

The Effects of the Application of Foliar Sprays with Stabilized Silicic Acid: An Overview of the Results From 2003-2014

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Abstract The silicic acid agro technology (SAAT) is the application of stabilized silicic acid on the plant. SAAT can be used as a foliar spray or as a soil amendment. The foliar application of (stabilized) silicic acid induces significantly better results for growth, yield and quality parameters compared to ‘traditional’ silica soil fertilizers and foliar sprays with silicates. Foliar silicic acid is only effective at very low dose rates during the vegetative stage and should be regarded as a biostimulant (‘plant growth promoter’). As well as its effectiveness, it is safe, eco-friendly and cost-effective.

Keywords Stabilized silicic acid · Foliar · Biostimulant · Growth · Water and mineral balance · Yield · Quality · Plant

1 Introduction

There are contradictory opinions on the effects of Si in the plant. This is partly due to the unpredictable and limited absorption and uptake of Si by the plant. Nevertheless there is increasing proof that Si has many beneficial roles in crop performance [1].

Silicon (Si) after oxygen is the most common element of the Earth’s crust. Silicon is present in almost any soil

type, mainly as silicates, silicon dioxide, (mono- and poly-) silicic acid and biogenic silica, but only monosilicic acid ($\text{Si}(\text{OH})_4$) is plant available, but its concentration is very low due to its instability. With increasing concentration it polymerizes and is no longer bioavailable. Furthermore, the solubility of monosilicic acid can be decreased by interactions with heavy metals, iron, aluminium and manganese.

Due to these factors, there is a *silicic acid deficiency* in many types of soil. To ‘prove’ this deficiency additional (stabilized) silicic acid was applied. Then striking differences (growth - and yield parameters) became visible [2]. So far Si-fertilizers (like silicates, diatomaceous earth and biogenic silica sources such as rice-hull ash) are used as an indirect source of silicic acid increasing growth and yield. By transformation from these silicon sources monosilicic acid is formed and taken up by the roots, transported via the xylem in the transpiration stream and distributed within plant tissues. In leaf sheaths and leaf blades silicic acid polymerizes into amorphous silica, which is deposited into the cell wall, cell lumen, intracellular spaces and trichomes increasing tissue strength.

Although the dry weight of Si in the dry matter of plants ranges from <0.1 % to >10 % [3], Si is not recognized as ‘essential’ in classically defined terms, however its importance in plant growth and plant development is nowadays increasingly recognized.

Plants differ in their ability to accumulate Si. Silicic acid uptake by the plant is mainly an active process mediated by specific transporters. Physiological studies have shown that the differences in Si uptake and accumulation result from the capacity of the roots to absorb silicic acid [4].

Based on their Si content plants have been classified as Si accumulator, intermediate-type and excluder species. In

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general monocots are Si accumulators and dicots belong to the intermediate-type or the rare excluder types, because dicotyledonous plants have a lower tendency to accumulate Si and some species may grow adequately with levels of about 0.1 % Si in plant tissue. Nevertheless, in Si deficient conditions dicots also show stunted growth, are structurally weak and more prone to abiotic and biotic stresses [1].

Trials on a variety of crops have shown the beneficial effects of using silicon fertilizers which include increase in root development, more effective tillers and an increase in plant mass. Leaves, stems and culms of plants, grown in the presence of adequate silicon levels, also show enhanced strength and rigidity and an erect growth e.g. in rice [1].

Many experiments under different soil and climatic conditions on many different crops have shown a significant increase in both crop productivity and quality as a result of silicon amendments. Beneficial effects also arise from a higher resistance to *biotic* stresses (e.g. plant disease and pest damage) and *abiotic* stresses (salinity, drought, high and low temperature, acidity, etc.) due to biofortification of the plant [1].

So far several different types of Si fertilizers are used such as silicate slags, crop residues of silicon-accumulating plants (like rice hull ashes), silica gel and diatomaceous earth. In addition to these soil amendments foliar sprays with silicates are also used. These silicate sprays (like K_2SiO_3 or Na_2SiO_3) reduce the incidence of some infections in specific species, such as powdery mildew in cucumbers, blast control in rice [5] and brown spot in rice. In coffee no effect in reducing coffee leaf rust incidence has been observed [6]. Most trials with silicate sprays have not demonstrated any effect on plant biomass or yield [5, 6].

