Natural silicon fertilizer in Queensland

Vladimir Matichenkov[1] and John Campbell[2]

[1] Institute Basic Biological Problems Russian Academy of Sciences, Institutskaja St. 2, Pushchino, Moscow region, 142290 Russia. Email vvmatichenkov@rambler.ru
[2] Synergy Fertilisers. PO Box Stone Corner, Qld 4120, www.synergyfert.com.au Email john@synergyfert.com.au

Abstract

Silicon is the second most abundant element in the Earth's crust. This element is recognized as beneficial but not as essential for plant growth. Numerous investigations have shown positive effects of silicon on both soil fertility and plant growth. A deposit of natural source of Si (Natural Silica, NS) near Mr Garnet in North Queensland can be used as a soil amendment. This material was tested in greenhouse investigations under drought and salt toxicity conditions and in unreplicated tests conducted on 150 commercial fields from Mossman to Bundaberg during 2008-2010. Natural Silica had a positive influence on soil properties and increased average yields of sugarcane, hay, potato, banana, and tropical fruits. Natural Silica provided the possibility of reducing the application of traditional fertilizers by 20 to 30% without negative impact on crop production.

Key Words

Silicon fertilizer, stress protection, salt toxicity, drought, field test

Introduction

Silicon (Si) is the second most abundant element in the soil after oxygen and is present in various minerals. However, this element is a constituent of many plants as well, but its roles in plant biology have been poorly understood (Liang 1999). Beginning in 1840, numerous laboratory, greenhouse and field experiments have shown beneficial effects of silicon fertilizers for rice, corn, wheat, barley, sugar cane, and other crops (Snyder et al. 2006). There are two main reasons for silicon fertilization. First, Si reinforces plant protection against insect- and fungal attacks, and unfavorable climatic conditions (Datnoff et al. 1997). Second, soil treated with Si has improved physical and chemical properties and maintains nutrients in plant-available forms (Matichenkov and Ammosova 1996).

Although Si has not always been listed among the generally essential elements of higher plants, there have been reports of direct effect of Si supply on plant defence system (Epstein 1999). Several mechanisms by which Si affects plant defence system were suggested (Biel et al. 2008). 1) Si provides mechanical plant protection via accumulation in epidermal tissue and formation of a thick layer, which protects plants against fungi and insect attacks (Ma and Takahashi 2002). 2) Si provides physiological protection related to optimizing root formation and enhancing photosynthesis (Snyder et al. 2006). 3) Chemical protection by Si is realized due to the interaction between monosilicic acid and some contaminants such as the heavy metals, Mn, and Al in plant tissue (Matichenkov and Bocharnikova 2001). Soluble forms of Si are supposed to be able to play a role in additional catalytic synthesis of specific and non-specific stress hormones and antioxidants (Biel et al. 2008).

The potential of silicon fertilisation for North Queensland was investigated by BSES and CSIRO in 1999-2003 in which: "One of the primary objectives of this study was to quantify responses in cane yield and ccs to Si application. To address this objective, three field trials were established in Bundaberg, Innisfail and Mossman…" (CSIRO, BSES 2003). In the report, it was declared that "soil Si supply, as distinct from its role as a plant nutrient, but due to its effect on other soil properties, can be an important factor associated with maximum production"(CSIRO, BSES 2003). The results of this project clearly indicated that Si should be treated as an integral part of any fertilizer strategy associated with cane production on these soils. However, the main problem, as noticed in the report, was to find an efficient local source for

Si fertilizer. The application of Si-rich slag, as usually used in USA and Brazil, induces a risk of pollution because of heavy metal content. Natural Silica from an open mine near Mt Garnet in North Queensalnd represents a natural mineral high in plant-available Si. The main aim of this study was to investigate the effects this source of Si has on crop productivity in the Queensland.

Methods

Greenhouse tests

Greenhouse experiments were conducted at the Institute Physical-Chemical and Biological Problems in Soil Science Russian Academy of Sciences, Pushchino, Russia. Natural Silica (NS) (Synergy Fertilisers Pty Ltd, North Queensland, Australia) and amorphous silicon dioxide (SiO_2) (surface area 30 m^2 /g) were used as sources of plant-available Si. The chemical composition of the materials is presented in Table 1. Amorphous silicon dioxide was included in the experiments as a chemically pure substance high in plant-available Si. Barley (*Hordeum vulgare* L) was grown in washed quartz sand under various levels of water deficit and salt toxicity. In the first experiment, 100, 80, 60, and 40% of the optimal irrigation rate were used to simulate water deficit. The optimal rate was determined in a preliminary study with the same plant and equal to 50 mL of water per kg pot per day. In the second experiment, salt toxicity was simulated by plant irrigation with NaCl solutions contained 0, 0.2, 0.6, and 1% of Na. In the both experiments, the Si substances were applied to the soil at the rates 0, 1, and 2 g per pot. After 3-weeks growth, barley plants were harvested and weighed. The content of active Si in the soil was tested by the method of Matichenkov (2007). All data obtained were analyzed using one-way analysis of variance (ANOVA) to determine average and confidence intervals.

