Silicon in Agriculture
L.E. Datnoff, G.H. Snyder and G.H. Korndörfer (Editors)

Chapter 7

Effect of silicon on plant growth and crop yield

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Integrated management of six macronutrients: nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg) as well as the seven micronutrients iron (Fe), manganese (Mn), zinc (Zn), boron (B), copper (Cu), molybdenum (Mo), and chloride (Cl) are the ones that most agronomists only consider as essential for sustainable crop yields. However, under special crop/soil agriculture conditions there are some "non-essential" elements, like silicon (Si) that will enhance crop yield by promoting several desirable plant physiological processes.

Due to the desilication process, Si in the soil is continuously lost as a result of leaching process. Subtropical and tropical soils are generally low in plant-available Si and would benefit from Si fertilization. Silicon content in some regions might be limited to sustainable crop production. The need for proper Si management to increase yield and sustain crop productivity appears to be necessary in temperate as well in tropical countries. In addition, Si diminution in the soil can occur in intensive cultivation practices and continuous monoculture of high-yielding cultivars. As a result, these soils are generally low in plant-available Si (Juo and Sanchez, 1986; Foy, 1992). Rice and sugarcane grown in rotation on organic and sandy soils have shown positive agronomic responses to pre-plant applications of calcium silicate slag (Anderson, 1991).

7.1. GENERAL ASPECTS OF SILICON IN SOILS

Soils are considered to be formed as a result of the interaction among parent material, climate and living organisms as influenced by relief and time. Soils are interpreted also as a result of several processes that can be grouped into additions, transformations, removals, and translocations. Most chemical transformations are related to the silicate minerals. These Si-rich minerals vary with the duration and intensity of many specific processes related to the soil forming factors. Under conditions of high rainfall weathering, the less resistant silicates release silica that in most conditions is rapidly leached to the nearby streams. The proper management of highly weathered soils must be based on the understanding of their nature and properties. According to Fox (1980), a soil fertility program needs to take into consideration the return nutrients exported by the harvest as well as depletion by leaching.

7.2. SILICON AND RICE

Since 1955, Japanese farmers have increased and sustained average rice yields up to 6 t ha^{-1} (IRRI, 1993). This could be due to adoption of a balanced integrated nutrient management that includes Si fertilization. Silicate slag application at an optimum rate of 1.5-3.0 t ha^{-1} is now widely used in degraded paddy fields in Japan (Kono. 1969; Takahashi and Miyake, 1977). Yield increases of 10% are common when Si is added and at times exceed 30% when leaf blast is severe (Yoshida, 1981). Rice grain quality is also affected by Si application. The percentage of perfect grain in brown rice and in milled rice hull where Si n was applied increased by 7.5% and 3.5% respectively, as compared with the NPK application (without Si) (Kang et al., 1997).

More than 100,000 Mg of calcium silicate are used annually in Florida to provide Si for rice and sugarcane. Growers often apply calcium silicate at the rates of 4.5 Mg ha^{-1} (2 tons per acre), although higher rates, up to approximately 6 Mg ha^{-1}, have been shown beneficial for increasing rice grain yield (Snyder et al., 1986; Anderson et al., 1987).

Korndörfer et al. (1999), working on wet-land rice and 28 field experiments grown in the Everglades Agricultural Area (Histosol), throughout a 5-year period (1992-1996) concluded that in 19 out of 28 field experiments, Si had a positive effect on yield (Table 7.2). When considering only sites with Si response, the average increase yield was 1007 kg ha^{-1}. Based on the calibration study, the authors established three categories for the soil test - low (L), medium (M), and high (H). The lower third (< 75 % RY) of the response zone was arbitrarily called the low category and corresponded with the range of Si in the soil from 0 to 6.4 mg L^{-1} (Figure 7.1). The upper zone (75 - 95 % RY) was called medium and corresponded to those soils with Si content between 6.5 and 24.0 mg L^{-1}. The high category was any soil tested above 24.0 mg L^{-1} (RY > 95 %). The equation describing the curve was: RY (%) = 54.9 + 46.32 (1 - $EXP^{(-0.088X)}$)]; (R^2 = 0.24**). The relatively poor fit of this model (Figure 7.1) suggested that factors such as cultivar variation, insect damage, lodging, and other biotic and abiotic stresses

