Proceedings of The 5th International Conference on Silicon in Agriculture

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Welcoming address

Dear Guests, Friends, Ladies and Gentlemen:

On behalf of The International and Local Organizing Committees, I am pleased and honored to welcome all of the delegates throughout the world to participate in the 5th International Conference on Silicon in Agriculture at The Friendship Hotel in Beijing, China from September 13-18, 2011.

The international silicon community has gone through a glorious history of more than one decade. The first conference was successfully held in Florida, The United States (1999), followed by the second in Tsuruoka, Japan (2002), the third in Uberlandia, Brazil (2005), and the fourth in KwaZulu-Natal, South Africa (2008).

The theme of the 5th International Conference on Silicon in Agriculture is "Silicon and Sustainable Agricultural Development". As we know, rapid progress and great breakthrough have been achieved in research on the roles of silicon in plant molecular biology and agriculture over the last decade. This conference will provide a forum for the distinguished scientists, colleagues, students, fertilizer producers and consumers to present their most recent findings and achievements, and to exchange their valuable experiences with their international partners.

Although silicon (Si) is not recognized an essential element for the growth of higher plants, it has been proved that Si is beneficial or quasi-essential to plants, especially gramineous plants such as rice, wheat, barley, maize, sorghum and sugarcane etc.. The beneficial effects are particularly distinct on plants exposed to various forms of biotic (e.g. plant disease and pest damage) and abiotic stress (e.g. alumiunum and heavy metals toxicity, salinity stress, drought and high temperature stress, chilling stress, mineral nutrient deficiency stress and UV radition etc.). Currently, slag-based calcium silicate fertilizers are extensively applied to rice and sugarcane in many countries, especially in Asian, African, North and South American countries. Silicon is now playing ever-increasingly important roles in the sustainability of agriculture. In the last two decades, the roles of silicon in plants and agriculture have been widely recognized by scientists, government officials and farmers throughout the world due to the great advancements in both basic and applied research on silicon. The Si community has also grown up, with more than 150 participants from 28 countries presenting 112 papers (abstracts) in this conference

China is one of the origins of rice, a typical silicon-accumulating plant species. According to statistics in 2006, there were about 29.3 million hectares of paddy rice fields in China, accounting for 30% of its total arable land. Surprisingly, approximately 50% of the paddy rice soils in China are Si-deficient. Silicon deficiency is a yield- and quality-limiting factor, especially in tropical and subtropical regions of China. It is estimated that about 35 million tons of silicon fertilizer per year are potentially required for rice production.

Confucius once said, "How happy we are to meet friends from afar!" The organizing committee wishes to extend its cordial invitation to all the attendees to participate in the 5th International Conference on Silicon in Agriculture. I believe deeply that your participation will contribute undoubtedly to the success of the conference.

I would like to thank The Chinese Academy of Agriccultural Sciences (CAAS), International Co-operation Bureau of CAAS, Institute of Agricultural Resoureces and Regional Planning (IARRP), CAAS, Chinese Society of Plant Nutrition and Fertilizer Sciences and Leading Bio-agricultural Co. Ltd., for their joint organization of this conference. I am particularly grateful to all my colleagues and friends from both inside and outside China for their encouragement and support. Special thanks are also given to National Natural Science Foundation of China (NSFC), Leading Bio-agricultural Co. Ltd., Tisco Harsco Technology Co. Ltd., Agripower Australia Limited and LF Green for their generous sponsorship.

Finally, I wish that all the participants would benefit from this conference and enjoy staying in Beijing.

Yongchao Liang

Chair

The Organizing Committee of the 5th Silicon in Agriculture Conference

Contents

Mitigating global warming potentials of methane and nitrous oxide gases from rice paddies by soil amendments in Bangladesh

Ali MA [1]*, Faruque G [2], Haque M [3], Islam MN [4]

1. Department of Environmental Science, Bangladesh Agricultural University (BAU), Mymensingh 2202, Bangladesh,

2 & 3. Department of Agricultural Extension Education, GTI, BAU, Bangladesh,

4. Department of Environmental Science, BAU, Bangladesh,

**Corresponding author: Muhammad Aslam Ali (Phone: +88-01731921248, Fax: +88-091 -55810, E-mail: litonaslam@ yahoo.com*

Abstract

A field experiment was conducted in Bangladesh Agricultural University Farm to investigate the mitigating effects of soil amendments on methane (CH_4) and nitrous oxide (N_2O) emissions during rice cultivation under continuous and intermittent irrigation methods. Five treatments such as urea alone, urea plus calcium carbide, urea plus calcium silicate, urea plus phosphogypsum, and urea plus biochar amendments were selected in this experiment. Soil amendments significantly decreased the total global warming potentials of CH_4 and N_2O gases in both irrigation methods. The total global warming potential from the control plot was 3.22 Mg CO_2 ha^{-1} which was decreased by 22%-28% and 25-30% with soil amendments under continuous and intermittent irrigation methods, respectively. Soil amendments decreased total seasonal CH_4 flux by 21-27% and 24-31% under continuous and intermittent irrigations respectively; while total seasonal N_2O emission was decreased by 20-32% and 16-30% under continuous and intermittent irrigations, respectively. Among the amendments calcium silicate and phospho-gypsum significantly decreased CH_4 emission rate due to their electron accepting effects, while N_2O fluxes were decreased remarkably with biochar and calcium carbide amendments probably due to their contribution as nitrification inhibitors. In addition, the soil physico-chemical properties such as soil porosity, soil pH and redox potentials (soil Eh) and the content of electron acceptors in rice paddy soil after amendments were improved under continuous and intermittent irrigation methods, which probably controlled CH_4 and N_2O gas emissions from rice field. Rice grain yield was increased by 9-21% and 10-26% over the control (4089 kg ha^{-1}) with soil amendments under continuous and intermittent irrigations, respectively. Finally, our findings suggest that the application of soil amendments having electron acceptors and nitrification inhibitors under intermittent irrigation could be an effective mitigation strategy for decreasing total global warming potentials of CH_4 and N_2O gases in a sub-tropical country like Bangladesh.

Keywords: Electron, Global warming, Methane, Nitrous oxide, Rice.

Silicon nutrition for mitigation of salt toxicity in sunflower (*Helianthus annuus* L)

Ashraf M, Saqib RM, Afzal M, Tahir MA, Shahzad SM, Imtiaz M

University College of Agriculture, University of Sargodha, Pakistan

Email: mashraf_pk94@hotmail.com

Abstract

Soil salinization is a worldwide problem which poses a severe threat to land, water and infrastructure throughout the world. The excessive salts in soil or irrigation water interfere with plant growth through ion cytotoxicity, osmotic effects, nutrient imbalances and/or oxidative damage. Different techniques to deal with salinity include engineering and reclamation approaches as well as use of salt tolerant species to sustain the productivity of salt affected soils. However, supplemental application of silicon (Si) may help to overcome the deleterious effects of salinity and improve the adaptation capability of plants to saline environment. In present study, we investigated the damaging effects of NaCl on growth and ionic composition and role of Si to mitigate salt-induced deleterious impacts in sunflower. Three NaCl levels (control, 60 mM and 100 mM) were used in triplicates to plants grown with 30 and 60 ppm Si as sodium silicate. Results revealed that applied NaCl significantly ($P \leq 0.05$) increased Na concetration, reduced K concetration and K: Na ratio compared to control. Dry matter production and its partioning into roots and shoots were also significantly ($P \leq 0.05$) influenced by both levels of added NaCl. But supplemented Si interacted with Na, reduced its uptake and accumulaton as well as distribution within plant tissue. Biomass production was significantly ($P \leq 0.05$) higher in Si treated plants in comparison to salt treated plants without supplemental Si. Salinity induced reduction in K concentration and K: Na ratio was significantly improved with the addition of Si to salinised growth medium. Shoot dry matter was positively correlated with K: Na ratio at different levels of NaCl and Si. These findings suggested that external Si enrichment not only reduced Na uptake and accumulation but also influenced its distribution in plant parts and consequently improved adaptation capability of sunflower to salinity stress.

Key words: Adaptation capability, Cultivar, Dry matter, K: Na ratio, NaCl, Sunflower.

Effects of silicon and cycocel application on yield components and quantity yield of rice (*Oryza sativa* L.) in Iran

Arab R [1], Dastan S [2], Mobasser HR [3], Ghanbari-Malidarreh A [4]

1.Department of Agriculture, Sari Branch, Islamic Azad University, Sari, Iran.

2.Department of Agronomy, Science and Research Branch, Islamic Azad University, Tehran, Iran

3.Department of Agronomy, Qaemshahr Branch, Islamic Azad University, Qaemshahr, Iran

4.Department of Agriculture, Jouybar Branch, Islamic Azad University, Jouybar, Iran.

Abstract

In order to investigate effects of silicon and cycocel application on yield components and quantity yield of rice at different growth and development stages, an experiment was carried out in split plot in completely randomized block design with three replications in Iran (Babol Region) in 2009. Main factor was silicon rates in four levels including (0, 200, 400 and 600 kg Si ha^{-1}) and cycocel rates as a subfactor in three levels (0, 2 and 4 litre ha^{-1}). Results showed that 600 kg Si ha^{-1} due decreased of 4th internode bending moment and filled spikelet percentage per panicle. Minimum of the plant height and panicle per m^2 and maximum of filled spikelet percentage per panicle and 1000 grain weight were obtained in CK (no silicon application). Most and least of the grain yield and harvest index were obtained on application of 600 and 0 kg Si ha^{-1}, respectively. With cycocel application the plant height and panicle length decreased but the tiller number per plant, filled spikelet percentage per panicle and grain yield increased. Least of the filled spikelet percentage per panicle was obtained in interaction of the 600 kg Si ha^{-1} × non application of cycocel. Therefore application of 600 kg Si ha^{-1} and 4 litre cycocel ha^{-1} was the best treatment.

Keywords*:* Bending moment, Cycocel, Grain yield, Rice, Silicon.

Release of Silicon from Soil Applied with Graded Levels of Fly Ash with Silicate Solubilizing Bacteria and Farm Yard Manure

Balasubramaniam P[1*]., Pedda Ghouse Peera S.K[1]., Mahendran P.P[2]., Tajuddin A[1].

[1]*Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur-621712. Tiruchirappalli, Tamil Nadu, India.*

[2]*Agricultural College and Research Institute, Madurai, Tamil Nadu, India.*

Email: balu_tnau@yahoo.co.in

Abstract

An incubation experiment was conducted to study the release characteristics of silicon from native soil and applied sources *viz*, Fly Ash (FA), Silicate Solubilizing Bacteria (SSB) and Farm Yard Manure (FYM). The soil for incubation study collected from Eastern block of Agricultural Engineering College and Research Institute which is low status of plant available silicon. The treatments consist of graded levels of FA *viz.*, 0, 12.5, 25, 37.5 and 50 g/kg of soil with and without SSB and FYM. Six sets of plastic containers consist of 40 numbers in each set to accommodate 20 treatments with 2 replications under Factorial Completely Randomized Design for 15, 30, 45, 60 75 and 90 days duration of incubation. The calculated quantity of FA, SSB and FYM was applied to each container containing 10 g of soil and mixed thoroughly. Extracted plant available Si by using 1N NaOAc (pH 4.0) and estimated calorimetrically at 15 days interval i.e 15, 30, 45, 60 75 and 90 days duration of incubation.

The results revealed that among different treatments, addition of SSB + FYM resulted a consistent increase of N NaOAc (pH 4.0) extractable Si from 144.7 mg per kg to 272.2 mg per kg during 15^{th} to 60^{th} days after incubation, thereafter a slight decline in N NaOAc (pH 4.0) extractable Si was observed up to 90 days. Among the different treatments the application of SSB +FYM recorded the highest N NaOAc (pH 4.0) extractable Si of 272.2 mg per kg at 60^{th} day followed by FYM (258.0 mg per kg) on 75^{th} day of incubation. The control recorded the least N NaOAc extractable Si throughout the incubation period. Imposition of graded levels of fly ash and their interaction with various sources viz., SSB, FYM and SSB+FYM have shown significant variations in the N NaOAc (pH 4.0) extractable Si throughout the incubation period. Imposition of fly ash at 50 g kg^{-1} of soil with SSB + FYM resulted in more release at 15,30,45,60 and 75 days after incubation which was on par with addition of fly ash at 25 g kg^{-1} of soil at 90 days after incubation.

Key words: Fly ash, Plant available silicon, Silicate solubilizing bacteria, Farm yard manure

Silicon transporters and disease resistance

Belanger R, Julien V, Wilfried RB, Jonatan M, Genevieve AL, Caroline G, Caroline L, François B, James M

Departement de phytologie-FSAA / Universite Laval / Quebec, Qc G1V 0A6, Canada

Abstract

Silicon (Si) is not considered as an essential element for plant growth yet its uptake is beneficial in alleviating abiotic and biotic stresses. These positive effects are variable since accumulation differs among plant species. This differential accumulation would be attributable to the presence of specific genes involved in Si uptake. These genes have first been recently described in rice with homologs reported in maize and barley. Wheat is another plant species known to accumulate fairly large concentrations of Si and to respond well to Si treatment. From this premise, we sought to identify and characterize the presence of Si-transport genes in wheat, and to determine their functionality and localization. Our results have allowed the identification and the cloning of a putative Si-transport gene presenting high homology (>80%) with the Si-influx protein in rice known as Lsi1. Transient expressions of the wheat Lsi1 Si transporter (TaLsi1) coupled with GFP in Nicotiana benthamiana indicated that this protein was localized across the plasma membrane, a feature typical of other members of the Lsi1 family. The Si transport activity of TaLsi1 was confirmed in a heterologous system, Xenopus laevis oocytes, and its efficiency at transporting Si was comparable to that of the rice Lsi1. The discovery of these transporters provides a unique opportunity to understand and optimize the uptake of Si in a strategy to control plant diseases.

