si nonaccumulators and Si excluders.

Silicon accumulators include several primitive plants including the horsetails (*Equisetum* spp.) and wetland grasses such as paddy rice that contain Si at 4.6 percent to 7 percent of their leaf dry weight. These plants contain much more Si than is carried to the surface of the roots as the plant loses water through transpiration. The roots of these plants must deplete the silicic acid from the soil water adjacent to their root surfaces allowing additional silicic acid to diffuse toward the roots. This requires active Si uptake by the roots. Si nonaccumulators contain .5 percent to 1.5 percent Si in their dry leaf tissues and include most dry land grasses including sugarcane, cereals and turfgrasses. These plants absorb as much Si as is transported to their roots by the mass flow of transpirational water.

The Si excluders contain less than .23 percent Si in their dry leaf tissues. These plants contain less Si than transpirational water would deliver to their roots. Here, water is absorbed more rapidly than the silicic acid it contains, indicating that Si is in some way excluded from entering the roots. It might be good to realize that even at .25 percent to .1 percent of dry tissues, Si is present at levels comparable to the macronutrients sulfur (S), phosphorus (P) and magnesium (Mg).

Since accumulator plants and nonaccumulators growing in low silicic acid concentrations can concentrate Si to levels greater than that of the growing medium, it is assumed that an active transporter is involved.

Studies reported by Tamai and Ma (2003) show that rice can accumulate silicic acid through the action of a membrane transporter that has a low affinity for silicic acid, is inhibited by a number of metabolic toxins and is only

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weakly in competition with the uptake of other nutrients. A rice mutant defective in this specific transporter protein couldn't concentrate silicic acid to the levels observed in wild-type rice.

These findings support the conclusion that silicic acid is absorbed by an active process that uses metabolic energy through a specific transport protein that loads silicic acid into root epidermal cells or from root cells into xylem elements.

Silicon is transported in plants from roots to leaves mainly through the xylem, which can contain silicic acid levels many times that of the soil or nutrient solution. There is little evidence of silicic acid being translocated by the phloem to sites of carbohydrate storage.

Silicon and cell wall structure

Within plants, Si transport is marked by the presence of abundant silicic acid polymers incorporated in cell walls. These occur as amorphous silica deposits known as "opal" or as more crystalline-shaped opal phytoliths (Marschner, 1995). Such deposits are most abundant in the outer epidermal cell walls, and hairs of leaves and stems — the sites of greatest transpirational water loss.

These impregnated Si layers within cell walls are most developed in older leaves and present a barrier to cuticular transpiration and fungal penetration of leaves. The strengthening effect of silica polymers in cell walls can prevent xylem vessels from collapsing during times of maximum water stress.

The interaction of Si with lignin biosynthesis and structure, mostly in vascular cells, has been studied, and several theories of silicic acid binding with phenolic groups have been proposed. That such reactions can occur is unquestioned, but their role in determining lignin structure and physical properties is less certain.

Silicic acid can form ester-like linkages between phenolic groups of lignin, and it is likely that such structures will stabilize and strengthen the cell walls. It is also likely that the action of other nutrients, e.g. boron, will be increased when Si is present. At present, however, there is no evidence that Si is essential for cell wall biosynthesis and its involvement with cell wall structure plays no part in Si excluding species.

It has frequently been observed that the presence of Si reduces the toxicity of some heavy metals in plants. The mechanism of such protection is incompletely understood, but it appears to depend on Si binding with metals and preventing their concentration to toxic levels at localized sites. Iron, manganese and aluminum are the metals most often found to be less toxic in the presence of Si. In Si-accumulator plants, iron and manganese are immobilized within the roots before they can be transported to shoots (Ma and Takahashi, 1990). This is enhanced in wetland plants because Si increases the rigidity and volume of aerenchyma (air-filled spaces in roots and shoots) that favors the transport of oxygen into the roots, oxidizing iron and manganese to their less toxic form.

In nonaccumulator plants, Si can suppress the transport of metals to shoots by forming complexes with the metals and binding them in root cell walls. Some nutrient elements like calcium can also be immobilized in this way.

Wear tolerance

The Si content of turfgrasses places them squarely in the ranks of nonaccumulator grasses. Leaf blades of tall fescue, Kentucky bluegrass and bermudagrass contained 23.9 grams (g), 36.6 g and 24 g silica/kilogram (kg) dry tissue, respectively (Street et al. 1981). When the Si supply was increased, the tissue silica concentrations increased to 41.4 g, 61 g and 38.5 g/kg dry weight, respectively. Clearly, these turfgrasses are not Si excluders.