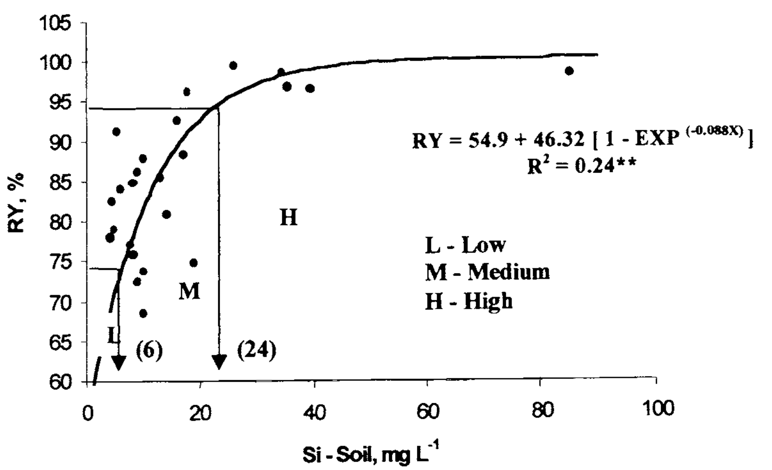

Figure 7.1. Calibration of soil test Si to relative yield (RY) for rice grown in the EAA, Histosol.

Table 7.1
Si in the soil (before planting) and tissue (at harvesting), predicted check and maximum yield by the model, yield increase, and relative yield.

Experiment Site	Soil Si (before planting) mg dm^{3}	Tissue Si (check treatment) g kg^{-1}	Predicted Check Yield kg ha^{-1}	Predicted Maximum Yield kg ha^{-1}	Predicted Yield Increase[1] kg ha^{-1}	Relative Yield[2] %
			1992			
C.F.- 715	85.0	39.00	7030	7141	---	98
Brida	19.0	16.00	3800	4802	1002	74
New Farm - 12	14.0	17.00	4966	5926	960	81
Baker	9.0	29.00	4843	5526	683	86
Shawano	6	27.00	5280	6138	850	84
			1993			
31ABE	8.0	22.58	4947	6110	1163	76
18CDE	9.0	23.00	4223	5360	1137	73
67-1-4	8.0	md	7015	8152	1000	84
15-ABW	5.0	24.50	4853	5853	665	79
			1994			
10ABW	10	16.71	5608	6273	1132	88
33BNS	10.0	18.00	4280	5412	734	74
L6SE2	18.0	29	4712	4907	---	96
			1995			
2-52-CDW	4.0	md	3377	4111	1625	78
13-54S	md[3]	26.17	5773	5835	---	99
			1996			
29DNS	26.0	31.40	6473	6476	---	100
29ANS	10.0	15.60	5216	6841	1625	69
4-H-21-EW	13.0	28.14	5947	6857	910	85
F.9-17N	17.0	md	6485	7240	755	88
N.H. 1-4N-5	20.7	26.50	2804	2804	---	100
N.H. 1-4N-6	39.5	26.50	2976	3072	---	97
N.H. 1-1W-8	11.2	18.55	3733	4986	1253	66
N.H. 1-1W-9	35.5	32.27	5335	5478	---	97
C.F.48-EF-9N	5.3	21.83	7380	8059	679	91
S.F. 2-E-7	md	24.17	5117	6179	1062	79
S.F. 2-E-8	4.5	22.00	5159	6026	867	83
48CG32W	7.6	23.29	4401	5439	1038	76
N.H. 2-20E-4	16.0	36.83	5307	5577	---	93
N.H. 2-20E-3	34.5	37.00	5575	5630	---	99

[1] Predicted Increase Yield = Maximum Yield - Check Yield
[2] Rel. Yield (%) = 1 - [Predicted Maximum Yield - Predicted Check Yield/ Predicted Check Yield]
[3] md = missing data

probably had an important impact on yield. According to the same authors, lower Si concentrations in the straw were associated with lower relative yield. Si in the straw concentration in the EAA were grouped and associated with one of the three classes: low Si in the straw concentration ranging from 0 to 17 (< 75 % RY); medium concentration, 17 to 34 (75 - 95% RY), and high concentration exceeding 34 g kg^{-1} (> 95 % RY) (Figure 7.2). The amount of calcium silicate needed to correct Si deficiency in the soil and to obtain optimum rice yield were 7.5, 5.6, and 0 Mg ha^{-1} for low (< 6 mg L^{-1}), medium (6 to 24 mg L^{-1}), and high (> 24 mg L^{-1}) level of Si in the soil, respectively. However, 5.6, 4.3, and 0 kg ha^{-1} of calcium silicate were needed for the low, medium, and high level of Si in the straw, respectively (Table 7.2).

