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Silicon: The Estranged Medium Element[1]

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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, $H4SiO4$, 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 has 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. Naturally, 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

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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 the 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.

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 HCI in 0.025 N H_2SO_4.		

Will 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 in 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

Initially, 39 liner-sized ornamental plant species (Table 2) were grown in 4" (10 cm), 6" (15 cm) or 8" (20 cm) pots containing Canadian peat, vermiculite and perlite or a Canadian peat and pine bark mix (orchids only) wherein all plants except the controls were fertigated with a water-soluble fertilizer supplemented with 47 ppm Si (K2SiO3); the controls were fertigated with the same water-soluble fertilizer supplemented with K only. 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.

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	
Orchid	*Dendrobium nobile*
Silver Vase	*Aechmea fasciata*
Peace Lily	*Spathipyllum*
Peacock Plant	*Calathea makoyana*
Evergreen Giant	*Lirope muscari*
Boston Fern	*Nephrolepsis exaltata*
Spider Plant	*Chlorophytum comosum*
Asparagus Fern	*Asparagus seteceus*
Flamingo Lily	*Anthurium scherzerianum*
Horsetail	*Equisetum arvense*
Bamboo	*Bambusa glaucescens*
Century Plant	*Agave americana*
Parlor Palm	*Chamaedorea elegans*
Croton	*Codiaeum variegatium*
Kentia Palm	*Howea forsteriana*
Umbrella Tree	*Schefflera actinophylla*
Arrowhead Plant	*Syngonium podophyllum*
Si accumulation only	
Ti Plant	*Cordyline terminalis*
Tree Ivy (Pia)	*Hedera helix*
Pink Splash	*Hypoestes phyllostachya*
Ivy (large leaves)	*Hedera helix*
Purple Passion	*Gynura aurantiaca*
Weeping Fig	*Ficus benjamina*
Philodendron	*Philodendron scandens*
Red-hot Cat's Tail	*Acalypha pendula*
Chinese Evergreen	*Aglaonema commutatum*
Umbrella Sedge	*Cyperus alternifolius*
Baby Rubber Plant	*Peperomia clusifolia*
Pothos	*Epipremnum aureum*
Dumb Cane	*Dieffenbachia maculata*
Dragon Tree	*Dracaena deremensis*
Dragon Tree	*Dracaena marginata*

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

B. Si Nonresponsive Plants	
Dragon Tree	*Dracaena sanderiana*
Zebra Plant	*Aphelandra squarrosa*
Cast-iron Plant	*Aspidistra elatior*
Artillery Plant	*Pilea cadeirei*
Umbrella Tree (dwarf)	*Schefflera arboricola*
Yucca	*Yucca elephantipes*
Pineapple	*Anana comosus*

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 greater 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 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

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

Aluminum is extremely toxic to plants, mainly inhibiting growth. We have found that without K2SiO3 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 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. 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 a Canadian peat and pine bark mix. 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 (Table 3). 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, the prominent presence of Si 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 by balancing nutrient uptake, transport and distribution in plants, and by enhancing the resistance of plants to diseases. We are currently generating data on silicon's effects on the rooting of cuttings and the extension of the shelf life of cut flowers and cut greens.

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

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