A highly economical 'refined not mined' alternative to entrenched agricultural products such as Gypsum with the added benefit of Silica and other trace elements.

The Effect of Silicon on Crop Growth, Yield and Quality

Silicon (Si) has widely been reported to increase the growth and biomass, yield and quality of a broad range of crops including monocotyledonous crops such as rice, wheat, maize, barley, millet, sorghum and sugarcane that actively take up and accumulate high amounts of Si in their organs and dicotyledonous crops such as cotton, vegetables tree and fruit crops. The yield increment, however, may be attributable not only to the beneficial effects of Si including growth promotion, lodging resistance, relieving pest pressure and biotic and abiotic stress resistance but also to some indirect effects such as pH adjustment and the control of major, macro and micronutrients, whether deficient or in excessive toxic levels (see our Tech Sheet on Silicate in the Mitigation of Heavy Metal Stress) (Lian 1976[1] ; Elawad and Green 1979[2] ; Savant et al. 1997[3],1999[4] ; Wang et al. 2001[5] ; Singh et al. 2005[6]; Guntzer et al. 2012[7]). The major crops that are widely reported to positively respond to Si fertilisation include some monocotyledonous crops such as rice, wheat, maize, barley, millet, sorghum and sugarcane that actively absorb and accumulate high amount of Si in their organs and some dicotyledonous crops such as cotton, soybean and some vegetable, tree and fruit crops that are also able to accumulate Si through specific transporters.

Viability

The table below shows the effect of largescale field application of silicate fertiliser on crop yield and economic benefit indicated by ratio of added revenue to Si fertilizer cost in north eastern China during 2005–2006 (Y. Liang et al., unpublished).

Crops tested	Yield increase percentage range	Average yield increase (%)	Benefit/Cost ratio	No. of trials
Rice	3.5-28.5	10.3	4.4	50
Maize	5.6-10.4	7.7	3.1	44
Cucumber	9.35-25.6	13.7	42.9	40
Tomato	8.7-15.9	12.0	35.7	35
Soybean	7.5-13.6	11.0	1.7	32

The data from the table clearly show that although the average yield increase percent for all the crops tested except maize due to Si fertiliser application was above 10%, the ratio of benefit to cost differed greatly with crop species mainly due to the per unit area crop yield and the price of the products. The application of Si fertiliser to greenhouse grown cucumbers and tomatoes led to extremely high economic benefits and thus was welcomed commercially in China.

Silicon-Improved Growth and Yield of Monocotyledonous Crops

Rice

Field application of silicon in rice paddy fields started in Japan in the early 1950s and in South Korea in the 1960s–1970s. This practice contributed greatly to rice production sustainability and food security in these countries (Savant et al. 1997[3]; Park 2001[8] ; Ma and Takahashi 2002[9]). The use of silicon is also a rather common agricultural practice to increase the growth and yield of rice in Southeast Asia (Lian 1976[1]; Snyder et al. 1986[10]; Yamauchi and Winslow 1989[11]). Lian (1976[1]) and Elawad and Green (1979[2]) reviewed the rice yield responses to Si fertilisation, mostly in temperate regions such as Japan, Korea and Chinese Taiwan, while Savant et al. (1997[3]) summarized the positive effects of silicon on the growth and yield of rice grown in the subtropical to tropical zones. The beneficial effects of Si may be attributed to an increase in water use efficiency (WUE) and maintenance of photosynthetic activity. At the cell level, the growth promotion by the addition of Si in rice has been linked to enhanced cell elongation, but not cell division in the epidermal cells (Hossain et al. 2002[12]).

Wheat

Wheat is another staple food crop that is widely reported to positively respond to silicon (Wang et al. 2001[5]) and that also has an active uptake and accumulation of Si in plant organs (Rafi and Epstein 1999[13]; Montpetit et al. 2012[14]). Zhu and Chen (1963[15]) reported an obvious yield increase in wheat ranging from 6 to 12% following the application of calcium silicates in northern China. Subsequent field trials conducted across China also showed significantly positive yield responses to application of silicates (ranging from 5 to 12%) (Wang et al. 2001[5]). Yu and Gao (2012[16]) investigated the effects of Si on the yield of two wheat cultivars and found that appropriate Si levels could increase the grain yield of wheat, and the increase resulted from the increase in spike number and grain number per spike.