It has been suggested that rice straw should contain approximately 30 g kg^{-1} of Si (dry weight basis) for optimum production (Snyder et al., 1986). In the absence of adequate Si, diseases such as brown spot are often severe, giving the standing rice an overall brownish appearance.

7.3. SILICON AND SUGARCANE

Sugarcane strongly responds to Si applications. Ross et al. (1974) reported the removal of 408 kg ha^{-1} of total Si from soil by a sugarcane crop (tops + millable cane) yielding 74 t Si per ha^{-1}. The removal of Si from soil could be more important in intensively cultivated areas. As a result of an Si export of this magnitude, a temporary depletion of bio-available Si in soils could also be a possible factor of declining yields of ratoon crops. In other words, there may be an apparent need for consideration of Si nutrient management in developing appropriate integrated nutrient management systems for sustainable sugarcane production, especially in certain ecoregions having Si-deficient weathered soils and organic soils. Several reports in the literature suggest that Si nutrition has a definite agronomic role in sugarcane crop cultivation, especially on weathered tropical soils such as Oxisols, Ultisols, Entisols, and Histosols (organic soils).

Silicon may be involved in cell elongation and/or cell division. In a field study, plant crop height was quadratically related to the rate of Si applied, while plant crop stem diameter was linearly related (Elawad et al., 1982). Gascho (1978) reported that application of TVA slag

Table 7.2
Calcium silicate recommendation for rice grown on Histosol (EAA) based on the Si soil test and Si in the straw.

Si soil test	Soil class category	$CaSiO_3$ recommended
mg L^{-1}		Mg ha^{-1}
< 6	Low	7.5
6- 24	Medium	5.6
> 24	High	0
Si in the straw	**Si-straw category**	**$CaSiO_3$ recommended**
g kg^{-1}		Mg ha^{-1}
< 17	Low	5.6
17 - 34	Medium	4.3
> 34	High	0

and Na silicate to greenhouse-grown sugarcane increased plant height. Plucknett (1971) indicated that some of the effects of Si on sugarcane were longer stalks with larger diameters and increased number of suckers. These observations on cane and observations for other crops suggest a possible role of Si in cell elongation and/or cell division (Elawad et al., 1982). Ayres (1966) determined that only 15% of the total plant Si is present in sugarcane stalks at 14 months. The leaf sheaths on the best cane-growing soils contained about 2.5 percent Si. Using the sixth leaf sheath, Halais (1967) suggested critical levels of 1.25 percent of Si and 125 mg kg^{-1} of Mn. If the Si level were below this value, Si responses could be expected.

Research work, largely conducted in Hawaii, Mauritius, and Florida, demonstrated the use of silicate slag as a source of Si for sugarcane. Yield responses were great enough that sugarcane grown in the Everglades (South Florida) is routinely fertilized with calcium silicate when soil tests indicate the need. However, Si fertilization requires large quantities of slag (generally 5 Mg ha^{-1}), making it quite costly (Alvarez et al., 1988). Yields of cane and sugar in Hawaii have been increased 10-50% on soils low in Si, and many sugar plantations regularly apply calcium silicate in responsive fields (Ayres, 1966; Clements, 1965; Fox et al., 1967). Increased yields of sugarcane fields have been reported in Mauritius (Ross, 1974) (Table 7.4) and Puerto Rico (Samuels, 1969). While in South Africa (Preez, 1970) and Brazil (Franco and Korndörfer, 1995), several sources of silicate were found to increase sugarcane yields in pots.

Sugarcane is a Si-accumulator plant (Table 7.3). The Si form which sugarcane usually absorbs has no electric charge (H_4SiO_4) and is not very mobile in the plant. Because the uptake of undissociated H_4SiO_4 may be nonselective and energetically passive, and its transport from root to shoot is in the transpiration stream in the xylem, the assumption has sometimes been made that the movement of Si follows that of water (Jones and Handreck, 1965). The silicic acid is deposited mainly in the walls of epidermal cells, where it is integrated firmly into the structural matter and contributes substantially to the strength of the stem.