2 Materials and Methods

The Silicic Acid Agro Technology (SAAT) is the application of stabilized silicic acid (sSA). It can be used as a foliar spray, hydroponically or as a soil amendment. Since 2002 experiments have been carried out using plant available silicic acid itself instead of the ‘indirect Si sources’ like silicate fertilizers or foliar silicate sprays.

In this survey only the effects of the foliar application of sSA are summarized.

Because silicic acid itself is used, the applied quantity of Si in the foliar sSA sprays (20–40 gm Si/ha/crop cycle) is much lower compared to the quantity of Si in the silicate sprays (400–5000 gm Si/ha/crop cycle).

An overview of the results on the application of foliar sprayed sSA on different crops from 2003–2014 is presented.

Stabilized non-colloidal silicic acid (sSA) is made according to patented production processes in which polymerization is prevented. From this non-colloidal (= mono, oligomeric or microcolloidal SA) monosilicic acid is released.

Oligomeric silicic acid is silicic acid containing a moderate number of monomeric silicic acid molecules combined chemically (polymerized) to form a larger mass of molecules. The bioactive monosilicic acid molecule remains the basic repeat unit. The process can be reversed to release monosilicic acid and intermediates. Microcolloidal silicic acid contains hundreds to many thousands of molecules forming particle sizes ranging from 1–8 nm.

Not being registered in the legislation concerning fertilizers it was not possible to use just silicic acid. To fulfill these regulations other micronutrients had to be added like boron, copper, molybdenum, zinc, etc.

Initially (up to 2012) trials have been done with 2.5 % oligomeric silicic acid (= 0.8 % Si) in combination with 1.2 % potassium chloride (KCl), 0.8 % boric acid (= 0.2 % B), 47.0 % demi water and 47.5 % PEG-400 (stabilizer) with generic name OSAB (sSA + B). From 2012 on trials were done with PEG-400 stabilized microcolloidal silicic acid in combination with 2 % micronutrients: B = 0.3 %, Cu = 0.15 %, Mo = 0.1 % and Zn = 1.5 % (brand name: AB Yellow®).

The concentrated sSA stock solution (+ micronutrients) is very acidic (pH = 0.8) and must be diluted with water (250–500 times) to be used as a foliar spray (pH: 5–6).

In initial experiments the efficacy of OSAB was compared with several control sprays: a. demi water, b. demi water with PEG-400, c. boric acid (0.8 %) in demi water with PEG-400 plus B. In these experiments the efficacy of OSAB on growth and yield showed an increase between 9–47 % compared to controls, while the controls did not show significant differences mutually. This was done to demonstrate that only silicic acid is the effective agent and not the other components in OSAB.

In experiments with OSAB on lettuce, onions, potatoes, flowers and fruit trees the optimal concentration of sSA as well as the optimal spraying frequency were determined: 2–4 ml OSAB / litre of water and 3–4 sprays at two week intervals starting early in the vegetative stage, resulting in an overall guideline: first spray 400 ml OSAB in 200 litres of water / hectare at the moment when 3–4 real leaves have appeared, followed by a second spray with 600 ml OSAB in 300 litres water / ha, a 3rd and 4th spray of 1000 ml OSAB in 500 litres water/ha each with 2 weeks interval.

Since 2003 a variety of trials have been conducted (Tables 1 and 2):

1. Scientific trials on rice, sugarcane, tomato, grapes and tobacco. The experiments were laid out in randomized

complete block design with three replications and were done on different soil types (sandy loam, loam, clay) with soil pH varying between 5.5 and 7.8, on several locations with different climatic conditions (Universities of Agricultural Sciences of Bangalore, Karnataka and Navsari, Gujarat, India). A more detailed description of the methodology is given in articles on rice and finger millet [7, 10].

2. Extension trials (in cooperation with Scientific Institutes): Proefboerderij (official testing farm) de Rusthoeve, Nieuwdorp, the Netherlands, by L. Kamp (2003) on potatoes and onions, University of Navsari by Prof. S.P. Shukla (2012) on eggplant and University of Navsari by Dr. C.K. Timbadia (2013) on sweet corn and watermelon.
3. Farmer trials (in cooperation with Scientific Institutes): trial supervised by Coromandel Ltd. on cardamom (in Tamil Nadu, 2013) and trials on wheat in very saline soil (MV Tehno Group / Aktiv Green Tech, supervised by V. Ionescu, Braila region, Romania, 2014).

