Silicon: A Beneficial Substance

By Joseph Heckman

Silicon (Si) has been officially designated as a plant "beneficial substance" by the Association of American Plant Food Control Officials (AAPFCO) and plant-available Si may now be listed on fertilizer labels.

Silicon is a major component of sand, silt and clay minerals. Because of this abundance, it typically has not been considered as a limiting factor in soil fertility. However numerous field studies have shown that supplying crops with adequate plant-available Si can suppress plant disease, reduce insect attack, improve environmental stress tolerance, and increase crop productivity.

Chemical Names and Terminology

Silicon refers to the chemical element, while silica, silicon dioxide, or SiO_2, are compounds containing both Si and oxygen. Silicate refers to Si-containing crystalline or amorphous compounds such as calcium silicate ($CaSiO_3$), magnesium silicate ($MgSiO_3$), sodium silicate (Na_2SiO_3), or potassium silicate (K_2SiO_3). Silicic acid or mono silicic acid [$Si(OH)_4$, or H_4SiO_4] refers to the soluble, plant-available forms of Si. These materials should not be confused with silicone, which is a rubber-like synthetic compound used as a sealant or adhesive.

Function of Silicon in Plants

Silicon is classified a "beneficial nutrient" in plant biology. Under controlled hydroponic conditions, Si does not meet the classical definition of an essential nutrient. However in the real world where plants are exposed to multiple stresses, Si plays an important role in plant health.

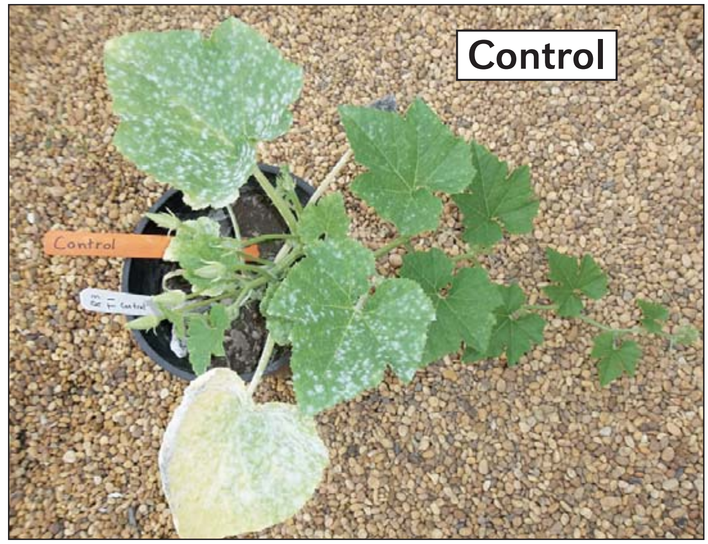
One major contribution of Si is reinforcement of cell walls by deposition of solid silica. It is translocated from the roots as silicic acid [$Si(OH)_4$] through the xylem until it deposits under the cuticle and in intercellular spaces (**Figure 1**). These silica bodies are called phytoliths, or plant opal. These structures are very resistant to decomposition. Many persist in soils as "plant fossils" for very long periods, which is useful in archaeological and paleoecological research.

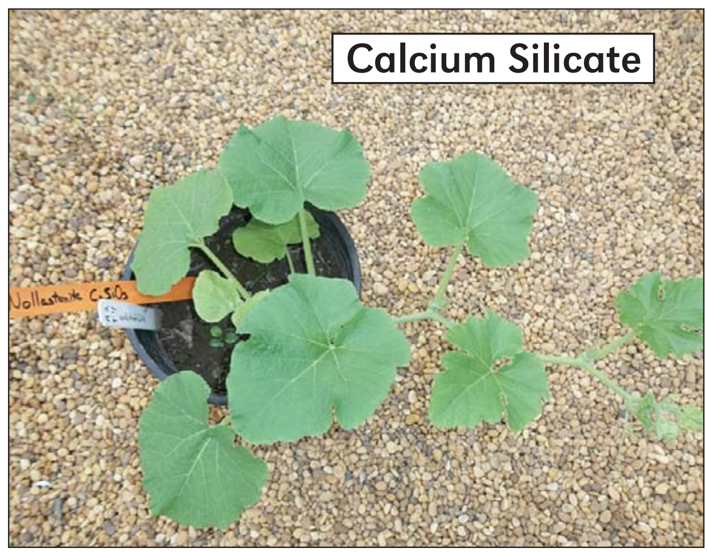
In addition to naturally occurring soluble Si in soil, many crops respond positively to additions of supplemental Si. Plants, especially grasses, can take up large amounts of Si where it contributes to their mechanical strength. Besides a structural role, Si helps to protect plants from insect attack, disease, and environmental stress. For some crops, Si fertilization of soils increases crop yield even under favorable growing conditions and in the absence of disease.

