Let's Put the Si back into Soil

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There is an expressed doctrine that plants need 16 essential nutrient elements to grow. These include macronutrients: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and micronutrients: boron, chlorine, copper, iron, manganese, molybdenum and zinc. In reality, however, plant growth requires far more than 16 elements. Of the elements, not included in the 16 but proven a quantitatively major inorganic constituent of plants, is silicon (Si). Silicon is the second most abundant element on the surface of the earth and accounts for up to 31% of the earth's crust by weight, 3 to 17 ppm in soil solution. It is most commonly found in soil solution as silicic acid, H_4SiO_4, which is readily absorbed by plants.

Tissue analyses from a wide variety of plants found Si concentrations in those plants to range from 0.2% to 10% of dry weights depending on plant species. This concentration range is equivalent to those (in tissue) of calcium, magnesium, phosphorus and sulfur, four of the included essential elements. Despite this prominence of Si found within a plant's physical makeup, Si has not been considered as an essential element, and not been included in any standard formulation of nutrient solutions and fertilizers. However, continuing evidence suggests that Si does enhance the growth of a wide range of crops, from rice, sugarcane and wheat, to citrus, strawberry, cucumber, tomato and rose. Expressly, Si supplements have been widely used in China, Japan and Korea in rice and sugarcane production and in Europe for the production of greenhouse crops. Subsequently, Si is now considered a "quasi-essential" element for plant growth and development.

In the ornamental plant industry, most plants are grown in containers using organic substrates such as peat, bark and coir dust combinations as growing media, in which soil is almost completely excluded. Natually, Si in those media is quite limited. In order to determine if Si had ornamental applications, we first tested a series of some widely used potting media and found that extractable Si concentrations in those media ranged from 10 to 25 ppm where sand or soil was not incorporated (Table 1 shows three of tested media). We also measured the Si concentration in shoots of container-grown foliage plants and found that the Si concentrations in those plants ranged from 30 to 500 ppm, suggesting that foliage plant roots absorb Si from the organic substrate based media, and apparently translocate a great fraction of the absorbed Si from roots to shoots.

Do Si applications improve the growth of containerized plants? This question prompted a series of experiments using containerized foliage plants as models. The specific findings were presented at the First International Symposium entitled "Silicon in Agriculture" held in Fort Lauderdale, Florida 1999. General findings are discussed here. All experimentation was done using a completely randomized design. Note that only one cultivar of each evaluated species was used in these studies. Therefore, results may vary significantly according to cultivar.

Foliage plant responses to Si application

Liners of 39 ornamental plant species (Table 2) were transplanted into 4" (10 cm), 6" (15 cm) or 8" (20 cm) pots containing 60% Canadian peat, 20% vermiculite and 20% perlite or a 1:1 mix of Canadian peat: pine bark (orchids only). Plants were fertigated with (1) a Peter's water-soluble fertilizer 24N-8P_2O_4-16K_2O containing micronutrients (1 gram dissolved in 1 liter of deionized water) and 47 ppm Si (K_2SiO_3, Dyna-Gro, Co. San Pablo, CA), or (2) the same Peter's fertilizer with the addition of 20 ppm K (control) once a week. Plants were grown in a glasshouse under species required light levels and temperature ranges. Medium pH and soluble salts were monitored monthly. Plant quality was graded after marketable sizes were reached; plants were then harvested and fresh and dry weights were measured. Silicon and other nutrient elements in roots and shoots were determined.

At the time of harvest, all plants were of marketable quality regardless of the addition of Si or not. We found that 32 of the 39 evaluated species were able to absorb additional Si when Si was supplied, but the remaining 7 showed no response to Si addition. We have classified the 32 responding species as Si-responsive and the remaining 7 as Si-nonresponsive, i.e. no Si increase in shoots when fertigated with additional Si (Table 2). Among the 32 responsive species, 17 showed an increased concentration of Si in shoots and had corresponding dry weight increases, whereas the remaining 15 exhibited Si increases in shoots only with no differences in dry weight as compared to the plants grown in no Si-treated media. The dry weight increase in those Si-responsive plants ranged from 6 to 80% depending on species. Among them, *Dendrobium nobile*, *Anthurium*, *Spathiphyllum*, *Chlorophytum comosum* and *Aechmea fasciata* showed an 18% or more increase compared to their corresponding control. Silicon concentration in shoots ranged from 39 to 700 ppm for control plants and 74 to 1498 ppm for plants fertigated with Si. In addition, Si responsive plants had greater leaf thickness when Si was supplied which could constitute structurally or physically stronger plants.