Effect of foliar silicic acid and boron acid in Bangalore blue grapes

Bhavya HK [1], Nache gowda V [2], Jaganath S [3], Sreenivas KN [1], Prakash NB [4]

1.Department of Horticulture, University of Agricultural Sciences, Bangalore, India 560065, 2.Special officer, College of Horticulture, Kolar, UHS (Bagalkot), Karnataka,

3. College of Horticulture, Mysore, UHS (Bagalkot), Karnataka,

4.Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, Bangalore, India 560065;

Email: bhavyaphk811@gmail.com

The role of Silicon in plant biology is subjected to multiple stresses including biotic and abiotic stresses. It is also known to increase drought tolerance in plants by maintaining plant water balance, photosynthetic activity, erectness of leaves and structure of xylem vessels under high transpiration rates. Studies on effect of foliar silicon supply on grapes, cucumber, muskmelon, zucchini squash and miniature rose revealed benefits of the element related to resistance against disease, pests and drought. However, majority of the studies with horticultural crops generally emphasized on disease management or physiological difference between silicon treated and untreated control. There is a limited evidence that silicon supplementation affects the growth, yield and quality in fruit crops. Although, few studies have confirmed the benefits of silicon as foliar applications, very limited information was available on yield parameters and uptake of nutrient elements. In this context, field experiment was conducted to evaluate the effect of soluble silicic acid (SA) and boron (B) as foliar spray on growth, yield and quality of Bangalore Blue grapes.

The field experiment was conducted during 2009 in a Randomized complete Block Design with 9 treatments (T_1: Control, T_2: 2 ml L^{-1} foliar SA as 6 sprays at 10 days interval, T_3: 4 ml L^{-1} foliar SA as 6 sprays at 10 days interval, T_4: 6 ml L^{-1} foliar SA as 6 sprays at 10 days interval, T_5: 2 ml L^{-1} foliar SA as 3 sprays at 20 days interval, T_6: 4 ml L^{-1} foliar SA as 3 sprays at 20 days, T_7: 6 ml L^{-1} foliar SA as 3 sprays at 20 days, T_8: 0.01% L^{-1} borax as 3 sprays at 10 interval and T_9: 0.02% L^{-1} borax as 3 sprays at 20 interval and replicate 3 times) to examine the response of Bangalore Blue grape vines to foliar Silicic acid (SA) and Boron (B) spray.

The highest cane length (110.09 cm), leaf area (179.44 cm^2) and total leaf chlorophyll content (13.73 mg/g) were observed in 4 ml L^{-1} foliar SA at 10 days interval (6 sprays). The highest number of bunches per vine (325.53), yield per vine (37.19 kg) and yield per hectare (16.74 t) was recorded in 6 ml L^{-1} foliar SA at 10 days interval (6 sprays) followed by 4 ml L^{-1} foliar SA at 20 days interval (3 sprays). The quality parameters *viz*., total soluble solids, acidity, total sugar, reducing sugar, non reducing sugars, physiological loss in bunch weight and per cent rotten berries were significantly influenced by foliar applied B and Si. The maximum total soluble solids (15.33^{o}B) and lowest titratable acidity (0.76%) was recorded with 0.02 per cent borax at 20 days interval (3 sprays) which was followed by 4 ml L^{-1} foliar SA at 20 days interval (3 sprays). The minimum loss in bunch weight (6.30%) and per cent rotten berries (16.15) was recorded in 4 ml L^{-1} foliar SA at 10 days interval (6 sprays) and maximum was recorded in control during storage. In general, the uptake and accumulation of Si in petiole was found to be higher in foliar SA treatment compare to B treatment and control.

Roles of silicon in improving oxidative stress resistance by increase of chlorophyll content and relative water content of rice (*Oryza sativa* L.) genotypes

Biglary F [1], Haddad R [2], Hosseini R [2], Sotudehniya A [3]

1.Department of Agricultural Biotechnology, Imam Khomeini International University.

2.Department of Agricultural Biotechnology, Imam Khomeini International University, Qazvin, IR of Iran, POBox 34149-288. Tel: (0098) 281 8371165, Fax: 3780073. (Corresponding author: raheemhaddad@yahoo.co.uk)

3. Department of Irrigation, Imam Khomeini International University.

Abstract

Drought stress actually causes to decrease water potential. Effect of silicon was studied on upland rice under drought condition in two upland rice varieties which were different in silicon uptake ability. Results of this study revealed further that upland rice varieties, when grown under high silicon culture solution, resulted in increasing relative water content (RWC) and decreasing stomatal resistance of leaves when compared to non-silicon culture solution. In the present study, effects of sodium silicate were investigated to analyze drought induced oxidative stress on chlorophyll and RWC in two rice (*Oryza sativa* L.) cultivars namely Hashemi (tolerant) and Khazar (sensitive) at different developmental stages. A factorial experiment was performed in a completely randomized design with three treatments (control, drought and silicon-drought) with three replications in the green-house. It might be concluded that silicon increased drought tolerance in both cultivars. Therefore, exogenous silicon should be applied to reach a higher efficiency of plant production. The RWC was considerably decreased by drought stress in the sensetive cultivar, but was significantly increased by Si amendment. The results showed that RWC and chlorophyll content were increased with the application of silicon compared to the control and drought treatments. Decline of such characters was higher in Khazar than Hashemi cultivar.

Key words: Chlorophyll content, Drought stress, Rice (*Oryza sativa* L.), RWC.

Effect of Si on barley and corn under simulated drought condition

Bocharnikova EA [1], Benes S [2]

1.Institute of Physical-Chemical and Biological Problems in Soil Science Russian Academy of Sciences, Pushchino, Moscow region, 142292, Russia E-mail: mswk@rambler.ru

2.Department of Plan Science, California State University, Fresno, 2415 East San Ramon Ave., M/S AS72, Fresno, CA, USA, sbenes@csufresno.edu

Barley (*Hordeum vulgare* L) and corn (*Zea mays* L.) are ones of the most important food crops grown all over the world (totally 56.7 mil. ha of barley and 161 mil. ha of corn). Faced with scarcity of water resources, drought is the single most critical threat to world food security. There are numerous facts indicating that when silicon is readily available to plants, it plays a significant role in their growth, mineral nutrition, mechanical strength, and tolerance to biotic and abiotic stresses. Literature data and our preliminary results have demonstrated that Si has a positive effect on plants under drought conditions. In the greenhouse experiment, barley and corn were grown in pots under simulation of water deficiency. Solid and liquid Si fertilizers were applied before planting. Water regimes in the pots were maintained as 100, 80, 60, and 40% from optimal irrigation level by adding potable water from the Fresno City pipe line. The biomass of roots and shoots were measured after 1 mo. growth. The plants were analyzed for total Si and monomers and polymers of silicic acid in the sap of roots, shoots, and leaves by elaborated method. Plant-available Si in the soil after the experiment was measured as well. The additional Si both liquid and solid benefitted the plant tolerance to water stress in spite of the fact that irrigation water contained high monosilicic acid (26 ppm of Si). The maximum Si effect was observed on the root biomass. The obtained data has shown that improved Si nutrition increased the volume of water in plant body. The results on soluble Si forms in plant sap also supported the hypothesis that polysilicic acid can provide additional accumulation and storage of water in leaves. This water could be used by plant when water is lack. As evident from the results, the application of Si fertilizers or Si soil amendments could make possible to reduce the irrigation water application rate by 20 to 30 % without negative influence on crop productivity and quality.

Methodology for testing of the silicon fertilizer quality

Bocharnikova EA [1], Matichenkov VV [2], Pogorelov AG [3]

1.Institute Physical-Chemical and Biological Problems in Soil Science RAS, 142290, Pushchino, Russia

2.Institute Basic Biological Problems RAS, 142290, Pushchino, Russia

3.Institute of Theoretical and Experimental Biophysics RAS, 142290, Pushchino, Russia.

Email: agpogorelov@rambler.ru

Abstract

Practical implementation Si fertilizers and Si-rich soil amendments require availability the methods for testing of their quality. The total content of Si in such materials can't be used, because in solid materials the major part of Si is represented by inert forms. The possibility of using water and acid extractions (0.1n HCl) for determination of the potential efficiency of Si-rich substances as silicon fertilizer was investigated. Using scanning electron microscope allowed the relationship between solubility of the Si-rich substances and their surface structure to be determined. The complex parameter for characterizing Si-rich materials was suggested. This parameter includes the actual (water soluble) and potential (acid soluble) forms of Si, it has high correlation coefficients with soil concentrations of soluble forms of Si, total content of plant Si and mass of barley plants grown under the application of Si-rich materials. The suggested parameter is following

$$ActSi = 10 \times (AclSi_{1day} + AclSi_{4days}) + PtnSi \qquad (1)$$

Where ActSi – active Si in fertilizer, AclSi – water extractable Si, PtnSi – acid extractable Si.

Effects of silicon on yield contributing parameters and its accumulation in abaxial epidermis of sugarcane leaf blades using energy dispersive x-ray analysis

Bokhtiar SM

Soils and Nutrition Division, Bangladesh Sugarcane Research Institute Ishurdi 6620, Pabna Bangladesh

Corresponding author email: bokhtiarsm@yahoo.com

Abstract

The current study has highlighted the effects of silicon (Si), supplied as calcium silicate (Ca-silicate) fertilizer (14% Si) on the productivity and Si accumulation in the sugarcane plant. The major objectives of this study were to quantify responses in growth parameters (dry matter accumulation, cane and sugar yields), gas exchange characteristics, leaf nutrient concentrations and on soil properties as well. Seven rates of Ca-silicate (0, 20, 40, 60, 80, 120 and 150 g pot^{-1}) were applied with traditional fertilizers and plants were grown in a greenhouse. The added Ca-silicate increased photosynthesis, transpiration and stomatal conductance significantly over the non-amended treatment. Leaf tissue contents of phosphorus (P), sulfur (S), calcium (Ca), magnesium (Mg) and sodium (Na) did not differ remarkably. With increasing silicate application, iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn) contents significantly decreased in both leaf tissue and soil contents. Si amended treatments significantly increased yield in dry matter (26 to 70%) and in cane yield (30 to 66 %) per pot over non-amended. The Si content up to 2.64% per dry mass was found in top visible dewlap (TVD) leaf tissues when amended with Ca-silicate fertilizer in our 12 months study. Soil pH, soil Si, and leaf tissues silicon content progressively increased with increasing rate of Ca-silicate. The available S, exchangeable potassium (K), Na, Ca and Mg increased more or less progressively as rate of Si application increased over non-amended. Nevertheless, the scanning electron microscopy (SEM) with energy dispersive x-ray analysis (EDAX) revealed that different rates of Ca-silicate responded differently in accumulation of Si and other elements in epidermal cells, silica cells and stomata cells.

Key words: Chlorophyll, Energy dispersive X-ray analysis, Gas exchange characteristics, Leaf nutrient, Scanning electron microscope, Soil fertility.

Exogenous silicon and manganese increases antioxidant enzyme activity and alleviates salt stress in leaves of canola (*Brassica napus* L.)

Bybordi A

Faculty of Soil Science, Baku State University, 23 Z. Khalilov Street, 370148, Baku, Azerbaijan.
Email: ahmad.bybordi@gmail.com

Abstract

In order to study effect of salinity stress, silicon nourishment and foliar application of manganese on growth, antioxidant enzyme activity and fatty acid profile of canola an experiment was conducted under controlled conditions. The canola plants were grown in hydroponically system and nourished with Hoagland solution. Silicon was added to Hoagland solution at three levels 0, 2 and 4 mM. Also, salinity stress was induced by NaCl solution a three levels that is 0, 200 and 300 mM. Manganese foliar application was performed at two levels 0 and 0.04%. The results demonstrated that, salinity stress significantly increased, antioxidant enzyme activity, proline accumulation, oleic acid and linoleic acid while decreased weight of plants, chlorophyll content and euresic acid percentage. Also, silicon application increased fresh and dry weight of plants, proline accumulation and oleic acid but decreased euresic acid percentage. Manganese foliar application increased fresh and dry weight, catalase, superoxide dismutase, glutathione s-transferase activity and proline accumulation. Finally it can be suggested that, silicon application is useful under conditions of salt stress especially in hydroponically systems.

Keywords: Antioxidant enzyme, Canola, Manganese, Salt stress, Silicon.