Better Si-accumulating cultivars may have the advantage of requiring lower rates of Si fertilizer or less frequent applications. A relatively narrow base of sugarcane germplasm demonstrated significant variability for Si content in leaf tissue (Deren et al., 1993). Korndörfer et al. (1998) also found that sugarcane cultivars have different capacities to accumulate Si in the leaves. The Si levels in the leaf were of 0.76, 1.04, and 1.14 g kg^{-1}

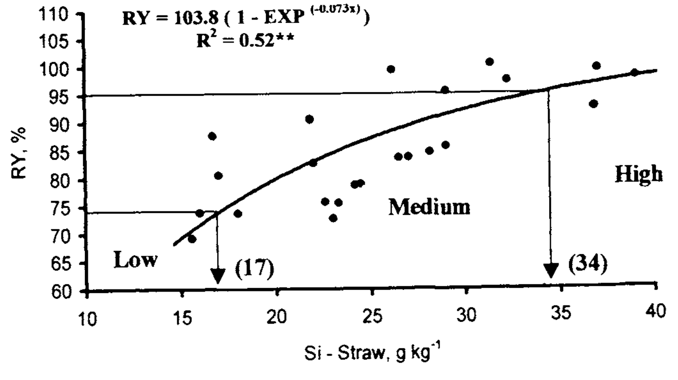

Figure 7.2. Relationship between Si in the straw at harvest and relative yield (RY) for rice grown in the EAA.

Table 7.3
Effect of wollastonite in an Oxisol on the Si content in the plant and soil, and Si accumulation by the aerial part of the sugarcane plant.

Si applied kg ha^{-1}	Si in the tissue %	Si accumulated g pot^{-1}	Si in the soil mg dm^{-3}
0	0.70	0.36	14
116	0.89	0.43	17
231	1.41	0.68	19
462	1.77	0.74	30
924	1.93	1.03	46

respectively for the cultivars: RB72454, SP79-1011, and SP71-6163.

In Brazil, on sandy soils, sugarcane has shown consistent response to Si fertilization mainly. The increase yield, using cement and calcium silicate on soils with low Si content, ranged from 7 to 12% (Table 7.5). The benefits of Si fertilization are generally observed in sugarcane grown on Si-deficient soils such as weathered tropical soils and Histosols. Ayres (1966) obtained increases in tonnage of sugarcane to 18 % in cane and 22 % in sugar for plant cane crop following the application of 6.2 t ha^{-1} of electric furnace slag to aluminous humic ferruginous Latosols in Hawaii. The beneficial effect of the slag lasted on low Si soils for four years, and the first ratoon crop also produced about 20 % more cane and sugar. In Mauritius, calcium silicate slag applied at 7.1 t ha^{-1} to low Si soils (less than 77 mg dm^{-3} Si extractable with modified Truog's extractant) at planting gave annual cane increases that were economically profitable over a 6-year cycle. A net return from the application of calcium silicate could be expected if the total Si level in the third leaf lamina was below 0.67 % of Si or if the acid-soluble soil Si was below 77 mg dm^{-3} Si (Ross et al., 1974) (Table 7.4).

Based on the results of a 3-year study, Gascho and Andreis (1974) concluded that Si is beneficial and probably essential for sugarcane grown on the organic and quartz sand soils of Florida. For TVA calcium silicate slag applied at 4.9 to 11.6 t ha^{-1} to muck and sand soils, Gascho (1979) observed significant positive response at all seven muck locations and two out of four sand locations. The economic analysis of the results of these field tests showed the profitability of Si management under the given field conditions (Alvarez and Gascho, 1979). In the early days, in the same area, the addition of calcium silicate slag (obtained from El SIGLO Corporation, Columbia, Tennessee) at 6.7 t ha^{-1} the yields of five inter-specific

Table 7.4
Effects of calcium silicate on cane yields average of 2 cultivars.

	Plant cane	Ratoon					
	t ha^{-1}						
Treatments	1968	1969	1970	1971	1972	1973	Means
Control	400	784	538	711	611	552	599
7.1 t calcium silicate	63.5	922	621	839	728	685	738
14.2 t calcium silicate	685	962	645	905	768	720	781

Table 7.5
Effect of calcium silicate on sugarcane yield cultivated on sandy soil in Brazil.