The exact roles of Si in plant metabolism are still not completely understood, but a general notion is that Si addition improves plant growth, or Si is responsible for the "improved growth" of plants. Silicon application has been shown to (1) increase leaf chlorophyll content and plant metabolism, (2) enhance plant tolerance to environmental stresses such as cold, heat and drought, (3) mitigate nutrient imbalance and metal toxicity in plants and (4) reinforce cell walls, increase plant mechanical strength thereby protecting plants against pathogens and insects.

Silicon balances plant nutrient uptake

The use of peat and bark based media often encounters pH related problems, of which medium acidification is foremost. With the release of organic compounds from roots to the growing medium combined with continuous fertigation/irrigation, the medium gradually loses its buffering power and cation exchange capacity; the pH often drops to 5.0 or lower. Once the pH reaches to this level, aluminum (Al) and manganese (Mn) become available.

Aluminum is extremely toxic to plants, mainly inhibiting growth. We have found that without K_2SiO_3 application, Al in shoots of *Anthurium* reached 150 ppm, whereas, the addition of Si reduced Al to only 41 ppm. This Al uptake reduction is most likely attributed to (1) the increased pH of the potting media after Si application, (2) Si adsorption onto aluminum hydroxides which impair Al mobility, and/or (3) the adsorption of the mobile Al onto Si-rich compounds.

Available Mn in media, however, can be readily absorbed by roots wherein great amounts of the absorbed Mn will be translocated to shoots. The excess Mn in the shoots then often leads to the development of Mn toxicity symptoms manifested by dark brown necrotic spots on leaves caused by the accumulation of manganese oxides. Golden Pothos (*Epipremnum aureum*) and several other popular foliage plants fall victim to Mn toxicity. Our study with Golden Pothos showed that Si applications did not reduce the Mn concentration within the shoots but did mitigate Mn toxicity symptoms in the plants. This is because Si promotes the homogenous distribution of Mn in leaves and prevents the heavy deposition of Mn into selected confined areas. Nevertheless, a great benefit of Si application is that Si can balance nutrient elements in plant tissue through the suppression of Al, Mn and Na and by mediating the uptake of others such as P, Mg, K, Fe, Cu and Zn.

Si improves plant resistance to pests

In 1814, the scientist Sir Humphery Davy wrote: "The siliceous epidermis of plants serves as support, protects the bark from the action of insects and seems to perform a part in the economy of these feeble vegetable tribes (Grasses and Equisetales) similar to that performed in the animal kingdom by the shell of crustaceous insects". Collective early twentieth century evidence has demonstrated that Si application protects cereals from powdery mildew (*Erysiphe graminis*) infections, and increases the resistance of wheat to Hessian fly (*Mayetiola destructor*) and rice to stem borer (*Chilo suppressalis*). Within the last 30 years, Si application has been shown to reduce disease incidences of blast (*Magnaportha grisea*), brown spot (*Cochliobolus miyabeanus*), sheath blight (*Thanatephorus cucumeris*) and leaf scald (*Monographella albescens*) in rice, and powdery mildew (*Sphaerotheca fulginea*), damping-off (*Pythium*), root rot (*Fusarium oxysporum*), botrytis blight (*Botrytis cinerea*) and black mould (*colletotrichum gloeosporioides*) in fruit and vegetable crops.

In 1998, we studied the effects of Si on rooting of ivy (*Hedera helix*) cuttings. Trays were filled with 50% Canadian peat and 50% pine bark. Half of the total number of trays were drenched with either 0, 64.6, 132, 261 or 393 ppm of Si solution. Unrooted ivy cuttings were immediately stuck into the Si saturated medium. The remaining trays were drenched with deionized water only. The second set of designated ivy cuttings were soaked in the aforementioned solutions for 24 hours before sticking. All trays were placed into a glasshouse under recommended production conditions. Root rot occurred due to *Phytophthora* infection in the water-drenched only treatment. No disease symptoms were observed in the cuttings stuck in Si-drenched medium. The results suggest that Si has the potential for controlling some ornamental plant diseases.