Silicate fertilization in sugarcane: effects on soluble silicon in soil, uptake and occurrence of stalk borer (*Diatraea saccharalis*)

Camargo MSartori de [1*], Júnior ARG [2], Korndörfer GH [3]

1.Agência Paulista de Tecnologia dos Agronegócios (APTA), Pólo Centro Sul, Piracicaba, SP, Brazil,

2.University of Sao Paulo, Piracicaba,SP, Brazil,

3.University of Uberlândia, Uberlândia, MG, Brazil.

E-mail: mscamargo@apta.sp.gov.br.

Abstract

The objectives were evaluation of Si availability, Si uptake, yield and borer stalk (*Diatraea saccharalis*) damage in two cultivars of sugarcane growing in low silicon content soil with and without silicate application.The experiment was set up in Quartzapsament (March, 19 2009) in a completely randomized factorial scheme with four replications. Four Si rates (0, 55, 110 and 165 kg ha^{-1} Si) and two cultivars: IAC 87 3396 (A) and SP 89 1115 (B) were evaluated. The source of silicon was Ca-Mg silicate (262.1 g kg^{-1} Ca; 56.8 g kg^{-1} Mg; 108.4 g kg^{-1} de Si) applied in furrow at planting. All plots received the same Ca and Mg quantities with additions of lime (320g kg^{-1} Ca, 29.5 g kg^{-1} Mg) and/or $MgCl_2$ (11.9% Mg) when necessary. After harvest (July 01, 2009) the best yield was obtained by 103.2 kg ha^{-1} Si (952 kg ha^{-1} silicate) supplied to cultivar B and no differences were observed in cultivar A. There was an increase of soluble Si in 0.5 mol L^{-1}acetic acid and 0.01 mol L^{-1} $CaCl_2$.The Si concentration in leaves were just only different between cultivars (A =3 g kg^{-1}; B =2.18g kg^{-1}). In the stalks, best dry matter and Si uptake were obtained with 89 kg ha^{-1} Si, but no effect was observed on stalk borer damage.

Keywords: Cultivar, Fertilization, Monocots, Nutrition, Yield.

Introduction

Several soils in humid tropical areas show low silicon contents. Silicon is not an essential plant element (Epstein, 1999), but Si-accumulating plants such as sugarcane could exhibit reduced yields associated with the intensive management and monoculture in these soils (Korndörfer et al., 2002). There is little information in Brazil, the major world sugarcane producer. Positive results have been obtained with silicon application in many countries, including Brazil (Berthelsen et al., 2002; Kingston et al., 2005; Elawad et al., 1982; Korndörfer et al., 2000; Brassioli et al.,2009). Most of these results were not exclusive from silicon because the high rates of silicate can improve pH, Ca, and Mg contents. The silicate fertilization applied in furrow planting could be useful to reduce the cost of this product used in rates similar to lime (>2 or 3 t ha^{-1}) and study the direct effects of Si on sugarcane. Another beneficial advantage of silicon to sugarcane is the possibility of reducing damage of insects. Studies with Si have shown positive effects to control of African stalk borer *Eldana saccharina* (Keeping & Meyer, 2006; Kvedaras et al., 2005; Meyer & Keeping, 2005). An increase of silicon uptake in sugarcane with silicate applications could reduce the damage of 'brazilian' stalk borer as showed by Elawad et al. (1982). The objectives were evaluation of Si availability, Si uptake, yield and borer stalk damage in two cultivars of sugarcane growing in low silicon content soil with and without silicate application.

Materials and methods

The study was conducted in the first crop of sugarcane (March, 19 2008 to July, 1 2009) in a commercial area located at Piracicaba, in the south central region of São Paulo state. The chemical analysis of the soil at Quarzapsament (0-25cm) showed : organic matter (g dm^{-3})=17; 0.5 mol L^{-1} Si-acetic acid (AA) and 0.01 mol L^{-1} Si-$CaCl_2$(mg kg^{-1}Si) = 3.3 and 2.4; P anionic resin (mg dm^{-3})=4; K, Ca, Mg, CEC ($mmol_c$ dm^{-3})=0.4; 18; 1; 41.4; Sum of bases = 47 %. The content of clay, loam and sand were 6; 4 and 88 g kg^{-1}. There were no problems with nematodes in the experimental area (75 x 100 m) and lime, termophosphate, and vinasse were not used in the 3 previous years. During this period the volume rain was 1079 mm and minimal and maximum temperatures were: 28.5 and 14.6^{o} C, respectively. The experiment was set up in a completely randomized factorial scheme with four silicon rates (0, 55, 110 and 165 kg ha^{-1} Si), two cultivars (IAC 87 3396 and SP 89 1115), and 4 replications.

The source of silicon was Ca-Mg silicate containing 262.1 g kg^{-1} Ca; 56.8 g kg^{-1} Mg; 108.4 g kg^{-1} Si. All plots received the same Ca and Mg quantities with additions of dolomitic lime (320g kg^{-1} Ca, 29.5 g kg^{-1} Mg) and/or $MgCl_2$ (11.9% Mg) when necessary. The cultivars were chosen based upon yield potential, precocity, good number of sprouts under sugarcane mulch residue and differences on stalk borer tolerance (*Diatraea saccharalis*): low tolerance (SP 891115) and intermediate tolerance (IAC 87 3396).During sugarcane planting (March, 19 2008), the treatments were applied in furrow and soil was fertilized based upon soil analysis (Spironello et al., 1997). Rates of 40 kg ha^{-1} of N, 100 kg ha^{-1} of P_2O_5 and 100 kg ha^{-1} of K_2O (10-25-25) were used at planting. Each plot was 5 rows wide and 10 m long. The surface nitrogen (40 kg ha^{-1} N was supplied as ammonium sulphate, 20%N) and potassium fertilization (postash, 60% K_2O) took place 30 days after planting. Sugarcane was harvested (20 plants per plot) on July 01, 2009 and harvested materials were divided into leaves and stalks. The height and diameter of the stalks and the weight of the dry matter were evaluated. The Si content determination in plant was done as described by Elliot & Snyder (1991). After harvest, soil sampling (0-25; 25-50 cm) was done. The Si concentration in soil was performing with acetic acid (0.5 mol L^{-1}) and $CaCl_2$ (0.01 mol L^{-1}), according Korndörfer et al. (1999). The analyses of variance were made applying the F test. The soils were compared by the Tukey test and rates of Si by polynomial regression.

Results and discussion

The rates of silicate increased soluble silicon in both extractants, in agreement with Korndörfer et al., 1999; Korndörfer et al., 2000. There was a significant effect on Si content extracted by acetic acid (AA) in samples collected at 0-25 and 25-50 cm (Figure 1). The values were 50% higher with cultivar SP 89 1115. This could be related to the larger volume of its root system. According to Ball-Coelho et al., (1992) there are large differences between cultivars in root system, and they provide increase of organic material during the growing period. The calcium chloride (CC) extractant showed no increase in Si concentration in the 0-25 cm of soil (Figure 1), and the cultivars did not show any differences. The lower extraction power of CC is related to pH of the solution. The acetic acid has higher extraction due to the low pH (1.0-2.0) necessary to form a molybdosilic complex (Camargo et al., 2007). Both cultivars showed higher sugarcane yield compare to the Sao Paulo state average (85 t ha^{-1}). The cultivar SP 89 1115 showed the highest yield, height, and stalk dry matter. The best yields were obtained by 103.2 kg ha^{-1} Si (952 kg ha^{-1} de silicato) to SP 89 1115 ($Y = -0.001X^2 + 0.2064X + 120.1$; $R^2 = 0.98$* where Y=yield; X=rates of Si; *=$p<0.05$ – data not shown) and no differences in yield due to Si supplementation were observed with cultivar SP 87 3396. Other studies have shown yields responses in sandy soils, but they used higher rates of silicate (2 t ha^{-1}) in broadcast and incorporated applications (Korndörfer et al., 2000a, 2002; Brassioli et al., 2009). On the other hand, Leite et al. (2008) did not observe significant increases in yield due to low rates of Si use (450 kg ha^{-1} of silicate). The silicon content in leaves was higher than stalks, as expected. The Si concentration on leaves were different between cultivars (SP 891115 =3 g kg^{-1}; IAC 87 3396 =2.18g kg^{-1}). In the stalks, highest dry matter and Si uptake were obtained with 89 kg ha^{-1} Si without differences between cultivars. Unlike some studies (Kvedaras et al., 2005; Keeping & Meyer, 2006), there was no significant effect of silicate applied on stalk borer damage despite increases in Si uptake. It is possible that the low level of economic damage to control of stalk borer in field conditions (SP89 1115=4%; SP 87 3396 =2.8%) was responsible for absence of any significant effect due to silicon fertilization.Added Si as calcium magnesium silicate increased the amounts of extractable Si in a Quartzapsament soil, as well as increasing the yield and Si uptake in stalks of cultivar SP 89 1115. Rates of 103 kg ha^{-1} Si and 89 kg ha^{-1} Si provided the best yield and absorption of silicon of SP 89 1115, respectively, but it did not promote less stalk borer damage.

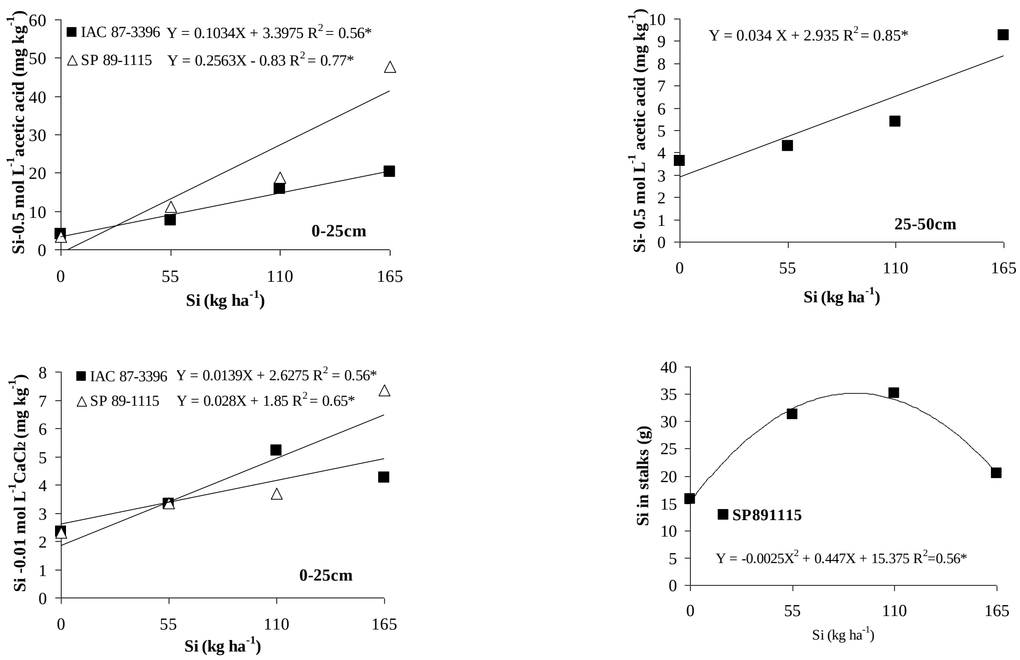

Fig. 1 Soluble silicon concentration in 0.5 mol L^{-1} acetic acid and 0.01 mol L^{-1} $CaCl_2$ in soil samples (0-25 cm and 25-50 cm) and Si uptake on stalks of two cultivars of sugarcane with rates of Ca-Mg silicate .

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Foliar spray of soluble silicic acid----a source of silicon for wetland rice at southern dry zone and coastal zone soils of Karnataka, South India

Chandrashekar N [1*], Prakash NB [1], Jagadeesh BR [2], Patil SU [3]

1.Department of Soil Science and Agricultural Chemistry, University of Agricultural Science, Bangalore, GKVK, Bangalore, India

2. ZARS, VC Farm, UAS, Mandya, Karnataka

3. ZARS, UAS, Brahmavar, Karnataka

**Email: chandra.gudumba@gmail.com*

Abstract

Most Silicon is present in the soil as insoluble oxides or silicates, although soluble silicic acid occurs in the range of 0.1-0.6 mM. Silicon is also one of the most abundant mineral elements in plant tissues and shoots concentrations in excess of 10% dry weight. Plants growing under natural conditions do not appear to suffer from Si deficiencies. However, Si containing fertilizers are routinely applied to several crops including rice, and sugarcane to increase crop yield and quality. Increased Si supply improves the structural integrity of crops and may also improve plant tolerance to diseases, drought and metal toxicities. Absorbed in the form of silicic acid [$Si(OH)_4$], along with water, Si follows the transpiration stream to finally deposit as silica.

The effect of foliar silicon (silicate) supply on rice, wheat, cucumber, cotton and other crops revealed benefits of the element related to resistance against disease, pests and drought. However, information on performance of silicic acid as foliar spray on rice seedlings and in the main rice fields regarding growth and yield is very limited. With this in view, field experiments were conducted at southern dry zone (ZARS, VC Farm, Mandya) and coastal zone (ZARS, Brahmavar) soils during 2010. Field experiments consisted of treatments with spraying soluble silicic acid at 2 ml L^{-1} in rice nursery and 2 or 4 ml L^{-1} in the main rice field along with recommended dose of fertilizers and need based pesticide sprays. In one of the treatments, seedlings were also dipped in the foliar silicic acid solution before transplanting in the main field. Treatments also consisted of 0.8 % of boric acid spray at 2 or 4 ml L^{-1} and seedling dip in 4 ml L^{-1} before transplanting in the main field. Field experiments at both the locations were laid out in a randomized block design with three replications.