Calcium silicate	Barreiro Farm	Amoreira Farm
kg ha^{-1}	---------- t ha^{-1} ----------	
0	145	128
700	153	134
1400	154	136
2800	163	137
5600	161	135

hybrids of sugarcane were increased by an averages of 17.2 % and 21.8 % during 1989 and 1990, respectively (Raid et al., 1992). Anderson et al. (1986 and 1987) observed that a single application of silicate slag to Terra Ceia muck in the Everglades (Florida) prior to planting of rice increased production of rice and sugarcane in rotation, but to a lesser extent than the slag applied prior to cane planting. In an investigation to determine multi-year response of sugarcane (cv. CP72-1020), the application of 20 t ha^{-1} of slag (100% passing through 40 mesh screen) increased cumulative cane yield as much as 39 % and sugar yield as much as 50 % over the three crop years (Anderson, 1991).

In Mauritius, Ross et al. (1974) observed that there was a marked increase in sugarcane yield with calcium silicate application throughout the cycle (Table 7.4). Preez (1970) also has reported positive yield responses of sugarcane to applied silicate materials in southern African soils.

Silicon plays the role of a beneficial nutrient in sugarcane by improving cane plant growth. Application of TVA and Florida calcium silicate slag (up to 20 t ha^{-1}) to sugarcane (cv. CP 63-588) grown in a Pahokee muck soil increased plant height, stem diameter, number of millable stalks, and cane and sugar yields in both plant and ratoon crops (Elawad et al., 1982). This suggested that Si improved the photosynthetic efficiency of individual plants as well as of the whole stand. The application of 15 t ha^{-1} of slag increased cane and sugar yields by 68 % and 79 % in the plant crop, and 125 % and 129 % in the ratoon crop. Similar results have been reported in Taiwan (Shiue, 1973), Australia (Hurney, 1973) and Puerto Rico (Samuels, 1969). In most of the above reports, the increases in cane and sugar yields associated with the application of silicate materials have been attributed to increased number of millable stalks and increased plant size, not to Pol reading.

In field trials at two non-irrigated sites in south Africa conducted during 1983-1985 on fine-textured acid soil (pH 4.5), steel slag from Japan was applied at a rate of 1-3 t ha^{-1} before planting cane. The results of the trials indicated an increase in cane and sugar yields in the plant and ratoon crop (Allorerung, 1989).

In Hawaii, based on the economic evaluation of field experiments conducted during 1976 to 1982, the calcium silicate recommendations for sugarcane have been set based on soil and plant Si indexes:

(1) For fields not fertilized with $CaSiO_3$ for two or more consecutive crops, apply 4.48 t ha^{-1} $CaSiO_3$ to the current crop, if soil Si levels are at or below the critical level of 112 kg ha^{-1}.

(2) For fields to which $CaSiO_3$ was applied to one or both of the preceding crops (plant cane and ratoon), apply 2.24 t ha^{-1} $CaSiO_3$ to the current crop if the soil Si levels are at

or below the critical level of 78 kg ha^{-1}. Thereafter, apply 2.5 t ha^{-1} to each succeeding crop, if soil Si levels fall below 78 kg ha^{-1}.

(3) The critical levels for the "Crop Log" sheath Si (0.7 %) and the Mn/SiO_2 ratio = 75 established by Clements (1965) remain the same: if sheath Si levels of "Crop Log" samples are less than 0.7 % or the sheath Mn/SiO_2 ratios are above 75, apply 2.5 t ha^{-1} of $CaSiO_3$ to the current crop (Hagihara and Bosshart, 1985).

In Florida, finely ground slag has been recommended under the following specified conditions (Kidder and Gascho, 1977):

- The land in question must be located more than five km from Lake Okeechobee.
- Soil pH must be less than 8.
- Leaves of sugarcane grown on the soil in question must have shown heavy freckling symptoms.
- Calcium silicate slag used as the soil amendment must be ground finer than 60 mesh.
- Slag must be applied broadcast and disked into the soil prior to planting the cane.

When the slag is applied to sandy soils with Mg test levels below 120 (according to Everglades Research and Education Center, laboratory test), concurrent Mg fertilization at the rate of 40 kg Mg ha^{-1} at planting is suggested as a precaution (Kidder and Gascho, 1977).

7.4. SILICON AND OTHER CROPS

According to Clark et al. (1990), the relatively high leaf concentration of Si in pearl millet and sorghum may have contributed to its ability to yield well on acid soil (Colombia, South America). The chemical properties of the relatively acid soil were: 60% Al saturation; pH 4.0 (1 water: 1 soil); 7.9% organic matter; 4.0 $cmol_c$ kg^{-1} Al (Table 7.6).