The mechanism(s) underlying Si-mediated disease prevention is not entirely known. However, its prominent presence in the cell walls, in the form of solid amorphous silica and its association with some cell wall proteins does not support Si inertia, as originally thought, but does indicate an active biochemical function(s).

Silicon application improves plant growth through balancing nutrient uptake, transport and distribution in plants, and enhancing the resistance of plants to diseases. We are currently generating data on how silicon's effects on the rooting of cuttings and the extension of the shelf life of cut flowers and cut greens..

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Table 1. Average concentrations of extractable Si in selected ornamental plant growing media*.

Medium	Component	Si conc. (ppm)
UF-2:	50% Canadian peat + 50% pine bark	25.0
Coir Mix:	50% coir + 25% pine bark + 25% peat	26.0
Yard Trimmings Mix	Composted yard trimmings with 10% sand	108.0

*Extracted using Mehlich I extraction solution (0.05 N HCl in 0.025 N H_2SO_4).

Table 2. Responses of ornamental foliage plants to additional Si applications.

Common name	Scientific name
A. Si Responsive Plants:	
Si accumulation in tissue with increased dry weight	
1. Orchid	*Dendrobium nobile*
2. Silver Vase	*Aechmea fasciata*
3. Peace Lily	*Spathiphyllum*
4. Peacock	*Calathea makoyana*
5. Evergreen Giant	*Liriope muscari*
6. Boston Fern	*Nephrolepis exaltata*
7. Spider Plant	*Chlorophytum comosum*
8. Asparagus Fern	*Asparagus seteceus*
9. Flamingo Lily	*Anthurium scherzerianum*
10. Horsetail	*Equietum strobili*
11. Bamboo	*Bambusa glaucescens*
12. Century Plant	*Agave americana*
13. Parlor Palm	*Chamaedorea elegans*
14. Croton	*Codiaeum variegatium*
15. Kentia Palm	*Howea forsteriana*
16. Umbrella Tree	*Schefflera actinophylla*
17. Arrowhead Plant	*Syngonium podophyllum*
Si accumulation only	
1. Ti Plant	*Cordyline terminalis*
2. Tree Ivy (Pia)	*Hedera helix*
3. Pink Splash	*Hypoestes phyllostachya*
4. Ivy (large leaves)	*Hedera helix*
5. Purple Passion	*Gynura aurantiaca*
6. Weeping Fig	*Ficus benjamina*
7. Philodendron	*Philodendron scandens*
8. Red-hot Cat's Tail	*Acalypha pendula*
9. Chinese Evergreen	*Aglaonema commutatum*
10. Umbrella Sedge	*Cyperus alternifolius*
11. Baby Rubber Plant	*Peperomia clusifolia*
12. Pothos	*Epipremnum aureum*
13. Dumb Cane	*Dieffenbachia maculata*
14. Dragon Tree	*Dracaena deremensis*
15. Dragon Tree	*Dracaena marginata*

B. Si nonresponsive plants

1. Dragon Tree	*Dracaena sanderiana*
2. Zebra Plant	*Aphelandra squarrosa*
3. Cast-iron Plant	*Aspidistra elatior*
4. Artillery Plant	*Pilea cadeirei*
5. Umbrella Tree (dwarf)	*Schefflera arboricola*
6. Yuca	*Yucca elephantipes*
7. Pineapple	*Ananas comosus*

Table 3. Survival rate (%) of (a) ivy (*Hedera helix*) cuttings rooted Si-drenched medium and (b) Si-soaked ivy cuttings rooted in deionized water drenched medium

Si treatment	Si concentration (ppm)				
	0	64.6	132	261	393
(a) Si-drenched medium stuck with cuttings not soaked	40	100	100	100	100
(b) Si-soaked cuttings stuck in medium not drenched	35	50	80	100	100