The results of the studies conducted at southern dry zone revealed that foliar spray of soluble silicic acid for nursery seedlings was found to be effective in obtaining healthy and vigor seedlings. Spraying of soluble silicic acid at 2 ml L^{-1} for nursery seedlings followed by spray of silicic acid at 4 ml L^{-1} after transplanting for 3 or 4 times along with need based pesticide noticed higher yield compared to non-sprayed seedlings. Foliar spray of silicic acid at 4 ml L^{-1} for 4 times noticed significantly higher grain and straw yield over control.

Studies conducted at coastal zone also revealed a positive increase in grain yield of rice treated with foliar spray of soluble silicic acid at 2 ml L^{-1} in nursery and dipping of seedlings in silicic acid at 4 ml L^{-1} and with silicic acid spray for 2 times after transplanting at 4 ml L^{-1}. However, there was no significant increase in straw yield in plots with silicic acid treated. There was no significant increase in grain and straw yield among the plots receiving foliar spray of 0.8% boric acid (BA) at 2 or 4 ml L^{-1}. However, significant increase in grain yield was observed in the plots with foliar spray of BA at 2 ml L^{-1} in nursery and dipping rice seedlings in BA at 4 ml L^{-1} with twice spray application of boric acid for transplanted rice at 4 ml L^{-1}.

The study concludes that application of foliar spray of soluble silicic acid in nursery and dipping rice seedlings in silicic acid solution before transplanting is effective in attaining higher yields.

Silicon and salicylic acid induced defense response in rice (*Oryza sativa* L.) against *Magnaporthe grisea*

Chen JN, Cai KZ *, Ge SB, Luo SM

Key Laboratory of Ecological Agriculture of Ministry of Agriculture, South China Agricultural University, Guangzhou 510642, China
E-mail: kzcai@scau.edu.cn

Abstract

Rice (*Oryza sativa* L.) is one of the most important staple crops in many countries, blast disease caused by the ascomycete fungus *Magnaporthe oryzae* is one of the most serious and widespread diseases for rice production in the world. Salicylic acid (SA) and silicon (Si) have been verified to have important role to increase blast resistance, but their interactive effects on physiological response of rice in infected plants are unknown. Two near-isogenic lines of rice, CO39 (susceptible) and C101LAC (*Pi-1*) (resistant) were chosen to investigate the individual and combined effects of SA and Si on the activities of defense-related enzymes (peroxidase, POD; polyphenol oxidase, PPO; phenylalanine ammonia-lyase, PAL; chitinases, CHT; β-1, 3-glucanase, GLU) in inoculated rice leaves. Gene expression related to pathogen resistance was also analyzed. Exogenous application of SA and/or Si significantly reduced the blast disease index for two rice lines, effects of disease control was better with Si and SA treatment together than they did it alone. Application of 2 mM Si alone increased the activities of GLU by 77.22% and 59.77% at 7 d post-infection (dpi) for CO39 and C101LAC(*Pi-1*) respectively, POD, PPO and PAL activity of CO39 were also increased at 5 dpi. Foliar spraying of 0.5 mM SA alone significantly increased the activities of POD, PAL and GLU in leaves of both rice isogenic lines. The activities of PAL and GLU in leaves were enhanced by Si and SA treatments together for both isogenic lines. Under *M. oryzae* infection, Si and SA treatments activated and increased the gene expression levels of PAL, PR3-1 and PR3-2. The expression of gene PR1a and PR4 were up-regulated for CO39 but down-regulated for C101LAC (Pi-1). The expression of gene PR2 had no significant change. These results suggest that rice plants treated with SA and/or Si exhibited an enhanced resistance against infection by *M. oryzae*, and this resistance appears to be associated with the increased enzyme activities and gene expression related to defense response.

Key words: Defense-related enzyme, Induced resistance, *Magnaporthe oryzae*, Peroxidation, Resistance genes, Rice (*Oryza sativa* L.), Salicylic acid, Silicon.

Silicon exists in association with DNA and RNA in plant embryos

Chen NC [1, 2], Inanaga SJ [1*], Chishaki N [1]

1. Lab of Plant Nutrition and Fertilizers, Faculty of Agriculture, Kagoshima University, Kagoshima 892-0065, Japan,

2. Lab of Pollution Control and Remediation, Guangdong Institute of Eco-environmental and Soil Sciences, Guangzhou 510650, China,

** Corresponding author: inapi02@yahoo.co.jp*

Abstract

Attempts were allowed to investigate the silicon existing forms in polynucleic acids (PNA) extracted from embryos of rice (*Oryza sativa* L.), a siliceous plant, and peanut (*Arachis hypogaea* L.), a calciphilous plant, using the molecular sieve chromatography, and to study some elements containing silicon and aluminum in embryos of 10 plant species. When the PNA solutions from rice and peanut embryos were loaded onto the Sephacryl-400 column, silicon in both PNA solutions were eluted with RNA and DNA. A ratio of silicon to RNA or DNA in elute fraction was different between both plant embryos and both nucleic acids, but each showed constant value, respectively. In both plant embryos, the ratio of silicon to DNA was more than one to RNA, and one to DNA was higher in the peanut embryo than in the rice embryo, while one to RNA was opposite to the result of DNA. In case of loading the PNA acted DNase or RNase from the rice embryo onto one, a peak of silicon disappeared with that of OD_{260} corresponding to DNA or remarkably reduced with those of OD_{260} shown RNA, respectively. Although aluminum did not almost hound in the embryos of plant species except the tea and maize plant, silicon existed in embryos of all plant species.

These results indicate that silicon combines with DNA and RNA in the PNA of plant embryos, suggesting that silicon is essential for plant reproduction.

Key words: DNA, Peanut embryo, Silicon, Rice embryo.

Effects of potassium silicate on grapevine constitutive and induced defences against an Australasian leafroller pest and its natural enemy

Connick VJ [1*], Reynolds OL [2], Saliba A [3], Gurr GM [5], Guisard Y [1], Simmons AT [4], Nicol HI [4]

1.*National Wine & Grape Industry Centre, Charles Sturt University, PO Box 883, Orange NSW 2800, Australia*

2.*EH Graham Centre for Agricultural Innovation (Charles Sturt University and Industry & Investment NSW), Elizabeth Macarthur Agricultural Institute, Private Bag 4008, Narellan NSW 2567, Australia*

3.*National Wine & Grape Industry Centre, Charles Sturt University, McKeown Drive, Wagga Wagga NSW 2650, Australia*

4.*School of Agriculture & Wine Sciences, Charles Sturt University, PO Box 883, Orange NSW 2800, Australia*

5.*EH Graham Centre for Agricultural Innovation, Charles Sturt University, PO Box 883, Orange NSW 2800, Australia*

Abstract

Silicon (Si) fertilisation of agricultural crops has been shown to improve constitutional defences including increasing the leaf and stem thickness, resulting in greater leaf abrasiveness and reduced arthropod pest damage. In addition, Si has been shown to enhance the induced chemical defences of plants in response to arthropod herbivory, including herbivore-induced plant volatile (HIPV) production. HIPVs are compounds emitted by the plant used by arthropod predators and parasitoids to locate prey or hosts. This presentation will discuss the results from two studies of constitutional and induced effects of Si on grapevine, *Vitis vinifera* (L.) on an Australasian leafroller pest and its natural enemy. Both studies applied potassium silicate at the rate of 100 ppm to potted grapevines every 14 days for a period of seven and five months respectively. In the first study, an excised leaf from Si fertilised grapevines was infested with five third-fourth instar larvae of light brown apple moth, *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae). The area of leaf consumed by the larvae during a 24 hour period was measured using Delta-T Scan® image analysis software. Larvae were weighed immediately prior to and on completion of the experiment to ascertain weight gain/loss. *Epiphyas postvittana* consumed significantly greater quantities of leaf material from Si-treated plants compared to the

control, and larvae fed on Si-treated leaves lost significantly less weight than larvae feeding on control leaves. Regression analysis of Si content in individual grapevine plants suggested that the area of leaf consumed and *E. postvittana* larval weight were promoted by Si fertilisation. The increased consumption of Si-treated leaves may be due to reported reduced digestion efficiency of plant tissue containing high Si content. The second study measured the response of the generalist predator, red and blue beetle, *Dicranolaius bellulus* (Guérin-Méneville) (Coleoptera: Melyridae) to grapevines infested with larvae of *E. postvittana* using a Y-tube olfactometer. Predators exhibited a significant positive response to the pest-infested grapevines with the highest leaf Si content, suggesting that Si enabled plants to mount a stronger HIPV-based induced response to pest infestation making them more attractive to the predator. The effects of Si fertilisation on grapevines are not well understood, and there has been very little work investigating tri-trophic effects of Si fertilisation on beneficial arthropods. The results from the second study are promising as it suggests Si may be a useful tool in enhancing pest resistance in grapevines through the employment of natural enemies. Further research identifying and quantifying volatile production from Si-treated pest-infested plants is warranted to fully elucidate the mechanisms of Si-induced plant defences.

Silicon and grass blade biomechanics

Cooke J [1], Leishman M [1]

1.Department of Biological Sciences, Faculty of Science, Macquarie University, North Ryde, NSW, 2109.

Abstract

Increasing leaf silicon reduces lodging (plants falling over in wind/rain) and improves light interception through increasing leaf erectness; however changes in leaf biomechanic properties with increasing silicon concentration have not been quantified. We hypothesised that different amounts of silicon and varying phytolith (silica body) morphologies will alter leaf biomechanical properties. Grasses contain comparatively high levels of silicon and the Poaceae, with distinct phytolith morphotypes in each subfamily, is an ideal family with which to explore the role of silicon in leaf biomechanics. Ten species from five subfamilies within the Poaceae family were grown with four levels of silicon fertilisation. The strength, toughness and modulus of elasticity of leaf blades was measured and compared between species and subfamilies. We found that with increasing silica concentration, some species became tougher and stronger, but leaf stiffness did not change. Impacts of silicon content on leaf biomechanics may have implications for plant-herbivore interactions, light interception, water relations, decomposition rates and leaf carbon economics.

Nitrogen and silicon interactions on agronomical indices, lodging and chemical traits in rice (*Oryza sativa* L.)

[*] Dastan S [1], Ghanbari-Malidarreh A [2]

1.Department of Agronomy, Science and Research Branch, Islamic Azad University, Tehran, Iran. [*]Corresponding Author: E-Mail: Sdastan@srbiau.ac.ir. Mobail: +989111552587.

2.Department of Agronomy, Jouybar Branch, Islamic Azad University, Jouybar, Iran.

Abstract

Rice-based rain-fed lowlands are the major cropping system in north of Iran. This experiment was carried out in split plot in a randomized complete block design with three replications at north of Iran in 2010. The main plot was nitrogen rates including 0, 50, 100 and 150 kg N ha^{-1} applied as urea and sub-plot was silicon rates (0, 300 and 600 mg SiO_2 kg^{-1} soil) applied as calcium silicate. Results showed least of the plant height, fourth inter-node bending moment, blank spikelet, panicle per m^2, grain yield (4350 $kg.ha^{-1}$) and harvest index were obtained at N_0, as well as the most of the panicle length, panicle per m^2, spikelet number, due to grain yield (6063 $kg.ha^{-1}$) and harvest index were observed at N_{150}. Si_{600} in comparison Si_0 were significantly decreased blank spikelet number. As well as increased plant height, panicle length, third inter-node bending moment, tiller and fertile tiller number, spikelet number, filled spikelet percentage, cellulose, hemi-cellulose and lignin in ratio 7.8, 30.2, 18.7, 14.1, 15.6, 11.9, 12.4, 7.6, 34.5 and 26.3 %, respectively. Therefore, N_{150} and Si_{600} treatment the cause of the most of desirable agronomical indices and grain yield introduced the best of factors.

Key words: Bending moment, Chemical traits, Grain yield, Nitrogen, Rice, Silicon.

Effects of water stress and silicon application on agronomical indices, quantity yield and harvest index in rice (*Oryza sativa* L.)

Dastan S [1*], Ghanbari Malidarreh A [1], Mobasser HR [2]

1.Young Researchers Club, Jouybar Branch, Islamic Azad University, Jouybar, Iran. Sdastan@srbiau.ac.ir

2.Department of Agronomy, Qaemshahr Branch, Islamic Azad University, Qaemshahr, Iran.