A second mechanism for the beneficial effects of Si is its role in triggering a range of natural defenses. For example, the presence of Si has been shown to stimulate activity of active compounds such as chitinase, peroxidase, polyphenol oxidases, and flavonoid phytoalexins—all of which can protect against fungal pathogens.

Regardless of the mechanism, some observed benefits due to Si nutrition include:

- Direct stimulation of plant growth and yield through more upright growth and plant rigidity
- Suppression of plant diseases caused by bacteria and fungi (such as powdery mildew on cucumber, pumpkin, wheat, barley; gray leaf spot on perennial ryegrass; leaf spot on Bermuda grass; rice blast)
- Improved insect resistance (such as suppression of stem borers, leaf spider mites, and various hoppers)
- Alleviating various environmental stresses (including lodging, drought, temperature extremes, freezing, UV irradiation) and chemical stresses (including salt, heavy metals, and nutrient imbalances)
- Silicon is an important element for animals where it strengthens bones and connective tissue





Powdery mildew disease suppression on pumpkin plants in response to adding calcium silicate (Wollastonite) to soil.

Symptoms of Low Silicon in Plants

Symptoms of low Si are not generally observed in the field. However, indicators of low Si availability may be manifest as increased disease and pest damage. Grain crops lacking adequate Si are more susceptible to lodging, but this is rarely measured.

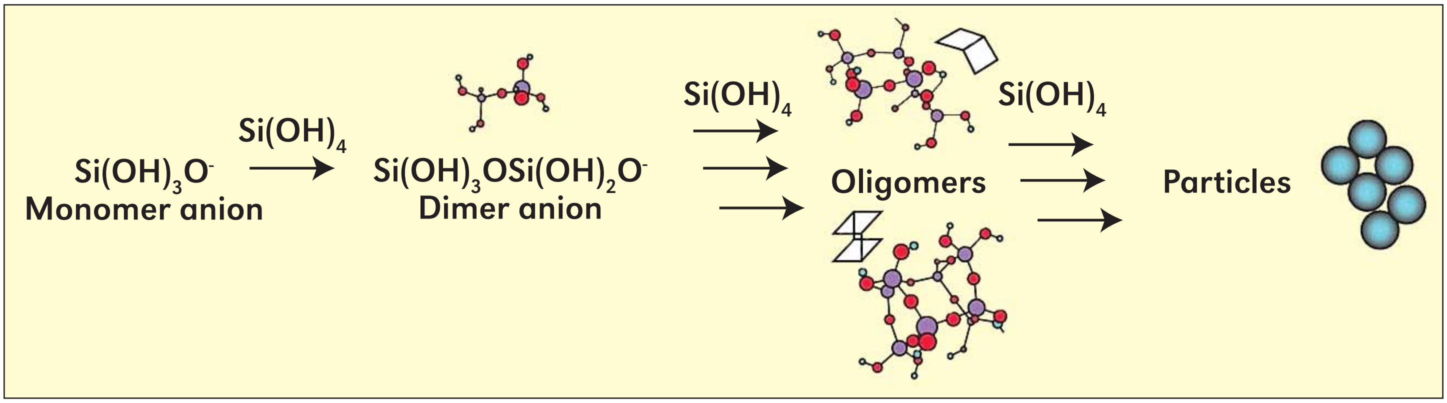


Figure 1. The polymerization of monomeric silicic acid to form larger silica particles proceeds though various condensation reactions with dimers, oligomers and aggregates as intermediates. Adapted from Currie and Perry, 2007.

Plant Tissue Analysis

Plant tissue Si concentrations will vary widely depending on plant species and the soluble Si concentration in the soil. It is not unusual to find Si concentrations in plants at levels comparable to or above those for macronutrients (up to a few percent of dry weight). Grasses and monocots generally accumulate higher concentrations of Si than dicots (approx. 0.1% Si). Concentrations as high as 10% Si are possible in some plant species such as *Equisetum* (Horse tail).