In all trials the application of foliar sSA (with boron and/or other micronutrients) has been compared with the controls being standard local / agricultural practice.

In all trials the quantity of pesticides in the sSA treated areas was reduced by 50 % compared to controls.

3 Results

Silicic acid treated plants demonstrated improved *growth parameters*: a. increased root growth (number, diameter and length) resulting in more root mass; b. increase in length and diameter of stem and number of tillers [7]; c. increase in leaf area and chlorophyll content [9] and d. more biomass [7].

In 2014 a study on organically grown cucumber was published (Estonia) [13]. Cucumber transplants were taller and stem diameter was greater in the silicic acid treatment as compared to the control.

Physiological parameters include: a. higher uptake of nutrients (as recorded in the xylem) and b. higher concentration of nutrients in petiole [9]. The concentration of NO₃, N, P, and Mg were higher in the Si treated plants [13]. This is in accordance with other studies, for example on grapes where the uptake and accumulation of nutrients (K, Ca, P, N, Si and B) was found to be greater in the foliar SA treatment compared to control and foliar sprays with boric acid [9].

Other parameters demonstrated: a. decrease in abiotic and biotic stresses [11, 12]; b. shorter growth cycle and c. positive results on acidic soils, on saline soils and under suboptimal conditions.

Yield parameters were (very) positive as shown in Tables 1 and 2. In Tables 1 & 2 the results are shown of the foliar application of OSAB and AB Yellow (during the period 2003–2014) on yield increases in as well monocots (onions, rice, sugarcane, finger millet, sweet corn, cardamom and what) as dicots (potatoes, apples papayas, grapes chili peppers, tomatoes, eggplant and watermelon). In a trial on wheat in very salty soil in Romania (Table 2) no fertilizers and pesticides were used. The yield of the foliar silicic acid treated wheat was over 3,4 ton/ha compared to 1 ton/ha of the control.

Quality parameters: in almost all crops improved quality was recorded (Tables 1 and 2): more uniformity of the produce (apples, potatoes), less physiological losses in grapes [9] and apples, higher Brix in papayas [8], pepper, eggplant, higher lycopene and vitamin C in tomatoes, higher protein content in wheat and higher non-reducing sugar content in sugarcane and grapes [9]. In trials with sugarcane (RCBD

Table 1 Results of the effects of foliar application of OSAB (oligomeric silicic acid and boric acid) on several crops during 2003–2012

Crop	Year	Country	Yield % increase compared to control plot	Type / (# of trials)	Remarks	Ref
Potatoes	2003	Netherlands	+ 6.5 %	ET [2]	Fewer infections	
Onions	2003	Netherlands	+ 10.8 %	ET [2]	Uniformity +	
Apples	2005–2008	Netherlands	+ 17 %	FT [1]	Brix: ++ Uniformity +	
Papayas	2007–2008	Colombia	+ 13.2 %	RCBD [1]	Brix: +	8
Rice	2007–2012	India	+ 15 – 45 %	RCBD [12]	Fewer infections	7
Grapes	2009–2010	India	+ 39 %	RCBD [2]	NRS: +	9
Sugarcane	2011–2012	India	+ 26 %	RCBD [3]	NRS: ++	

Abbreviations in the column ‘type of trial’: RCBD (randomized complete block design with 3 replications), ET (extension trials in cooperation with scientific institutes), FT (farmer trials in cooperation with scientific institutes) and NRS (non-reducing sugars)

Table 2 Results of the effect of foliar application of AB Yellow (microcolloidal silicic acid with 2 % micronutrients: B = 0.3 %, Cu = 0.15 %, Mo = 0.1 % and Zn = 1.5 %) on several crops during 2012-2014

Crop	Year	Country	Yield % increase compared to control plot	Type / (# of trials)	Remarks	Ref
Chili Peppers	2012	India	+ 39 %	RCBD [2]	Fewer infections	
Tomato	2012	India	+ 31 %	RCBD [2]	Brix: ++	
Eggplant	2012	India	+ 44 %	ET	Brix: ++	
Finger Millet	2012	India	+ 39 %	RCBD [2]	Blast reduction: 58 %	[10]
Sweet Corn	2013	India	+ 34 %	ET / FT [2]	Fewer infections	
Watermelon	2013	India	+ 38 %	ET / FT [2]	Fewer infections	
Cardamom	2013	India	+ 26 %	FT	Fewer infections Soil pH = 4.8	
Wheat	2014	Romania	+ 340 %	FT	Very saline soil	