Abstract

In order to investigate effects of water stress and silicon application on agronomical indices, yield and harvest index of rice in Iran, an experiment was carried out at split-plot in randomized complete block design with three replications at Mazandaran province (Sari region) in 2010. Main factor was water stress in four levels including irrigation halting at start and middle of tillering, heading initial and completely panicle stages and sub factor was silicon rates in three levels including 0, 500 and 1000 kg Si ha^{-1}. Results showed that the fertile spikelet percentage, 1000 grain weight, grain yield and harvest index were significantly different ($p<0.01$; $p<0.05$) at the water stress. Also, total tiller number per hill, fertile tiller number, unfertile tiller number and 1000 grain weight were significantly different ($p<0.01$; $p<0.05$) at the silicon rates. Hollow spikelet per panicle and panicle per m^2 were not significantly different ($p<0.01$; $p<0.05$) at none factors, as well as, only fertile tiller number per hill was significantly different ($p<0.05$) at water stress × silicon rates. Maximum total spikelet per panicle, fertile spikelet percentage, 1000 grain weight, grain yield and harvest index were obtained at water stress in start of tillering stage. Minimum grain yield and harvest index were produced in water stress at the complete panicle stage. Application of 1000 kg Si ha^{-1} increased total tiller per hill, fertile tiller per hill, total spikelet per panicle and 1000 grain weight by 27.8, 28.1, 14.7 and 8.4 %, respectively. Interaction of water stress at middle of tillering stage with silicon application rate of 1000 kg Si ha^{-1} produced maximum fertile tiller number.

Key words: Agronomical indices, Quantity yield, Rice, Silicon, Water stress.

Silicon and potassium effects on lodging-related morphological characteristics and agronomical indices of rice (*Oryza sativa* L.) in Iran

Dastan S [1*], Ghasemi-Mianaie A [1], Mobasser HR [2], Mirhadi MJ [1]

1.Department of Agronomy, Science and Research Branch, Islamic Azad University, Tehran, Iran. Sdastan@srbiau.ac.ir

2.Department of Agronomy, Qaemshahr Branch, Islamic Azad University, Qaemshahr, Iran.

Abstract

In order to investigate effects of silicon and potassium application rates on lodging-related morphological characteristics and agronomical indices in rice, an experiment was carried out in a split-plot in randomized complete block design with four replications at Mazandaran province in 2010. The main factor was application rates of silicon including 0, 250, 500 and 750 kg Si ha^{-1}, and sub-factor was application rates of potassium including 0, 30, 60 and 90 kg K ha^{-1}. The results showed that all of the traits tested except panicle length, fourth internode length, fourth internode bending moment and harvest index were significantly increased ($p<0.01$; $p<0.05$) with increasing of the silicon rates. Also, stem length, plant height, fourth internode length, fourth internode bending moment, fertile tiller number, filled spikelet number, filled spikelet percentage, unfilled spikelet number, 1000 grain weight, grain yield and harvest index were significantly increased ($p<0.01$; $p<0.05$) with increasing of the potassium rates. Only filled spikelet percentage and unfilled spikelet number were significantly ($p<0.05$) dependent on silicon and potassium interactions. The maximum of grain yield (612 $g.m^{-2}$) was obtained at 750 kg Si ha^{-1}, because of its best growth characteristics and yield compositions including the tiller number per hill, fertile tiller number, panicle number per m^2, total spikelet number per panicle and filled spikelet number this treatment. The least fourth internode bending moment was obtained at 90 kg K ha^{-1}. The highest grain yield (575.3 $g.m^{-2}$) and harvest index (35.6 %) were produced at 90 kg K ha^{-1} because of its highest fertile tiller number, filled spikelet percentage per panicle, and 1000- grain weight. The highest filled spikelet percentage per panicle was obtained in the combination treatment of 750 kg Si ha^{-1} × 90 kg K ha^{-1}. The grain yield had positive correlations with total tiller number per hill, fertile tiller number, panicle number per m^2, total spikelet number per panicle and filled spikelet number. The harvest index was positively correlated with flag leaf length, fertile tiller number, panicle number per m^2, filled spikelet number, filled spikelet percentage and grain yield. Therefore, the treatment with 750 kg Si ha^{-1} and 90 kg K ha^{-1} was the best treatment due to its best yield components, grain yield, biological yield and harvest index.

Key words: Agronomical indices, Bending moment, Potassium, Rice, Silicon.

Silicon and biotic stress

Datnoff LE

Department of Plant Pathology & Crop Physiology, LSU AgCenter, Baton Rouge, LA

Abstract

Onodera in 1917 was probably the first scientist to establish the association between silicon and a plant disease (rice blast). Since that time, a number of investigators have demonstrated the influence of silicon in suppressing foliar and root diseases in both dicots and monocots. Furthermore, this suppression has been effective against not only fungal diseases but those caused by oomycota, bacteria and viruses. Silicon appears to affect a number of components of host plant resistance, i. e. delays the incubation and latent period, reduces lesion expansion rates, lesion size, lesion number, the number of sporulating lesions and the number of conidia produced per lesion. As a consequence, disease progress and/or final disease severity is dramatically reduced. Two hypotheses have been proposed to explain how silicon enhances plant resistance against pathogen infection, 1) the insoluble silicon layer is deposited in epidermal cells preventing penetration by the pathogen (i. e. 'mechanical barrier hypothesis') and 2) that silicon affects the response of the plant at the biochemical and molecular level. For the latter hypothesis, a number of studies have shown increases in plant defensive compounds such as phenolics, phytolexins and plant resistance proteins. Genome wide studies for *Arabidopsis*, rice and wheat amended with silicon and compared to non-amended control plants also has shown a differential expression of a large number of genes, and these genes are known to be involved in host plant defense mechanisms. Based on the above, this element can play a major role in alleviating biotic stresses of plants grown under greenhouse and field conditions.

Silicate fertilization in tropical soils: silicon availability and recovery by sugarcane among three cycles

de Camargo MS [1*], Júnior ARG [2], Korndörfer GH [3]

1.Agência Paulista de Tecnologia dos Agronegócios (APTA), Pólo Centro Sul, Piracicaba, SP, Brazil,

2.University of Sao Paulo, Piracicaba,SP, Brazil,

3.University of Uberlândia, Uberlândia, MG, Brazil.

E-mail:mscamargo@apta.sp.gov.br.

Abstract

The objectives were to evaluate silicon availability, uptake and recovery by three cycles of sugarcane growing in tropical soils with and without silicate. The experiments were conducted in pots (100 L) with Si rates (0, 185, 370 and 555 kg ha-1 Si), soils (Quartzipsamment-RQ, 6% clay, Rhodic Hapludox-LV, 22% clay and Rhodic Acrudox-LVdf, 68% clay) and 4 repetitions. The source of silicon was Ca-Mg silicate (262.1 g kg^{-1} Ca; 56.8 g kg^{-1} Mg; 108.4 g kg^{-1} de Si). All plots received the same Ca and Mg quantities with additions of lime and/or $MgCl_2$ when necessary. Sugarcane was harvested on November 26, 2008 (1st crop), October 27, 2009 (1st ratoon) and October 5, 2010 (2st ratoon). Rates increased Si availability and uptake in sugarcane with strong residual effect. The soluble Si contents were reduced among cycles and the RQ soil showed the higher increase with silicate application, followed by LV and LVdf. Silicate rates promote increase in soluble Si-acetic acid among cycles in all soils, except to LVdf. The amounts of Si-$CaCl_2$ were not influenced by silicate in ratoon crops. The Si uptake increased with rates of Si and was higher in LVdf in all cycles. The amounts of Si provided by silicate were increased among cycles and LVdf showed best Si recovery.

Keywords: Cultivar, Fertilization, Monocots, Nutrition, Yield.

Introduction

Several classes of soils in Brazil have been used for sugarcane cultivation. New potential producers are located at highly weathered soils, characterized by low soluble silicon contents. Althought Si is not essential element, Si-accumulating plants such as sugarcane could exhibit reduced yields associated with the intensive management and monoculture that typically take place in these types of soils in humid tropical areas (Korndörfer et al., 2002). Under these conditions, silicon fertilization could be beneficial for plants, improving tolerance to drought, disease, and attacks by insects such as rust (Raid et al., 1982)_and stalk borers (Keeping & Meyer, 2006). In Australia, Berthelsen et al. (2002) classified soils in three groups as a function of the amount of soluble silicon extracted with $CaCl_2$ (0.01 mol L^{-1}): very low (0-5 mg kg^{-1}), low (5-10 mg kg^{-1}), limited (10-20 mg kg^{-1}), and sufficient (20 to >50 mg kg^{-1}). In Brazil, positive results (Korndörfer et al., 2002) have been shown with silicon fertilization in soils containing less than 6 to 8 mg kg^{-1} Si extracted by 0.01 mol L^{-1} $CaCl_2$. Considering the lack of data about silicon fertilization to sugarcane, especially in ratoon crops, the objectives were to evaluate silicon availability, uptake and recovery by three cycles of sugarcane growing in tropical soils with and without silicate.

Materials and methods

The experiments were conducted in pots (100 L) under field conditions at the APTA Pólo Centro Sul experimental farm in Piracicaba, SP, Brazil. The IAC 87 3396 sugarcane cultivar was used. It was set up in a completely randomized factorial scheme (4 x 3 x 2) with silicon rates (0, 185, 370 and 555 kg ha^{-1} Si) and soils: Quartzipsamment (RQ, 6% clay), Rhodic Hapludox (LV; 22% clay) and Rhodic Acrudox (LVdf; 68% clay), in 4 repetitions. The RQ, LV and LVdf showed 1; 8 an 10 mg kg^{-1} soluble Si in 0.5 mol L^{-1} acetic acid and 0.9; 4.9 and 5.7 mg kg^{-1} 0.01 mol L^{-1} $CaCl_2$. The Ca-Mg silicate contained 10.8 g kg^{-1} Si, 262 g kg^{-1} Ca, and 56.8 g kg^{-1} Mg. All plots received the same Ca and Mg quantities with additions of lime (343 g kg^{-1} Ca, 96 g kg^{-1} Mg) and/or $MgCl_2$ (11.9% Mg) when necessary. The materials (silicate, lime and or $MgCl_2$) were applied in soils remaining in incubation period during 40 days. Two sugarcane plants were transplanted in each pot on January 10, 2008. Soils received basal fertilization in planting (180 kg ha^{-1} P_2O_5 .30 kg ha^{-1} N; 100 kg ha^{-1} K_2O) and surface fertilization (30 kg ha^{-1} N, 100 kg ha^{-1} K_2O). Micronutrients were not used because their levels were sufficient. After harvest of 1st crop (November 26, 2008), two ratoon cycles growing in the same pots were evaluated. After harvest, the Si content determination in dry matter (Elliot & Snyder, 1991) and Si in soil extracted by acetic acid 0.05 mol L^{-1} and $CaCl_2$ 0.01 mol L^{-1} were done. The soils were compared by the Tukey test and Si rates by polynomial regression.

Results and discussion

The treatments influenced the amounts of soluble silicon in both extractants and the silicon uptake by sugarcane in three cycles (Table 1, Figure 1). The soluble Si concentrations were increased with rates of Si after 11, 20 and 30 months after silicate application. The RQ soil showed the higher increase in soluble Si concentration, followed by LV and LVdf as a consequence of their low initial values. For example, at first cycle, the rate of 555 kg ha^{-1} Si provided superior amounts of Si extracted by acetic acid superior than control treatment (rate zero) in RQ (5 times) and the low increases were found in LV (1.6 times) and LVdf (1.6 times) and the values obtained with $CaCl_2$ extractant were 3; 1.5 and 1.5 to RQ, LV and LVdf, respectively. Silicate rates promote increase in soluble Si extracted by acetic acid among cycles in all soils, except to LVdf. The soluble Si extracted by $CaCl_2$ was not influenced by silicate in ratoon crops due to low extraction power of $CaCl_2$ (Camargo et al., 2007b; Pereira et al., 2004).The Si uptake (Y) increased with rates of Si (X) at 1st crop ($Y=0.0025\ X + 3.087$; $R^2=0.50^*$), 1st ratoon ($Y= 0.0033X + 7.297$; $R^2=0.45^*$) and 2nd ratoon ($Y= 0.0103X + 8.108$; $R^2=0.66^*$). The Si uptake was higher to LV in the 1st crop and 1st ratoon and there was no difference among soils at the 2nd ratoon. It could explain the expressive decrease in soluble Si among cycles of sugarcane in these experiments. There was positive relationship between soluble acetic acid 0.5 mol L^{-1} (AA) or $CaCl_2$ 0.01 mol L^{-1} (CC) and Si uptake by sugarcane at 1st ratoon (AA R^2=0. 70; CC $R^2=0.44$; $p<0.05$) and 2nd ratoon (AA $R^2=0.40$; CC $R^2=0.31$; $p >0.05$). In the first cycle, there was no significative relationship. It could be related with the low Si uptake, provided by silicate (SiFF, Table 1) at first crop despite of higher Si concentration in both extractants to all soils (Figure 1).The rate of 555 kg ha^{-1} Si provided values of 1.3; 1.6 and 1.5 higher of SiFF comparing with control treatment to RQ, LV and LVdf, respectively, at the 1st crop. At the 1st ratoon, these values were 2.0; 2.7 e 1.1 and in the 2nd ratoon were 2.2; 1.6 e 1.5. It is important emphasize that the recovery of silicon applied (IR) were increased among cycles which could be