Sugarcane

Sugarcane is a Si-accumulating plant species and the second most Si-responsive crop after rice. Samuels (1969[17]) reported that the above ground parts of 12-month-old sugarcane plants contained 379kg ha of Si, compared to 362kg ha of K and 140kg ha of N. As a result, Si deficiency in soils could be a yield-declining factor in sugarcane, resulting in symptoms such as twisted leaves and leaf freckling (symptoms tend to develop during the peak growth phase in summer when the soil can no longer meet crop requirements) (Wang et al. 2001[5]). It has been well documented that Si nutrition has a definite agronomic role in sugarcane crop cultivation.

Earlier field trials conducted in Hawaii, Mauritius, Puerto Rico, Florida, South Africa, Brazil and Australia demonstrated that the use of silicate in sugarcane increased yield by 10–50% on Si-low soils (Ayres 1966[18]; Clements 1965[19]; Fox et al. 1967[20]; Samuels 1969[17]; Cheong and Halais 1970[21]; Haysom and Chapman 1975[22]; Gascho 1976[23]; Elawad et al. 1982[24]; Anderson et al. 1991[25]; Alvarez and Datnoff 2001[26]; Meyer and Keeping 2001[27]; Berthelsen et al. 2001[28]). Some recent trials in China also gave positive cane yield responses to application of Si fertiliser. For example, Jiang et al. (2011[29]) found that the application of Si (720kg SiO_2 ha) increased the sugarcane and sugar yields by 9.0 % and 9.7 %, respectively.

Flinders Agriculture Bundaberg sugarcane trials

Commercial-scale field trials in sugar cane with Flinders Agricultures low cost calcium silicate applied at 6 t/ha were conducted from 2014 to 2016 in the Bundaberg region in collaboration with Dr Graham Kingston. The results showed not only an improvement in sugar cane health and an increase in stalk height, but also an average sugar cane yield increase of 22% over a plant and

first ratoon crops. These observations were seen in conjunction with an increased level of silicon in the leaf tissue.

Huang et al. (2011[30]) also found that sugarcane yield was significantly increased by application of Si. The observed positive sugarcane responses to Si fertilisation have been attributable to a number of factors including prevention of Al and Mn toxicities in highly weathered acid soils, improved water use efficiency, protection from fungal and insect pest damage, improved P nutrition, improved mechanical strength and improved photosynthesis through better use of sunlight (Anderson et al. 1991[25]). Huang et al. (1992[31]) found that Si promoted the translocation of 11 nutrients including N, P, K, Mg, Ca, Mn, Zn, Cu, Fe, Mo and B to the growing parts of the plant, which could enhance the growth of sugarcane, as well as sugar synthesis and accumulation.

The improvement of sugarcane yields by Si may also be attributed to its induced resistance to various biotic and abiotic stresses. The cane yield responses to Si fertilisation are more significant under environmental stress than under normal conditions. Also, the cane yield response is genotype dependent. For instance, cane yield was increased with Si addition by 59% and 28% in the salt-sensitive and salt-tolerant genotype, respectively, compared with the controls (Ashraf et al. 2009[32]).