Khan and Roy (1964) showed a marked effect of silicate on growth and yield of jute plant (*Corchorus capsularis*). Optical measurement of fiber cell dimension of jute showed a greater cell elongation, fineness, and elongation/fineness ration due to silicate treatment (Table 7.7).

Table 7.6
Silicon accumulation in plants (sorghum and Pearl millet) and yield.

	Plant	
	Sorghum	Pearl millet
	Range	
Grain yield (kg ha^{-1})	325 - 3600	1980 - 3460
N (g kg^{-1})	12.3 -20.2	14.8 - 22.4
K (g kg^{-1})	4.5 - 15.4	2.8 - 8.6
Si (g kg^{-1})	8.1 - 18.8	27.9 - 43.4
Al (μg g^{-1})	429 - 1855	160 - 653

Table 7.7
Growth characteristics of jute plant with and without silicate (average of 116 kg ha^{-1} of Si as sodium silicate).

Treatment	Plant height (cm)	Green matter (g $plant^{-1}$)	Cell elongation (μm)	Cell fineness (μm)	Elongation: fineness ratio
Check	115	58.7	2409	173	140
Silicate	126	69.4	2840	164	174

Foliar sprays with potassium silicate showed increased chlorophyll content and plant growth (Wang and Galletta, 1998). Plants with Si significantly produced more dry matter, as measured by aerial and root weight, than the controls (Table 7.8). The enhanced growth was evident even at a low Si concentration (4.25 mM). The increase in strawberry plant growth by Si may be related to enhanced tissue elasticity and symplastic water volume, which were associated with cell expansion and plant growth (Emadian and Newton, 1989). Potassium silicate treatments also induced metabolic changes such as increases in citric acid and malic acid level, and decreases in fructose, glucose, and sucrose contents. These results suggest that Si has beneficial effects on strawberry plant metabolism. Since strawberry plants are classified as Si non-accumulators, Si has been regarded as unnecessary for their healthy growth. However, Miyake and Takahashi (1978) observed Si deficiency symptoms in the tomato plant, which is also a non-accumulator of Si.

Strawberry plants were grown in solutions containing 50 mg L^{-1} SiO_2 and lacking Si (Si-free plants) for about 10 weeks (Miyake and Takahashi, 1986). Treatments were divided into three series: plants continuously subject to 50 mg L^{-1} SiO_2 treatment (referred to as + Si + Si); plants subjected to the 50 mg L^{-1} SiO_2 treatment after initial Si-free treatment (referred to as - Si + Si); and plants continuously deprived of SiO_2 (referred to as - Si - Si). During strawberry growth, no abnormal symptom caused by the silicon-free treatment was observed; however, at harvest, the total amount of fruits produced was much higher in the plants with the + Si + Si and the - Si + Si treatments than in the plants with the - Si - Si treatment. The total amount

Table 7.8.
Growth enhanced by Si treatment in strawberry plants (means of four replications).

Si*	g dry matter $plant^{-1}$					Chlorophyll content**
mM	Leaves	Petiole	Crowns	Roots	Whole plant	μg chl a+b/cm^{-2}
0	1.55	1.37	0.48	0.45	3.85	40.20
4.25	2.10	1.37	0.67	0.53	4.67	57.34
8.50	2.13	1.39	0.69	0.50	4.71	63.95
12.75	2.24	1.38	0.67	0.56	4.85	62.76
1700	2.35	1.40	0.68	0.59	5.02	6423

* Foliar spray with K silicate

** Chlorophyll content: Leaf disk of 1.0 cm diameter were extracted with 30% acetone. Chlorophyll content of leaf disc was determined using spectrophotometric method.

Table 7.9
Effect of silicon supply on the growth and yield of strawberry plants (2 plants per plot).