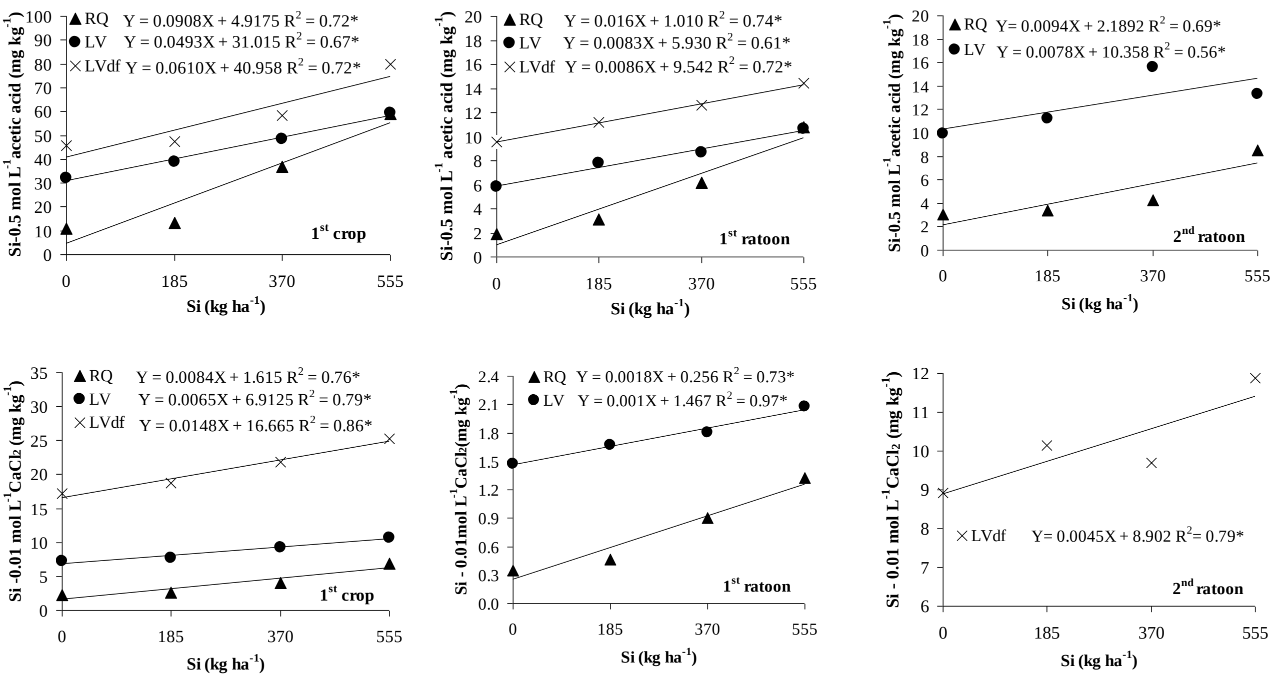

Fig. 1 Soluble silicon concentration in 0.5 mol L^{-1} acetic acid and $CaCl_2$ 0.01 mol L^{-1} in Quartzipsamment (RQ), Rhodic Hapludox (LV) and Rhodic Acrudox (LVdf) in function of rates of Si after harvest of 1st crop, 1st ratoon and 2nd ratoon of sugarcane.

Table 1 Silicon contents in sugarcane (Uptake), quantitites of Si provided by silicate (SiFF) and recovery index of Si (IR) in three soils with Si application.

Si	First crop			First Ratoon			Second Ratoon		
	Uptake	SiFF	IR	Uptake	SiFF	IR	Uptake	SiFF	IR
g / pot		g	%	g	g	%	g	g	%
				Quartzipsamment (RQ)					
0	3.2	0.0	----	6.6	0.0	----	5.9	0.0	----
9.25	3.4	0.2	2.04	6.9	0.4	3.91	7.9	2.0	21.40
18.50	3.4	0.2	1.20	6.6	0.4	2.16	10.1	4.2	22.53
27.75	4.1	0.9	3.29	6.9	1.3	4.79	12.8	6.9	24.97
				Rhodic Hapludox (LV)					
0	3.6	0.0	----	8.5	0.0	----	8.9	0.0	----
9.25	3.9	0.3	4.35	9.0	0.4	5.86	10.4	1.5	20.4
18.50	3.8	0.3	1.49	9.5	1.0	5.66	10.9	2.0	11.66
27.75	5.8	2.2	8.14	11.7	3.1	11.35	14.4	5.6	20.30
				Rhodic Acrudox (LVdf)					
0	2.8	0.0	----	7.1	0.0	----	9.1	0.0	----
9.25	3.3	0.5	6.13	7.4	0.3	3.67	11.1	2.0	26.71
18.50	3.6	0.8	4.44	9.5	2.4	13.66	14.8	5.6	32.12
27.75	4.2	1.3	4.86	8.6	1.5	5.53	14.0	4.8	17.62

SiFF (Si from silicate) = Si uptake – Si uptake by control; IR= recovery index (%) = (Si from silicate / Si applied) * 100 related with time to promote the interaction between root system and silicate. Additionally, these results were higher in LVdf in all cycles due to highest clay content, which promote best reactivity of silicate (Korndörfer et al., 1999). Considering these facts, we concluded that silicon fertilizer can increase Si availability and Si uptake in sugarcane with residual effect, even if high initial contents were presented.

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Effect of calcium silicate slag on yield and silica uptake by rice

Dhamapurkar VB [1], Talashilkar SC [1], Sonar KR [2]

1 Department of Soil Science and Agricultural Chemistry, Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli- 415712,

2.Swastik Apartment,Dr. Bhide Hospital Road, Savadi, Ahmednagar-414003,Maharashtra, India

Email: krs97@rediffmail.com

A field experiment was conducted to study the effect of calcium silicate slag (CSS, 45 % silica) on yield and silica uptake by transplanted rice (cv.RTN^{-1}) in a laterite soil of Maharashtra, India. The treatments consisted of 0, 2, 3, 4, 5 and 6 Mgha^{1} of CSS along with NPK fertilizers (N 60 kg ha^{1}, P_2O_5 30 kg ha^{1} and K_2O 50 kg ha^{1}).The N and P were applied through Urea-DAP briquettes and K through muriate of potash by 8-10 cm deep placement into the soil at transplanting of rice. The grain and straw yields were recorded separately. Rice grain and straw samples were analysed for silica content. Soil samples collected at initial stage and after harvest of rice were analysed for physico-chemical properties and available silicon content.

Rice grain and straw yields were increased due to application of increasing levels of CSS (43.62 to 60.95 Mg ha^{1} for grain and 44.08 to 58.70 q ha^{1} for straw, respectively).This increase in rice grain and straw yields were due to good initial growth of rice plants, improvement in yield contributing characters and reduction in pests and diseases infestation. Application of different levels of CSS increased rice grain yields from 8.18 to 17.33 Mg ha^{1} over no application of CSS. Rice yield index ranged from 39.0 to 18.6 % for grain and 27.9 to 72.9 % for straw. Silica content in rice grain and straw were increased due to application of different levels of CSS (4.48 to 7.40 % and 11.60 to 15.33 %, respectively). Total uptake of silica by rice grain and straw were significantly increased due to application of different levels of CSS from 820 to 1292 kg ha^{1} over no application of CSS. The increase in total uptake of silica by rice ranged from 72 to 472 kgha^{1}. This is attributed to better supply of essential nutrients and available silicon from native and applied sources to rice. Application of 6 Mg ha^{1} of CSS significantly increased available Si content of soil from 99 to 252 ppm (0.025 *M* citric acid) at harvest rice. It can be concluded that application of 6 Mg ha^{1} of calcium silicate slag (45 % silica) to rice is beneficial for sustainable rice production.

Keywords: Calcium silicate slag, Rice, Rice yield, Silicon uptake.

Silicon isotope compositions of rice plants and implications for the global silicon cycle

Ding TP [1], Tian SH [1], Gao JF [1], Wan DF [1], Sun L [2], Ma GR [2], Wu LH [2]

1.Institute of Mineral Resources, Chinese Academy of Geological Sciences,

2.Department of Environment and Resource Sciences, Zhejiang University

Abstract

Significant silicon isotopic variation is discovered in biosphere and hydrosphere, which provides us a great opportunity of using silicon isotope method to study the biological processes and global silicon cycle. Here a systematic investigation on silica contents and silicon isotope compositions of rice is presented.

It is found that the SiO_2 contents in field growth rice plants increased generally from roots, through stem and leaves, to husks. Large and systematic silicon isotope fractionation was observed among different organs of individual rice plants. Their □^{30}Si values show a general increasing trend from roots, stem and leaves, through husks to grains, which can be explained by kinetic isotope fractionation in a Rayleigh process.

The silicon isotope fractionation between rice plant and nutrient solution was studied experimentally. In the growth process the silicon content in the nutrient solution decreased gradually from 16 mM at starting stage to 0.1~0.2 mM at harvest and the amount of silica in single rice plant increased gradually from 0.00013 g at start to 4.329 g at harvest. At the maturity stage, the silicon content increased from roots, through stem and leaves, to husks, but decreased drastically from husks to grains. These observations show that transpiration and evaporation may play an important role in silica transportation and precipitation within rice plants.

It was observed that the ^{30}Si of the nutrient solution increased gradually from -0.1‰ at start to 1.5‰ at harvest, and the ^{30}Si of silicon absorbed by bulk rice plant increased gradually from -1.72‰ at start to -0.08‰ at harvest, reflecting the effect of the kinetic silicon isotope fractionation during silicon absorption by rice plants from nutrient solutions. The calculated silicon isotope fractionation factor between the silicon instantaneously absorbed by rice roots and the silicon in nutrient solution vary from 0.9983 at start to 0.9995 at harvest, similar to those reported for bamboo, banana and diatoms in direction and extent. In the maturity stage, the ^{30}Si value of rice organs

decreased from -1.33‰ in roots to -1.98‰ in stem, and then increased through -0.16‰ in leaves and 1.24‰ in husks, to 2.21‰ in grains. This trend is similar to those observed in the field grown rice and bamboo.

These quantitative data provide us a solid base for understanding the mechanisms of silicon absorption, transportation and precipitation in rice plants and the role of rice growth in the continental Si cycle.

It is inferred that monosilicic acid is the major silicon-bearing component taken up by rice roots. Passive uptake of silicon is important for rice and evapotranspiration may be the major mechanism for the transportation and precipitation of silicon in rice plants. It is suggested that silicon isotope study has a potential application in agriculture and biogeochemistry, and plants may play an important role in global silicon cycle.

A novel silicate-dissolving bacteria strain: Silicate-releasing capacity in soil and its agronomic implications in rice

Du YH [1], Zhuang ZJ [1], Zhang CY [1], Xu ZW [1], Chen HY [2]

1 Leading Bio-agricultural Co. Ltd. Qinhuangdao, China,

2.Yigeda Bio-Technology Co., Ltd. Beijing, China

Abstract

Silicon (Si) is known as the fourth largest element in plants after the three major essential elements, i.e. “N, P and K”. Silicon is also the second most abundant element after oxygen in the earth’s crust and in soils. The majorities of silicon in the soils, however, are unavailable to plants. Although Si has not been considered an essential element for higher plants, it has been documented to be beneficial for healthy growth and development of many plant species exposed to abiotic and biotic stresses, especially grasses such as rice, sugarcane, wheat and maize.

The major silicate fertilizers used widely in the world are slag-based fertilizers. However, the major disadvantages of such silicate fertilizers are their low solubility, high pH and inconveniency in use and transport due to their large application rates. Therefore, exploring novel silicate fertilizers is of crucial importance to the sustainability of agriculture. In the present study we obtained a novel silicate-dissolving bacteria strain with its preservation number of CGMCC NO.4667 by using microbial mutation technology. A three-day flask-shaking incubation experiment at 30^{o}C showed that this strain could effectively dissolve silicate from the powdered feldspar-containing culture medium. The water soluble silicon content in the culture media inoculated with the silicate-dissolving bacteria strain was 5.33 times as high as that in the control medium. Subsequently, we manufactured a compound bio-fertilizer containing the silicate-dissolving bacteria strain (Shi Li Kang) by fermenting and granulating. An 8-week incubation experiment with soils under saturation conditions at 25^{o}C showed that the available silicon content and water-soluble silicon content in the soils treated with the compound bio-fertilizer at the rate of 1.0 g/kg increased by 42% and 26%, respectively, compared with the control, suggesting that this compound bio-fertilizer could dissolve silicate in soil significantly. A pot experiment showed that the tillering number and grain yield were increased by 20% and 10.1%, respectively, in rice treated with the bio-fertilizer

compared with the control. In addition, total silicon, nitrogen, phosphorus and potassium contents were increased by 7.9%, 7.4%, 7.4% and 3.7%, respectively, compared with the control.

Since 2005, field experiments with the compound bio-fertilizer applied as a base fertilizer at the rates of 60-90 kg/ha have been conducted extensively in an area of 600,000 hectare of rice field in Heilongjiang, Liaoning and Hebei provinces. The results showed that the rice leaf angles became smaller with the photosynthesis improved greatly, compared with the control. Moreover, the lodging, rice blast, the grain discoloration and sheath rot incidences were decreased by 20-45%, 25-75%, 25-53% and 26-60%, respectively in the rice plants applied with the compound bio-fertilizer compared with the control. Application of the compound bio-fertilizer could significantly increase the tiller number and effective panicles number and, on the average, increase the rice yield by 7-11%.

Key words: Lodging, Photosynthesis, Rice, Rice blast, Silicate-dissolving bacteria.