Corn

Corn is also one of the cereal crops that actively take up and accumulate Si into its organs (Liang et al. 2006[33]; Mitani et al. 2009[34]). Corn (Maize) growth and yield are also highly responsive to Silicon (Yuan et al. 1996[35]; Wang et al. 2001[5]) Liu et al. 2011[36]). As early as the 1960s, Zhu and Chen (1963[15]) conducted field trials on Corn in the Liaoning province of northern China and reported a yield increment ranging from 8.5 to 10.2%. The application of Si significantly increased concentrations of N, P, Zn and Mn in Corn plants. Thus, the yield response to Si may be related to improved uptake of these nutrients (Li et al. 1999[37]). Yuan et al. (1996[35]) agreed that the positive corn yield responses to Si could be attributable to the increased ear numbers and grain size. Consecutive field trials indicated that, on the average, the application of Si resulted in corn yield increase's of 7.3 % (Liu et al. 2011[36]) and of 7.7% (Y. Liang et al., unpublished,). Corn yield responses to Si may be impacted by climate and plant available Si in soils as well. According to Li et al. (1999[37]), the application of Si resulted in a Corn yield increase by 10% in 1997 due to a severe drought stress during maize-growing season, while yield increment of 5% was observed in 1998 when no drought stress occurred. It seems to suggest that the beneficial effects of Si on plant growth and yield are particularly distinct under drought/stress conditions.

Dicotyledonous Crops

Cucumber

Cucumber is a typical intermediate type of plant species that also actively takes up and accumulates Si into its organs (Liang et al. 2006[33]; Nikolic et al. 2007[38]). Beneficial effects of Si on cucumber, especially under biotic and abiotic stress, have been most widely reported (Miyake and Takahashi 1983a[39] , b40 ; Adatia and Besford 198641; Marschner et al. 1990[42]; Chérif and Bélanger 1992[43]; Wang et al. 2007[44]; Pavlovic et al. 2013[45]; Liu et al. 2014[46]). Four-year field trials show that, on the average, the application of silicate to greenhouse cucumber increased the yield by 13.7% (Y. Liang et al., unpublished,). The beneficial effect of Si on the seed germination of cucumber has also been reported. For example, Li and Ma (2002[47]) reported that when the available Si in soil was in the range of 55 to 203mg kg, the activities of both protease and lipase and respiration rate were obviously increased during seed germination. The seed vigour was also increased. These results clearly show that suitable Si level could enhance the seed germination of cucumber.

During seedling growth, Li and Ma (2002[47]) observed Si-mediated increases of the photosynthetic rate, root activities and nitrate reductase activity. In a pot trial, Wang et al. (2007[44]) observed that applications of Si up to 125mg kg −1 improved leaf chlorophyll levels, photosynthetic rate and water use efficiency. Similar results have recently been observed in a hydroponic experiment (Liu et al. 2014[46]).

Tomato

Although tomato is a typical Si-excluder plant species as compared to rice. Si fertilisation has been reported to increase the growth and yield (Liang et al. 1993[48] ; Liu 1997[49]; Liu et al. 2011[36]). Liang et al. (1993[48]) showed that by adding Si to a nutrient solution increased tomato yield by 62%. Furthermore, field trials indicated that Si fertilisation in- creased tomato yield by up to 15–30% due to increased fruit numbers and sizes (Liang et al. 1993[48]). Tomato fruits became ripened four days earlier with higher commercially produced tomato yield due to Si fertilisation, compared with the control treatment (Liang et al. 1993[48]). Liu (1997[49]) conducted several field trials to compare the effects of Si and Ca fertiliser on tomato growth, yield and quality. The results showed that the application of Si fertiliser significantly increased tomato resistance to diseases, fruit size and consequently yield. In addition, the combined application of Si–Ca fertiliser improved the taste of tomato fruit due to increased sugar content, which was not observed if only Ca fertiliser was added without Si fertilisation.

Avocados

A collaborative research project between Professor Elizabeth Dann (UQ) and Dr Wendy Howe (Flinders Agriculture) analysing the protective effect of Si in avocados showed the following benefits to plant health and yield. Initial glass- house experiments assessed the effects of Flinders Agriculture on plant heights in the absence and presence of Calonectria ilicicola, the fungus causing black root rot of avocado. There were indications that Flinders Agriculture applied to seedlings increased plant heights 1.3-fold or 1.8-fold compared with untreated controls, when plants were uninoculated or inoculated, respectively. Silicon concentrations in leaves and roots also increased. Applying Flinders Agriculture also had a beneficial effect on tree health, and silicon accumulation in leaves and fruit peel was observed after only 10 months. This provides strong evidence that silicon from Flinders Agriculture is taken up by roots in mature avocado orchard trees and is translocated and deposited in leaves and fruit peel within a relatively short time frame.