Optimum Si concentrations have not been established for most crops. Research conducted on soils in New Jersey indicates concentration ranges that may occur for some crops. For example, adding supplemental Si increased concentrations in pumpkin leaf tissue from 700 to 3,500 mg Si/kg, in corn stem tissue from 1,300 to 3,300 mg Si/kg, wheat flag leaves from 1,530 to 11,750 mg Si/kg, and Kentucky bluegrass leaves from 4,200 to 7,200 mg Si/kg. Different parts within the same plant can also show large differences in Si accumulation. For example, polished rice contains 0.5 g Si/kg, while the rice hull may contain 230 g Si/kg (Currie and Perry, 2007).

Soil Analysis

Silicon is the second most abundant element in the Earth's crust after oxygen. Soils commonly contain about 30% Si by weight, but most of it is bound in insoluble minerals. With such abundance of Si in nature, the economic value of this element in agronomy and horticulture is sometimes not fully appreciated.

Soils that are highly weathered and have been subject to extensive leaching in a humid environment tend to be depleted of Si. This contrasts with geologically younger soils that generally contain more soluble Si. Soil testing for soluble Si is not a routine part of soil fertility testing, but some laboratories offer an acetic acid extractable Si analysis. At present, the database is very limited in correlating Si soil test levels with plant uptake.

Soil Factors Affecting Silicon Availability

Plants growing in soils with high percentages of sand tend to have low Si concentrations. Although sand is largely composed of Si dioxide, this material provides very little soluble or plant-available Si. Sandy soils also usually have good drainage, which prevents Si accumulation. Thus, it is not unusual for crops grown on sandy soils to benefit from applications of soluble Si.

Silicon is not a major component of soil organic matter. Therefore in soils composed almost entirely of humus and organic matter (muck soils or Histosols), certain crops grown on these soils may benefit from Si application. Similarly, the widespread use of soilless mixes in greenhouse production results in very little Si being supplied from the growth medium. Plants growing in these greenhouse production systems frequently show benefit from Si fertilization.

Silicon availability to plants does not change markedly across the soil pH range where most crops are grown. Many of the commonly used Si fertilizer materials also serve as liming agents and their application results in neutralization of soil acidity.

Crops Likely to Benefit from Silicon

Rice and sugarcane are crops that often exhibit beneficial responses to Si supplementation. Other crops that have shown positive responses to Si include pumpkin, cucumber, corn, wheat, oats, Kentucky bluegrass, and many ornamentals. This is an area that has not yet been extensively studied.

Silicon Sources

Crop residues, animal manures, and composts are all potential sources of Si. Straw from wheat and other small grain crops also return significant amounts of Si to the soil. Wheat straw concentrations range from 0.15 to 1.2% Si depending on the soluble Si concentration of the soil on which it was grown. The Si in crop residues may take many years to dissolve and become available for plant uptake.

To be beneficial for plants, Si amendments should provide a high percentage of Si in a soluble form. Other characteristics to consider are cost, physical properties, ease of application, and perhaps the ability to raise soil pH. Because geologic sources of Si are always combined with other elements, the nutrient value of the other elements present in the product should be considered.

Calcium silicate products are the most commonly applied Si amendments for field application. Steel mill slag by-products are a rich source of calcium silicate. Because this material also neutralizes soil acidity and supplies Ca, it is commonly applied to soil as an alternative liming agent in low pH soils. Wollastonite is a naturally occurring mined $CaSiO_3$ and can be a useful Si source when finely ground. Diatomaceous earth (80 to 90% SiO_2) is also used as a Si source.

Potassium silicate and sodium silicate are commonly used materials for horticultural or greenhouse crop applications. They are soluble Si products that can be added to nutrient solutions or used as foliar sprays. However, plants respond better to Si acquired through the root system than from foliar applications.

Some sources of Si amendments are industrial by-products and should therefore be checked for the presence of undesirable contaminants.

Silicon Fertilization and Rates of Application

The need for Si fertilizer is not easily predicted by currently available soil tests. But soil testing for soil pH and the need for liming may be useful in estimating appropriate application rates of $CaSiO_3$.

A practical approach to managing soil fertility for enhanced Si nutrition of crops is to use $CaSiO_3$ products as a liming material. Application rates can be determined by the need for soil pH adjustment or lime requirement of the soil (often up to several tons per acre).