Growth improvement of triticale for dry tolerance by antioxidant enzyme analysis

Elham S [1], Raheem H [2], Ghasemali G [2], Ramin H [2]

1.Department of Agricultural Biotechnology, Imam Khomeini International University.

2.Department of Agricultural Biotechnology, Imam Khomeini International University, Qazvin, I. R. of Iran, P. O. Box 34149-288. Tel: (0098) 281 8371165, Fax: 3780073. (Corresponding author: raheemhaddad@yahoo.co.uk)

Abstract

In the present study, effect of sodium silicate were investigated to analyze drought induced oxidative stress on antioxidant enzymes and protein content on two triticale (*X Triticosecale*) genotypes JUANILO92 (sensitive) and et-79-17 (tolerant) differing in an experiment with factorial test on three treatments and three replications. The effects of single stress of silicon on plant growth, oxidative stress and antioxidant enzymes were studied. Total protein, superoxide dismutase (SOD) and guaiacol peroxidase (GPX) contents were investigated to analyze the plant growth. Our results showed that compared to the plants treated with drought alone, Si treatment caused to increase the activities of SOD and GPX and also total protein content under drought stressed leaves of both cultivars. The extent of oxidative damage was induced by dry decrease of harvest. The combination of dry with silicon caused an increase in plant growth rather than the activities of antioxidant enzymes. There was also a marked difference between two studied triticale genotypes in the extent of increased antioxidant enzyme activity under dry and silicon stress.

Key words: Antioxidant enzymes, Dry stress, Silicon, Triticale.

Reduction of chemical pesticides by using of silicate fertilizer in paddy fields

Fallah A, Osko T, Khosravi V, Mohammadian M, Rosttami M

Faculty member of Rice Research Institute of Iran (Amol)

Email adders: afallah1@yahoo.com

Abstract

Soil and water contamination with chemical pesticides used in rice fields has been causing major problems for the environment, health of humans and the rice crop. For testing the effect of silica on the reduction of pest and disease outbreak, experiments in a randomized complete block design with three replications in 2010 and 2011 were performed in the greenhouse of Rice Research Institute of Iran (Amol). Pot experiments with three levels of nitrogen (69, 95, 115 kg/ha) with three levels of silicate fertilizer (0, 250, 500 kg/ha) were conducted in a factorial randomized complete block design. The Hhashemi Tarom cultivar was used and all pots were not sprayed with pesticides. Yield and yield components were measured at the maturity stage. From this experiment it was found that increased application rate of silica fertilizer increased silica concentration in shoot oranges, leaves and panicle of rice. Disease severity of blast increased with increasing of nitrogen in the treatment not receiving silicate fertilizer, but significantly reduced in the treatment receiving silicate fertilizer. The average sheath blight spots decreased in plants treated with silicate fertilizer in this experiment. Using of silicate fertilizer increased grain yield by 10% and reduced stem borer by about 10-20 percentage.

Key words: Disease, Performance, Pest, Rice, Silica.

Influence of silicon supply on arsenic concentration in straw and grain fractions of rice

Fleck AT, Schenk MK

Institute of Plant Nutrition, Faculty of Natural Sciences,

Leibniz University Hannover, Herrenhäuser Str. 2, 30419 Hannover, Germany.

Abstract

It was observed, that silicon (Si) supply potentially reduces arsenic (As) concentration in root and shoot of rice. Aim of this study was to investigate the influence of Si application on As concentration in grain of rice grown on different paddy rice soils.

Rice plants were cultivated in three Italian paddy rice soils with and without Si application in the greenhouse. For Si application, 10 g silicagel / kg soil were mixed with soil and each 35 plants were cultivated in 20 liter pots with 20 kg soil. Soil was flooded one week before rice cultivation and rice plants were harvested at maturity at 153 days after planting (DAP). Si and As concentrations in the soil solution as well as redox potential were measured weekly during the cultivation.

Si concentration in the soil solution of soils without Si fertilization (-Si) was below 10 mg / L from 40 DAP to the end of cultivation, while it was increased by Si fertilization to on average 30 mg / L. The As concentrations in soil solution increased during cultivation and reached in two soils a maximum of 180 µg / L at 14 DAP and declined subsequently to 100 µg / L whereupon As concentrations were slightly higher with Si supply. In the third soil As concentration in soil solution was very low at beginning of cultivation and increased continuously until it reached a plateau at 100 DAP at around 190 µg / L for -Si soil and 250 µg / L for +Si soil.

Si application increased straw and grain yield by on average 21 and 17 %, respectively. Si concentrations in straw dry matter ranged from 12 to 19 mg / g and from 36 to 43 mg / g in -Si and +Si treatments, respectively. As concentrations in straw were in the range of 4 to 11 µg /g dry matter in -Si treatments, while they were decreased by Si application by on average 52 %. Similarly, Si supply reduced husk As concentrations by half. However, As concentrations in polished rice were less reduced by Si application.

Obviously, the As uptake into the shoot parts which are supplied via the xylem is much more affected by Si fertilization than the phloem translocation from the leaf into the grain.

The Possible role of roots in silicon-induced resistance in rice against blast

Ge SB, Cai KZ *, Liu M, Luo SM

Key Laboratory of Ecological Agriculture of Ministry of Agriculture, South China Agricultural University, Guangzhou 510642, China

E-mail: kzcai@scau.edu.cn

Rice blast, caused by *Magnaporthe oryzae* is the most important and destructive disease for rice production in rice-growing areas worldwide. Silicon is proved to have a important role to increase the resistance of rice against blast. Silicon can deposit in epidermal cell walls beneath the cuticle, forming a cuticle-Si double layer in the leaf blade of rice. And it also can increase the activities of defense-related enzyme in rice leaves after inoculation with *M. oryzae*. But what is the role of roots in silicon-induced resistance of rice against blast disease is totally unclear. So we detect some indexes in roots to find the connection between roots and shoots in the resistance of rice against *M. oryzae*. We found that H_2O_2 concentration in Si-treated rice leaves significantly decreased by 30.4% and 29.7% respectively for CO39 (susceptible) and C101LAC (Pi-1) (resistant) compared to untreated plants at 7 days after inoculation (dai) with *M. oryzae*. In contrast, H_2O_2 concentration in roots increased significantly by 56.3% and 266.2% for CO39 and C101LAC (Pi-1) respectively. Ethylene level in infected rice leaves was significantly higher at 3 dai than those untreated ones, and it was also higher than the infected plants at 7 dai. There was no significantly difference among the treatments at 7 dai. In roots, ethylene level in infected plants increased at 7 dai compared to 3 dai. Silicon application reduced ethylene level in both roots and leaves. All the above results showed H_2O_2 and ethylene level of root and leaf had a reverse trend in Si-treated rice plants. The data show that H_2O_2 and ethylene may connect shoots with roots with as signal compounds. A corresponding induced defense response initiating intraplant signaling between leaves and roots may be existed in pathogen infection. Our results showed shoot pathogen attack and silicon application resulted in an increase in root concentrations of H_2O_2 and ethylene. But how the roots participate in the defense of rice against blast disease should be studied further.

Key words: Ethylene, H_2O_2, *Magnaporthe oryzae*, Rice (*Oryza sativa* L.), root, Silicon, Signal.

Effect of silicon and phosphorus rates on yield and yield components of rice (*Oryza sativa* L.)

Ghanbari-Malidarreh A [1], Alavi SV [2], Dastan S [1]

1.Department of Agronomy and Plant Nutrition, Member of Young Researchers Club, Islamic Azad University, Jouybar Branch, Jouybar, Iran. *aghanbari@jouybariau.ac.ir*

2.Department of Plant Pathology and Protection Division, Agricultural and Natural Resources Research Center of Mazandaran, Sari, Iran.

Abstract

Two important elements of silicon and phosphorus in rice production in areas with frequent cultivation that phosphorus pollution due to excessive use and immobility and the amount of silicon store in the soil because to fire and lack of use silicon fertilizer has been reduced. The project aimed to determine the relationship between these two elements and to evaluate use of silicon and phosphorus on yield and agronomic traits of rice was performed. Factorial experiment based on randomized complete block design with two factors phosphorus and silicon with four replications was conducted in 2010. Phosphorus levels, including 0, 50 and 100 kg ha^{-1} and silicon levels were containing 0, 500 and 1000 kg ha^{-1}. The results showed that levels of phosphorus and silicon on grain yield at 5 and 1 % probability level were significant, respectively. So that, the grain yield of 758 kg ha^{-1} with application 1000 kg ha^{-1} silicon was more than control that equal to 23 % increase in production. High phosphorus and silicon did not affect 1000-grain weight and had reduced but straw and biological yield had increase. High phosphorus and silicon the number of spikelet per panicle increased and decreased the number of blank spikelet per panicle. Number of panicle per square meter had increased with increasing phosphorus application, but with increasing silicon have not change significantly. The interaction effect indicated that grain yield at 5 % probability level was significant and did not use phosphorus and silicon had decreased grain yield. Because biological yield was the lowest and also increasing phosphorus and silicon application had increased grain and biological yield. It seems that these two elements are together in attracting alternative and perhaps attract each other by the roots due to having the same negative are in competition. If phosphorus application or stored in soil is increase or high, plant uptake of silicon and phosphorus had change and consequently grain yield had change. Thus, silicon application will protect lodging and blast disease of rice, and phosphorus application in the production of more photosynthetic material and fertility spikelet was affect and duo to increasing grain yield.

Key Words: Phosphorus, Rice, Silicon, Seed yield.

Interaction effects of silicon and phosphorus fertilizer on blast disease severity in rice (*Oryza sativa* L. var. Tarom)

Ghanbari-Malidarreh A [1], Ghasemi-Lemraski M [2], Alavi SV [3], Mobasser HR [2]

1.Department of Agronomy and Plant Nutrition, Islamic Azad University, Jouybar Branch, Jouybar, Iran. aghanbari@jouybariau.ac.ir,

2.Department of Agronomy and Member of Young Researchers Club, Islamic Azad University, Qaemshahr Branch, Qaemshahr, Iran,

3.Department of Plant Pathology and Protection Division, Agricultural and Natural Resources Research Center of Mazandaran, Sari, Iran.

Abstract

In order to evaluate the effect of silicon and phosphorus application on blast disease severity of rice, a field experiment was carried out in 2009 in a factorial experiment based on the complete randomized block design with four replications in Iran. The phosphorus was applied in three levels (0, 50 and 100 kg/ha) as (P_2O_5) and silicon was applied in three levels (0, 500 and 1000 kg/ha) as ($CaSiO_2$). There was a significant difference in seed yield at 5% probability and the highest grain yield was obtained by application of 1000 kg/ha silicon with 3849.5 kg/ha. There was significant difference in leaf blast at 5% probability whereas that the lowest leaf blast severity by application of 1000 kg/ha silicon led to decrease the disease severity up to 10% in comparison to the control. This amount of using silicon reduced significantly the average of lesion diameter (10.48 mm) in comparison to the control without using silicon, too. The rates of phosphorus, did not affect significantly the percentages of leaf, neck, nod and grain blast and the average of lesion diameters. The rates of silicon did not affect the number of infected nod, neck and grain. With regard to interaction effects of phosphorus and silicon, applying 1000 kg/ha silicon without phosphorus led to a significant reduction in the average diameter of blast lesion. In the rate of 100 kg/ha phosphorus and 1000 kg/ha silicon in comparison without using silicon, there was significant difference in the percentage of leaf blast. So, we can conclude that in contrast to using silicon alone, using silicon and phosphorus together cannot affect different traits of rice blast disease significantly.

Key Words: Leaf blast, Neck blast, Phosphorus, Rice, Silicon.

Effect of different sources of silicon content on grain yield and yield components of rice (*Oryza sativa* L.)

Ghanbari-Malidarreh A [1], Azimnejad A [2], Alavi SV [3], Mobasser HR [4]

1.Department of Agronomy and Plant Nutrition, Islamic Azad University, Jouybar Branch, Jouybar, Iran. aghanbari@jouybariau.ac.ir,
2.Department of Agronomy, Islamic Azad University, Qaemshahr Branch, Qaemshahr, Iran,
3.Department of Plant Pathology and Protection Division, Agricultural and Natural Resources Research Center of Mazandaran, Sari, Iran,
4.Department of Agronomy, Islamic Azad University, Qaemshahr Branch, Qaemshahr, Iran.