	Treatment		
	+ Si + Si*	- Si + Si	- Si - Si
	---------------------------- fresh matter - g ----------------------------		
Total yield			
- Number	91.5	77.7	67.5
- Fruit -weight	675.5	618.5	521.4
Useful yield[a]			
- Number	53.5	47.2	40.7
- Fruit -weight	528.7	516.7	422.3
Si content (%)			
- Leaves	57	0.45	0.03
- Crown	0.01	0.02	0.01
- Roots	0.03	0.03	0.00

[a] total value with a fruit-weight of 6g or above

* plants continuously subject to 50 mg L^{-1} SiO_2 treatment (referred to as + Si + Si): plants subjected to the 50 mg L^{-1} SiO_2 treatment after initial silicon-free treatment (referred to as + Si + Si); and plants continuously deprived of (referred to as + Si + Si).

of fruit produced by the plants grown with Si application (+ Si + Si) was much higher then that of the plants receiving Si after initial Si-free treatment (- Si + Si). The total yield of useful fruit was also much higher in the plants with the + Si + Si and the - Si + Si treatments than in the plants in which Si had been omitted (- Si - Si). The total yield of useful fruit of the + Si + Si plants was much higher than that of the - Si + Si plants (Table 7.9).

Si deficiency appeared in the tomato plant at the reproductive stage when cultivated on low Si levels solution culture (Miyake and Takahashi. 1978). It was observed in the first bud flowering stage. This suggests the possibility that reproductive growth might be affected by silicon treatment (Table 7.10). Moreover. tomato plants raised in a Si-free culture bore few fruit. The authors also observed that growth and fruiting were quite normal when 100 mg L^{-1} of SiO_2 was applied. but upon receiving Si-free treatment. the plant was able to bloom. but produced no fruit (Table 7.11). Field experiments were conducted in alluvial soils for 3 years to evaluate the effect of silicate fertilizers on the growth of cucumber plants. Application of silicate fertilizer promoted the growth and yield of cucumber plants. and also reduced damage caused by wilt disease (Miyake and Takahashi. 1983). At the end of the experiment. the total

Table 7.10
Effects of Si deficiency on tomato pollen fertility.

Treatment - SiO_2 (mg L^{-1})	Growth stage	Fertility ratio - %
0	Before bloom	82
0	In bloom	64
100	Before bloom	93
100	In bloom	91

Table 7.11
Effect of Si on the growth of tomato plants.

Treatment	Top-length (cm)	Root-length (cm)	Top-wt dry matter (g)	Root-wt (dry matter) (g)	Number of leaves	Number of fruits	Fruit-wt (fresh matter) (g)
+ Si + Si*	108	63	46.2	6.7	19	4	168
+ Si - Si	53	54	37.9	7.4	13	3	70
- Si + Si	88	59	32.5	3.7	27	0	0
- Si - Si	45	55	24.3	3.5	10	0	0

* 100 + 100 mg L^{-1} SiO_2

amount of fruit produced was higher in the plants with Si application than in the plants in which Si application had been omitted (Table 7.12). The difference in fruit yield between plants with and without Si application increased due to the presence of a larger number of wilted plants when Si application had been omitted than when Si had been supplied. The Si content in the leaves of plants with Si application increased considerably to values ranging from 1.3 to 1.9 % Si, while the content remained low at levels of 0.7-1.0% Si in the leaves of plants without Si application. The silicon concentrations in the stems were lower than in the leaves. The available-Si content increased markedly, 44-116 mg of Si/100g soil in the treatments with Si application, while they remained at 20-22 mg of Si/100g in the treatments where Si application had been omitted.

7.5. IN CONCLUSION

a) Silicon fertilization may increase and sustain crop productivity on different crops.
b) Silicon may affect positively not only accumulator plants but also non-accumulator Si plants.

Table 7.12
Effect of calcium and potassium silicate supply on yield of field-grown cucumber plants, incidence of *Fusarium* wilt disease, content of Si in plants and available Si in the soil.

Treatment	Sol. Si[a]	Fruit yield[b]	Wilted Plants[c]	Si-Leaves	Si-Stems	Available Si-soil[d]
	kg ha^{-1}	t ha^{-1}	%	---------- %	-----------	mg/100g
Ca-Si	327	143	20	1.3	0.5	44
Ca-Si	654	135	15	1.5	0.4	78
K-Si	327	139	11	1.3	0.4	54
K-Si	654	155	0	1.9	0.4	116
Control 1	0	121	37	0.7	0.2	20
Control 2	0	121	62	1.0	0.2	22

[a] 0.5 N HCl soluble Si
[b] yield to the end of harvesting
[c] estimated at harvest stage
[d] pH 4 ammonium acetate buffer solution soluble Si

c) Based on the economic approach. Si should be part of the fertilizer management of many different crops.

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