Table 1. Selected chemical properties of Si-rich materials.

Material	pH	Adsorption capacity, kg/t of material		CaO	MgO	Fe_2O_3	P_2O_5	Al_2O_3	SiO_2
		P	NH_3	--------------------------------------%------------------------------					
SiO_2	7.4-7.5	2.5-3.0	1.2-1.3	-	-	-	-	-	97-99
NS	6-7	4.3-4.5	20-24	3-4	1-2	5-7	0,1-0,2	3-4	80-82

Field tests

Unreplicated field tests were conducted on 150 commercial fields from Mossman to Bundaberg during 2008-2010 on sugarcane, hay, potato, banana, and tropical fruits. Each field trial had at least 3 control plots treated with standard mineral fertilizers and at least 3 plots treated with standard mineral fertilizers and NS. The design of 10 field trials included control plots (100% standard fertilization), treated plots (100% standard fertilization + NS 1 t/ha), and advanced treated plots (70% from standard fertilization + NS 1 t/ha). The design of 2 field trials included control plots (100% standard fertilization), treated plots (100% standard fertilization + NS 1 t/ha), advanced treated plots I (75% from standard fertilization + NS 1 t/ha), and advanced treated plots II (50% from standard fertilization + NS 1 t/ha). Each plot had the area at least 1 ha for fruits and at least 10 ha for sugarcane, potato, bananas or hay. The total area of field trials was about 2500 ha. Soil samples were collected each 3 mo. from each plot and analysed in the Si-Soil Technologies Laboratory. The crop quality was evaluated by farmers.

Results

Greenhouse tests

Both Si substances tested increased plant growth under optimum moisture and water deficiency. Maximum increases in plant biomass from 0.63 to 1.06 g and from 0.31 to 0.74 g of dry weight of 10 plants under 100 and 40 % of irrigation, accordingly, were provided by NS at the rate 2 g per pot. In general, the experiments demonstrated that the Si materials allowed a reduction of irrigation by 20 to 30% without negative impact on barley growth. The soil actual (water-extractable) Si concentrations increased as a result of the application of Si-rich materials. Natural Silica provided higher Si concentrations as compared with amorphous SiO_2. The reduction in irrigation rate led to a slight decrease in actual Si in the pots supplied with Si.

Table 2. Effect of SiO_2 and NS on soil Si and weight of barley grown under various regimes of irrigation.

Treatment	Optimum irrigation		80% irrigation		60% irrigation		40% irrigation	
	Dry wt. of 10 plants, g	Actual soil Si, mg/kg	Dry wt. of 10 plants, g	Actual soil Si, mg/kg	Dry wt. of 10 plants, g	Actual soil Si, mg/kg	Dry wt. of 10 plants, g	Actual soil Si, mg/kg
Control	0.63	3.2	0.54	3.3	0.43	3.4	0.31	3.2
SiO_2, 1 g per pot	0.86	20.1	0.84	17.8	0.74	21.6	0.65	18.7
SiO_2, 2 g per pot	1.05	35.5	0.92	34.8	0.80	36.1	0.72	31.5
NS, 1 g per pot	1.03	37.5	0.91	32.3	0.82	30.4	0.57	34.5
NS, 2 g per pot	1.06	35.2	0.95	41.2	0.81	44.6	0.74	42.6
LSD_{05}	0.03	1.0	0.03	1.2	0.04	1.3	0.04	1.5

The correlation coefficients between biomass of barley and soil actual Si ranged between 0.90 and 0.95 for different irrigation levels, implying that Si can limit plant growth under water stress.

Amorphous SiO_2 and NS significantly increased the resistance of barley to salt toxicity (Table 3). NS provided better barley growth under water deficiency and salt toxicity, compared with SiO_2. This fact probably can be explained by higher solubility of NS. Our results are consistent with published data (Snyder et al. 2006). Added silicon enhanced the growth of salt-stressed barley which was found to have improved photosynthetic activity and the ultrastructure of leaf cell organelles and reduced electrolytic leakage of the leaves (Liang 1999).

Table 3. Effect of SiO_2 and NS on soil Si and weight of barley grown under various levels of salt toxicity.

Treatment	Distilled water	0.2% Na	0.5% Na	1.0% Na

	Dry w. of 10 plants, g	Actual soil Si, mg/kg	Dry w. of 10 plants, g	Actual soil Si, mg/kg	Dry w. of 10 plants, g	Actual soil Si, mg/kg	Dry w. of 10 plants, g	Actual soil Si, mg/kg
Control	0.63	3.2	0.32	4.3	0.23	3.8	0.11	4.1
SiO_2, 1 g per pot	0.86	20.1	0.52	18.3	0.42	22.1	0.25	22.7
SiO_2, 2 g per pot	1.05	35.5	0.61	36.9	0.56	33.3	0.53	34.2
NS, 1 g per pot	1.03	37.5	0.81	35.6	0.54	32.4	0.34	33.8
NS, 2 g per pot	1.06	35.2	0.93	42.6	0.65	46.5	0.64	41.8
LSD_{05}	0.03	1.1	0.04	1.4	0.05	1.5	0.03	1.2

Several mechanisms by which silicon reduces sodium toxicity have been suggested. Silicon can block or decrease Na transport in the apoplastic pathway from root to stem and leaf. Probably, this mechanism is provided by the formation of complex compounds of silicic acid and sodium. Monosilicic acid was also found to increase the stability of chlorophyll molecules under sodium (Biel et al. 2008).