Other Crops

Recently, Si fertilizers have been applied to many other crops of agricultural and horticultural importance (Wang et al. 2001[5]; Korndörfer and Lepsch 2001[50]). For example, field trials with silicon showed that soybean's responded positively with its averaged yield increase of 11% (Y. Liang et al. unpublished). Long-term field trials in 26 provinces of China demonstrated that on the average, the application of Si increased the yield of:

Crop	Yield increase %	Crop	Yield increase %	Crop	Yield increase %
Potato	12.3%	Peanut	6.7%	Radish	11.2%
Soybean	4.7%	Green Bean	6.0%	Sugar Beet	4.7%
Cabbage	15.2%	Capsicum	8.4%	Pumpkin	11.7%
Peach	18.1%	Grape	6.5%	Banana	4.8%
Citrus	12.3%	Logan	10.7%	Tea	11.0%
Ginseng	3.2%	Papaya	9.7%		

Balakhnina et al. (2012[51]) observed that the application of Si stimulated the growth and biomass production of both shoot and roots in barley. In citrus, the application of Si enhanced the growth by 30–80%, promoted fruit maturation by 2–4 weeks and improved fruit quantity (Meena et al. 2014[52]). Li and Ma (2003[53]) found that, within a suitable range of Si application rates, the growth of cotton seedlings was promoted. Meanwhile, the uptake of P, Zn and B in seedlings was enhanced, while the uptake of N, K, Mn, Ca and Mg was decreased. These results suggest that Si could improve the nutritional metabolism of cotton plants and therefore the growth. Crop yield responses to Si are more evident under various forms of abiotic and biotic stresses than under normal conditions.

Crop Quality

Si is proven not only to enhance crop growth and yield but also to improve crop quality. Si is reported to improve the quality of rice grain, sugarcane, vegetables and fruits. For instance, brown rice rate, milled rice rate and head rice rate coupled with fatty acid content were significantly higher in Si-treated rice than in the Si-untreated rice, while chalky grain rate and chalkiness were lower (Zhang et al. 2007[54]; Shang et al. 2009[55]). Sugarcane juice quality characteristics like Brix (% soluble solids in juice), Pol (% sucrose in juice), commercial cane sugar (CCS) and sugar recovery in both salt-sensitive and salt-tolerant sugarcane genotypes were also significantly improved by Si (Ashraf et al. 2009[32]). While fertilisation of strawberries with Si resulted in an increased tissue consistency and durability of fruits during post harvest (Babini et al. 2012[51]). In apples, the application of Si increased the content of soluble solid and vitamin C and reduced the level of titratable acid in the fruit, but did not affect the fruit hardness (Su et al. 2011[56]). Shi et al. (2010[57]) found that Si applications increased the contents of total soluble solids, sugar and acids, but decreased the level of nitrate in grapes. Wang et al. (2007[44]) observed a yield increase in cucumber in the range of 5.1 to 10.2%, depending on the application rate of Si. Liu et al. (2014[46]) observed not only an increase in single cucumber fruit weight but also an improvement in cucumber quality. They found that the levels of sugar and vitamin C were significantly increased, while the level of NO3 (Nitrates) was decreased. The role of Si in increasing sugar concentration in the cucumber fruit is still unclear, but may be related to Si-promoted photosynthesis, as previously suggested (Li and Ma 2002[47]). The decrease of NO_3 level in cucumber may be due to Si-mediated increase in N use efficiency, as observed in rice (Detmann et al. 2012[58]).

Flinders Agriculture

Our Calcium Silicate products are unique, as they not only contain up to 27% Si and 14% plant available Ca and a host of essential trace elements, including Iron, Copper, Zinc, Boron and Manganese. And our Easyspread + S product contains elemental Sulphur allowing us to tackle the Sodium issue from yet another angle. We can also Custom Blend these products to add more Sulphur if it is required. Best of all they are sourced from 100% sustainable and recycled materials, containing no substances that will contaminate the soil.

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