Applications of Si did not alter turf growth, but water usage was reduced 10.2 percent and 17.5 percent by the low and high silica rates, respectively. Other plants have been observed to become more water efficient when supplemental silica was added. Apparently, the greater silica barrier deposited within the outer cell walls of leaf epidermal cells markedly diminishes cuticular transpiration. Stomatal transpiration is not significantly affected, so any net increase in water-use efficiency would be small.

Because Si promotes greater stem strength by stabilizing cell wall polysaccharide and lignin polymers, its impact on wear tolerance in turf has been studied (Trenholm et al. 2001). Spraying potassium silicate at 1.1 kg and 2.2 kg Si/hectare or applying a soil drench at 22.4 kg Si/hectare to two greens-quality ecotypes of seashore paspalum reduced wear injury by about 20 percent. However, potassium alone or together with Si produced the same effect. There was little evidence that Si alone enhanced the wear tolerance of turf.

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TABLE 2

Three classes of silicon absorbers: Si accumulator (rice), Si nonaccumulator (wheat) and Si excluder (soybean). Plotted from data of Vorm (1980) as presented in Marschner (1995).

Silicon sources used to augment soil Si or include Si in nutrient solutions.

Si source	Chemical formula	Si content	Use*%
Salicic acid	H4SiO4	29	None
Calcium silicate slag	CaAl2Si2O8	18-21	SM
Calcium silicate	CaSiO3	24	SM & NS
Potassium silicate	K2SiO3	18	NS
Sodium silicate	Na2SiO3	23	NS
Quartz sand (fine grind)	SiO2	46	SM

* SM = soil or solid medium; NS = nutrient solution; None = research use

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Because the structural effects of Si deposits require time to establish, it is questionable if frequently mowed turfgrasses would ever show greater Si-induced wear tolerance. Earlier studies demonstrated a decreased decomposition rate of Si-enriched turfgrass (tall fescue and Kentucky bluegrass) tissues incorporated in soil. This suggests that high Si levels in turfgrass shoots could slow the degradation of thatch and promote its accumulation.

Si and disease resistance

The Si content of plant tissues has been positively correlated with enhanced resistance to soil-borne and foliar diseases (Datnoff et al. 2001). A research team in Florida headed by Lawrence Datnoff demonstrated the effectiveness of Si enrichment in controlling several diseases of warm-season turfgrasses. About 30 percent of gray leaf spot on St. Augustinegrass was controlled by Si applications, and its addition increased the effectiveness of fungicide treatments (Brecht et al. 2001).

Common bermudagrass exhibited a doubling of its Si content when its growth medium was supplemented with calcium silicate (Datnoff and Rutherford, 2003). Leaf spot caused by *Bipolaris cynodontis* was suppressed about 40 percent in the high Si bermudagrass. This study demonstrated that the media used for greens construction are often low in plant available Si and the addition of this element can increase the Si content of bermudagrass turf and enhance its disease tolerance.

Studies of Si and disease resistance in cool-season turfgrasses have been less extensive but the results are similar. Tremblay et al. (2002) reported that under greenhouse and field conditions in Quebec, the addition of soluble Si to fertilizer significantly reduced dollar-spot injury on creeping bentgrass.

Hamel and Heckman (1999) at Rutgers University reported on greenhouse experiments in which Kentucky bluegrass sod plugs were grown on artificial media or native soil supplemented with several Si sources. They observed that the addition of Si to the artificial potting mix reduced powdery mildew with reasonable consistently, while these materials exhibited less consistent disease suppression when applied to the mineral soil. No Si analyses of plant tissues were reported.

While existing research on Si and disease suppression has hardly considered all turfgrasses or even many turf diseases, the results to date strongly suggest that insuring favorable Si status of turf will enhance its disease tolerance. The impact of Si on strengthening plant cell walls and stabilizing lignin formation provides a sound theoretical basis for plant disease suppression. Some of this research also indicates that current turf cultural practices may be producing turf low in Si and thereby less fit to tolerate a range of stress conditions.

To see the full text and charts of Dr. Hull's article, please go to:
www.turfgrasstrends.com.

Conclusions

Of all the beneficial plant nutrients, Si clearly has the greatest potential for being useful as a turfgrass management tool. Si's abundance in most soils can give the erroneous impression that it doesn't need to be supplemented in fertilizer. Heavily leached acid soils may be unable to restore silicic acid to the soil solution when it is being absorbed by vigorous plant growth.

The evidence available clearly suggests that supplying Si to turfgrasses may reduce water use by retarding cuticular transpiration, produce more erect plant growth (thereby increasing photosynthetic efficiency), promote a cleaner cut during mowing (thereby favoring more rapid regrowth), retard pathogen attacks by providing tissues less suitable for disease establishment and resist insect feeding due to the presence of less-digestible, toxic vegetation.

Silicon is certainly a potential cultural tool that the turf manager might want to consider seriously.

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