Field tests

The field tests of NS have demonstrated the positive effect it had on soil properties and yield of crop. The NS application optimized the contents of plant-available P, N, and K in soil. An increase in plant-available P could be explained by the exchange reactions between Ca-, Al-, and Fe- phosphates and monosilicic acid, which result in transferring plant-unavailable P into a plant-available form (Matichenkov and Ammosova, 1996, Matichenkov 2007). The improved nitrogen and potassium status by NS can be explained by high adsorption capacity of NS and increased microbial activity in the treated soil (Biel et al., 2008, Matichenkov 2007).

Table 4. Selected data of the effect of Natural Silica on available soil macronutrients and yield.

Region, crop tested and area (ha)	Mineral nitrogen (ppm)		Phosphorus (Colwell) (ppm)		Exchangable potassium (ppm)		Mean yield (t/ha)	
	Control	Treated	Control	Treated	Control	Treated	Control	Treated
Burdekin 1, sugar cane, 40 ha	8.6	9.2	3	6	8	8	69	75
Burdekin 2, sugar cane, 20 ha	7.6	12	37	59	86	126	73	88

Table Land, Passion fruit, 2 ha (yield, kg per tree)	25	21	50	54	41	50	35	54
Tableland, banana, 20 ha	25	20	27	30	282	240	3.4	3.8
Tableland, potato, 20 ha	16	20	66	57	75	78	25.4	28.7
Ingham, sugar cane, 20 ha	1.4	4.8	20	29	47	45	41	70
Kaban, hay, 10 ha	27.4	3.5	35	43	24	48	1.03	1.24
Innisfail, banana, 20 ha	0.6	6.5	18	21	19	25	4.3	4.8
MillaMilla, hay, 20 ha	185.3	42.0	181	131	93	89	0.84	1.03

In general, NS increased the crop production by 5 to 40% (on average 12.5%) for sugarcane with increasing of ccs as well, by 10 to 30% (on average 13.4%) for potato, by 15 to 25% (on average 17.8%) for banana and tropical fruits, and by 25 to 50% (on average 28%) for hay (Table 4).

Conclusion

NS had positive effects on soil parameters and crop productivity. However, the promising results of the field and greenhouse tests require detailed investigations in the future. Besides demonstration tests on commercial fields, testing at universities and agricultural stations is necessary.

References

Biel KY, Matichenkov VV and Fomina IR (2008). Protective role of silicon in living systems. In Functional Foods for Chronic Diseases. Advances in the Development of Functional Foods, DM Martirosyan (Ed.), Copyright ? by D&A Inc., Richardson, Texas, USA, vol 3. pp. 208-231.

CSIRO, BSES (2003). Improving cane yield & ccs in sugarcane through the application of silicon based amendments. Project Report CLW009. www.srdc.gov.au/ProjectReports/CLW009_Final_Report.pdf

Datnoff LE, Deren CW and Snyder GS (1997). Silicon fertilization for disease management of rice in Florida. Crop Protection 16, 525-531.

Epstein E (1999). Silicon. Annual Revue of Plant Physiology and Plant Molecular Biology 50, 641–644.

Liang Y (1999). Effects of silicon on enzyme activity and sodium, potassium and calcium concentration in barley under salt stress. Plant and Soil 209, 217-224.

Ma JF and Takahashi E (2002). Soil, fertilizer, and plant silicon research in Japan. Elsevier, The Netherlands.

Matichenkov VV (2007). Soil gradation on silicon deficiency for plant nutrition. Agrochemistry 7, 22-30.

Matichenkov VV (2007). Role of mobile compounds of silicon in plants and soil-plants system. Doctoral Diss. Institute Basic Biological Problems RAS, Pushchino.

Matichenkov VV and Ammosova YM (1996). Effect of amorphous silica on soil properties of a sod-podzolic soil. Eurasian Soil Science, 28, 87-99.

Matichenkov VV and Bocharnikova EA (2001). The relationship between Si and soil physical and chemical properties. In Silicon in Agriculture. Studies in Plant Science. Datnoff L, Snyder G, Korndorfer G (ed), pp. 209-219. Elsevier, Amsterdam.

Snyder GH, Matichenkov VV and Datnoff LE. (2006). Silicon. In Handbook of Plant Nutrition, Massachusetts University, p.551–568.