Abbreviations in the column 'type of trial': RCBD (randomized complete block design with 3 replications), ET (extension trials in cooperation with scientific institutes) and FT (farmer trials in cooperation with scientific institutes)

design with 3 replications) sSA foliar sprays recorded significant higher Brix value, lower reducing sugars and higher NRS (non-reducing sugars) compared to the control. In this trial the efficacy of sSA was compared with the control and with the application of calcium silicates (CS) showing a 26.2 % higher yield in the sSA treated area compared to 14.5 % for the plots with only silicates.

Effect of SAAT on soil properties

In several trials in Gujarat (2011-2012) on peppers, okra and tomato the N, P, K and Si content of the soil were analyzed before and after the trials. There were no significant differences for each of the four nutrients indicating no adverse effects on the basic status of the nutrients in the soil.

4 Discussion

After initial experiments in 2001 the efficacy of foliar applied sSA was repeatedly demonstrated in 2002. Foliar application is considered more efficient because the silicic acid is applied directly to the plant in a more certain quantity. When applied to the soil, many variable factors from the soil-water environment to the water balance of the plant affect the amount absorbed by the plant roots. Critics argue that the effects of SAAT are the result of the run-off of the spray to the soil / roots. This is refuted by initial experiments in 2002 and trials in which the soil has been covered with plastic (China, Fouchou, FuJian Academy of Agriculture, March 2014). Other experiments strongly suggest that Si is absorbed by the leaves [15, 16]. In all investigated plants (monocots as well as dicots) foliar applied sSA induces a significant increase in plant growth resulting in plants with higher mass, more and longer tillers, higher diameter of stems, larger leaf surfaces with significantly higher chlorophyll content resulting in higher yield, fewer infections, higher tolerance to abiotic stresses, higher quality of

produce, lower physiological losses and longer shelf-life compared to standard agricultural practice (including the use of traditional Si fertilizers). Foliar applied sSA has been shown to be very effective on plant growth in contrast with foliar sprays with silicates that have minimal or no growth stimulation [5, 6]. Trials with low dose silicic acid applied during the vegetative stage also stimulate growth and yield in monocots as well as dicots, including 'not responding' dicots (like tomato, clover and tobacco) compared to controls or the use of traditional Si fertilizers [17].

When sSA is applied in higher concentrations with other spraying regimes and in other growth phases there is hardly any (or no) effect on growth and yield.

The primary effect of SAAT is an increase of root mass compared to the controls resulting in higher uptake of nutrients from the soil as recorded in xylem sap concentration and in dry matter [9, 13]. At later growth stages higher concentrations of nutrients (including Si) have been recorded in the petiole [9]. The increase in quantity of Si in the plant as recorded in dry matter is much higher than the total quantity of Si applied via the foliar sprays. This shows that the foliar sprays induce a higher uptake of nutrients (including Si) due to the larger root system. There is good evidence from a study on cowpea that an increased concentration of ABA (abscisic acid) measured in the roots occurred as a result of enhanced silicon nutrition [14]. This suggests that foliar sSA induces ABA (- like) biosynthesis to promote root growth.

When compared to all other types of silicon amendments (silicates, etc.), foliar (non-colloidal) sSA is not a fertilizer ('nutrient') because the quantities applied are too low for an adequate Si nutrition. Foliar sSA should be regarded as a biostimulant (plant growth promoter) based on its physiological effects on the plant according to the definition as formulated by du Jardin [18]: "Plant biostimulants are substances and materials, with the exception of nutrients and

pesticides, which, when applied to plant, seeds or growing substrates in specific formulations, have the capacity to modify physiological processes of plants in a way that provides potential benefits to growth, development and/or stress response”.

5 Conclusion

Silicic Acid Agro Technology (SAAT) is the application of stabilized non-colloidal and plant available silicic acid as a foliar spray or as a soil amendment to the plant. Foliar applied sSA induces an increase in plant growth starting with an enhanced root growth resulting in a higher uptake of nutrients. The foliar sprays of SAAT are only effective when they are (a) started early in the vegetative stage, (b) have a specific (low) concentration and (c) follow a specific spray schedule.

Without question more research is needed to understand the mode(s) of action of SAAT.

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