High-value horticultural crops may benefit for soluble Si fertilizers, such as Na_2SiO_3 or K_2SiO_3, applied through drip irrigation systems or from $CaSiO_3$ additions to soil-less mixes.

An adequate Si supply can benefit plants in a variety of ways, especially when in growing in stressful environments. BC

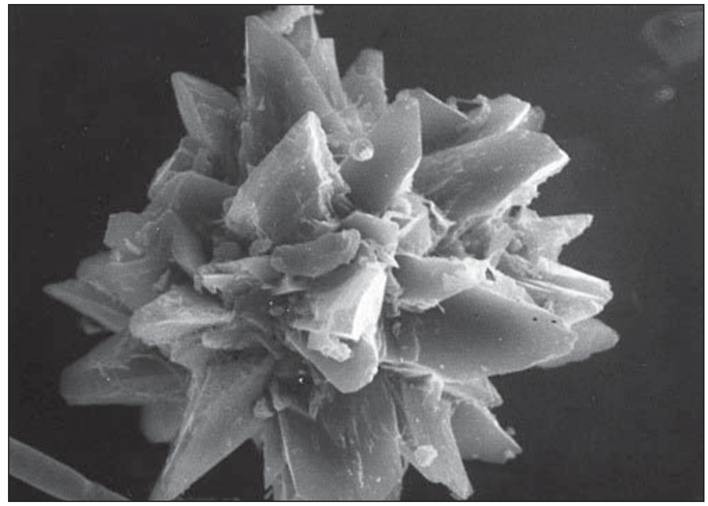
Dr. Heckman is a Professor and Extension Specialist, Rutgers University, New Brunswick, NJ; e-mail: heckman@aesop.rutgers.edu

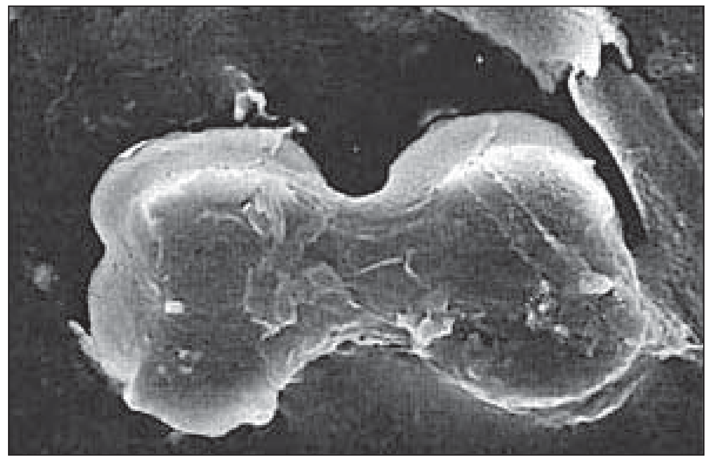
References

Currie, H.A. and C.C. Perry. 2007. Silica in Plants: Biological, Biochemical and Chemical Studies Annals of Botany 100: 1383-1389.

Further Reading

Epstein, E. 2009. Annals of Applied Biology. 155: 155-160.
Heckman, J.R., S. Johnston, and W. Cowgill. 2003. HortSci. 38: 552-554.
Provance-Bowley, M., J.R. Heckman, and E.F. Durner. 2010. Soil Sci. Soc. Am. J. 74: 1652-1661.





Images of Phytoliths or plant microfossils of (top) prickly pear (*Opuntia*) and (bottom) *Panicoid* (*warm season grass*) as viewed through a scanning electron microscope. http://www.texasbeyondhistory.net/varga/images/phytolith.html

Crop Nutrient Deficiency Photo Contest Entries Due December 12

December 12, 2013 (Thursday, 5 pm EDT) is the deadline for entries in the annual IPNI contest for photos showing nutrient deficiencies in crops. An individual can submit an entry for each of the four categories: nitrogen (N), phosphorus (P), potassium (K), and other nutrient deficiencies (i.e., secondary nutrients and micronutrients).

Preference is given to original photos with as much supporting/verification data as possible. Cash prizes are offered to First Place (US $150) and Second Place (US $75) in each of the four categories, plus a Grand Prize of US $200 will be awarded to the photo selected as best over all categories. Winners will be announced in January 2014… also look for details on the 2014 edition of this contest.

Entries can only be submitted electronically to the contest website: www.ipni.net/photocontest BC