Abstract

In order to study effect of different sources of silicon content on grain yield and yield components of two rice varieties, an experiment was conducted in 2010. The study based on randomized complete block design as split plot experiment was conducted with three replications. Main plot at two levels including rice varieties Tarom-Hashemi and Tarom-Neda. Sub-factors in eight levels include different sources of silicon content in the level eight (T_1= control), (T_2= rice straw), (T_3= silicon fertilizer) (T_4= rice straw and silicon fertilizer), (T_5= rice husk), (T_6= rice husk and rice straw) (T_7= silicon fertilizer, rice husk) and (T_8= rice husk and rice straw and silicon fertilizer). Results this study showed that the total number of spikelet per panicle and the interaction effect of varieties × sources at 1 % probability level were significant. So that in varieties, the total number of spikelet per panicle Tarom-Neda with 128.59 spikelet was more than cultivar of Tarom-Hashemi with 97.25 spikelet. In varieties, filled spikelet per panicle at 1 % level and the interaction effect cultivar × sources at 1 % probability level was significant. So in varieties, the number of filled spikelet per panicle Tarom-Neda cultivar with 109.07 spikelet was more than Tarom-Hashemi cultivar with 85.77 spikelet. Straw yield in varieties at 1 % probability level and sources at 5 % probability level was significant. So that in varieties, straw yield of Tarom-Hashemi cultivar with 888.48 $g.m^{-2}$ was more than Tarom-Neda cultivar with 730.14 $g.m^{-2}$. Grain yield of varieties was significant at 1 % probability level, so Tarom-Neda cultivar with 667.46 $g.m^{-2}$ was more than

Tarom-Hashemi cultivar with 368.87 g.m^{-2}. T_1 and T_6 had maximum and minimum straw yield with 863 and 740 g.m^{-2}, respectively. Grain and biological yields of T_7 was the maximum with 547 and 1400 g.m^{-2} and T_4 was the minimum with 489 and 1243 g.m^{-2}, respectively. Then, silicon duo to decreasing straw yield (control) and silicon application from different sources duo to increasing harvest index, because number of total spikelet and number of filled spikelet per panicle had increased.
Keywords: Rice, Silicon, Straw and Husk.

Regulation of silicon on photosynthetic gas exchange of *Triticum aestivum* L. in field drought conditions

Gong HJ

Institute of Vegetable Science, College of Horticulture, Northwest A&F University, South Campus, Yangling 712100, Shaanxi, P.R. China

E-mail: gongnavy@yahoo.com

Abstract

This study investigated diurnal changes in photosynthetic gas exchange of wheat (*Triticum aestivum* L.) plants at heading stage as affected by silicon application in field under drought. Silicon was applied to the soil before sowing and drought stress was applied by withholding watering throughout the plant development. The results showed that application of silicon increased the leaf relative water content and water potential, both of which were decreased under drought stress. The net photosynthetic rate and stomatal conductance of leaves were significantly decreased between 7:30 and 17:30 under drought. Silicon application increased the leaf net photosynthetic rate between 7:30 and 15:30, except at 9:30, when no significant difference was observed between plants with and without added silicon. Silicon applied plants showed significantly higher leaf stomatal conductance at 13:30 and 17:30 than those without added silicon under drought. The leaf transpiration rate was decreased by drought stress, and it was increased in silicon applied plants at 13:30 and 15:30. Compared with the control, the intercellular CO_2 concentration was increased at 7:30 under drought, regardless of silicon application, while it was decreased most of the time from midday to the afternoon. The stomatal limitation in stressed plants was significantly higher than that in the control from 11:30 to 17:30. At 13:30 and 17:30, silicon applied plants showed lower stomatal limitation than those without added silicon under drought. The instant water use efficiency was significantly higher at 7:30 and 11:30 in silicon applied plants than that in plants without added silicon. These results suggest that both stomatal and non-stomatal factors contribute to the silicon-induced increase in net photosynthetic rate of wheat in field drought conditions: in the early morning (at 7:30), the non-stomatal factor is the main contributor; 9:30 is a turning point, after which both stomatal and non-stomatal factors (mainly stomatal factor) contribute to the increase of net photosynthetic rate.

Keywords: Drought, Photosynthetic gas exchange, Silicon, *Triticum aestivum* L.

Influence of Si on Cd uptake and accumulation in wheat

Greger M [1], Landberg T [1], Lux A [2], Singh BR [3]

1.Department of Botany, Stockholm University, 106 91 Stockholm, SWEDEN,

2.Department of Plant Physiology, Faculty of Natural Sciences, Comenius University in Bratislava, Mlynská dolina B2, 842 15 Bratislava, SLOVAKIA,

3.Department of Plant and Environmental Sciences, Norwegian University of Life Sciences (UMB), P.O. BOX 5003, N-1432 Ås, NORWAY.

Abstract

Cadmium (Cd) is a toxic heavy metal which enters the human body via food crops. In Sweden, 43% of the Cd that enters the human body originates from wheat products. It is thus important to find ways to decrease the Cd uptake and accumulation in wheat grains. We have found that it is possible to decrease Cd concentration in wheat grains by adding Silicon to the nutrient medium. The aim of this work was to find out how Si influences the uptake and accumulation of Cd in wheat from soil to grain. This presentation summarises the results from various experiments on this topic.

Silicon decreases Cd in wheat grains up to 50%, especially in cultivars with high accumulation of Cd in wheat grains of *Triticum aestivum, T. durum* and *T. spelta*. One of the reasons is that Si influences the Cd bindings of the soil colloids and thereby decreases the Cd release to the soil water. Since the Cd concentration in the soil solution decreases also the Cd uptake decreases, even though Si has no influence on the Cd uptake from a soil solution with the same Cd concentration. Silicon also lowers the root to shoot translocation of Cd decreasing the Cd concentration in shoot and increasing that of the root. This may be due to structural changes of the roots; 1) Apoplastic barriers in endodermis are formed earlier in the root development, closer to the root apex in the presence of Si, which decreases the rate of Cd ion entery to the xylem flow, 2) silicon also decreases the concentration of Cd in the root apoplast due to the fact that Si increases cation exchange capacity of the cell wall and therefore Cd binds up to the wall to a higher extent in the presence of Si.

Acknowledgement

The Swedish Farmers´ Foundation for Agricultural Research, Magn Bergwall foundation, Norwegian University of Life Sciences (UMB), Kurt and Alice Wallenberg foundation, COST FA0905, and Slovak Research and Development Agency under the contract No. APVV-0140-10 and VEGA (1/0472/10) are acknowledged.

Silicon influence on As accumulation and speciation in lettuce

Greger M, Landberg T, Sandhi A, Bergqvist C

Department of Botany, Stockholm University, 106 91 Stockholm, SWEDEN

Abstract

Lettuce is a popular vegetable. It has a high arsenic (As) accumulation, a toxic metalloid that is present in various forms, so called species. To humans as well as to plants, the more common inorganic forms, arsenite and arsenate are more harmful than organic As like monomethylarsonate (MMA) and dimethylarsinate (DMA). Since silicon (Si) is known to influences the accumulation of toxic elements in plants the aim was to investigate the effect by Si on the uptake and speciation of As in lettuce.

Plants of lettuce (*Lactuca sativa* cv Americanischer brauner) were treated with arsenite and arsenate (0.5-5000 µM) with or without Si (1 mM added as K_2SiO_3) for 1-5 days in nutrient medium. The contents of total As in roots and shoots were analysed with AAS and As speciation with HPLC-AAS. More As was accumulated in roots compared to shoots, especially when arsenite was added. About 48% of the total As was bound to cell walls and was not influenced by Si. Silicon increased the shoot : root ratio of As when arsenite was added. In short term studies, Si reduced the uptake of As. There was always higher concentration of arsenate than arsenite in the plant. Solely when arsenate was added the lettuce contained MMA but never DMA. In the presence of Si, MMA decreased. Silicon addition decreased the As toxicity to the plant when arsenate was added.

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Silicon influences nutrient status in plants

Greger M [1], Landberg T [1], Vaculik M [2], Lux A [2]

1.Department of Botany, Stockholm University, SE 106 91 Stockholm, Sweden,

2.Department of Plant Physiology, Faculty of Natural Sciences, Comenius University in Bratislava, Mlynská dolina B2, SK 842 15 Bratislava, Slovakia.

Abstract

Silicon has many beneficial effects on plants, in particular on some plant species, e.g. from the family Poacae. Silicon enhances growth, improves protection against pathogens and increases drought and salinity resistance. Therefore, Si addition in crop cultivation might be major possibility for improvement of crop production economy. Since Si also reduces negative effects of toxic elements, like heavy metals by decreasing their level in the plant parts, there is a risk that Si also may additionally decrease the accumulation of some of the nutrient elements. The aim of this study was therefore to investigate how Si influences the nutrient status and other nutrient related factors in different plant parts of some crop plants.

Maize (*Zea mays,* cv Reduta), lettuce (*Lactuca sativa,* cv Amerikanischer brauner) and spring bread wheat (*Triticum aestivum,* cv Tjalve) were cultivated in Hoagland nutrient solution and treated with 0.5 – 5 mM Si, (added as potassium silicate) for seven days (lettuce and maize) and until full maturity (wheat). Biomass, protein content and the amount of N, P, S, Cl, K, Mg, Ca, Mn, Fe, Cu, Mo, B, Zn and Si was analyzed in roots and shoots of maize and lettuce, and in grains of fully ripened wheat.

Biomass increased by Si with unchanged proportion of root: shoot ratio. Silicon affected the uptake and distribution of some nutrients while others were unaffected. Protein content increased slightly with Si, especially in wheat grains. In contrast, N content decreased in all investigated plants parts, except of wheat grains. Phosphorous decreased with Si in maize and lettuce but not in wheat grains. Decrease of N and P is mainly a dilution effect; in fact the amount of N and P was unchanged or increased because of the Si-induced increase of biomass. Silicon increased Mn and B in all plant parts while decreased the distribution of Cu and Zn from shoot to root. In general, the other investigated elements were not affected by Si addition. While the Si concentration increased up to 100 times in the plants treated with Si, the decrease in

concentration of nutrient elements was not more than 40%. The changes in nutrient level seem thus to be within a natural interval.

Acknowledgement

Kurt and Alice Wallenberg foundation, COST FA0905 and Slovak Research and Development Agency under the contract No. APVV-0140-10 and VEGA (1/0472/10) are acknowledged.

Mitigation effects of silicon rich amendments on heavy metal uptake by rice (*Oryza sativa* L.) planted on multi-metal contaminated acidic soil

Gu HH [1], Zhan SS [1], Wang SZ [1, 2], Qiu RL [1, 2] *

1.School of Environmental Science and Engineering, Sun Yat-Sen University, Guangzhou 510275, China;

2.Guangdong Provincial Key Lab of Environmental Pollution Control and Remediation Technology, Guangzhou 510275, China;

** Corresponding author. Tel: +86 20 84113454; Fax: +86 20 84113616;*

Email: eesqrl@mail.sysu.edu.cn.

Abstract

Silicon was suggested to enhance plant resistance to toxic elements, and its beneficial role was mainly based on external and internal plant mechanisms. In this study, the mechanisms of stabilization by silicon-rich amendments of Cd, Zn, Cu and Pb in a multi-metal contaminated acidic soil and the mitigation of metal accumulation in rice were investigated. The results from a pot experiment indicated that the application of fly ash (20 and 40 g kg^{-1}) and steel slag (3 and 6 g kg^{-1}) increased soil pH from 4.0 to 5.0-6.4, decreased the phytoavailability of heavy metals by at least 60%, and further suppressed metal uptake by rice. X-ray diffraction analysis indicated the mobile metals were mainly deposited as their silicates, phosphates and hydroxides in amended treatments. A hydroponic experiment under the condition of 200 μM Zn contamination with the additional silicate supply at three levels (0, 0.5 and 1.8 mM) showed that the silicate addition significantly increased the seedling biomass, and decreased Zn concentration in both root and shoot of seedlings and in xylem sap flow. Zinpyr-1 fluorescence test and Energy-dispersive X-ray spectroscopy analysis showed the concentration of biologically active Zn^{2+} decreased, and Zn and Si co-localized in the cell wall of metabolically less active tissues, especially in sclerenchyma of root. The fractionation analysis further supported silicate supply increased about 10% the cell wall bound fraction of Zn. Finally, a field experiment showed the trace element concentrations in polished rice treated with amendments complied with the food safety standards of China. In a word, the application of Si rich amendments, fly ash and steel slag, could be a potential strategy to mitigate environmental and health risks around mining area by simultaneously modifying the restraint and sequestration processes of heavy metal in both soil and rice.

Keywords: Fly ash, Heavy metal, Restraint and sequestration effects, Rice, Silicon, Steel slag.

Field corn response to a blended calcium silicate slag/calcium sulfate soil amendment

Guth A, Miranda S, Provance-Bowley MC
Agriculture and Turfgrass, Harsco Minerals, Harsco Minerals International

359 North Pike Road, Sarver, PA 16055 USA

Abstract

In the Northeast United States where soils are acidic, liming every 3-5 years is common practice to raise soil pH to recommended levels for optimum growth of many field crops. As the most cost effective method to farmers in the United States in providing silicon to field crops are applications of processed stainless steel slag, which also acts to alter soil pH similarly to other liming agents, supplying enough silicon to affect a plant response may be limited by the need to neutralize soil acidity. A means of supplying silicon to plants with minimal pH altering effects is needed. In a field trial, field corn (*Zea mays* L.) response to either a calcium silicate slag/calcium sulfate blend or a calcitic limestone was compared. Data on plant growth parameters, yield, silicon uptake, and soil silicon availability will be presented.

Silicon-mediated rice plant resistance to the rice stem borer *Chilo suppressalis*: effects of silicon treatment, rice varietal resistance and larval stage

Han YQ [1], Hou M [1, 2]

1.State Key Laboratory for Plant diseases and Insect Pests, Institute of Plant Protection, Chinese Academy of Agricultural Sciences, 2 Yuanmingyuan W. Rd., Beijing 100193, China.

2. Correspondence to: mlhou@ippcaas.cn

Abstract

The rice stem borer *Chilo suppressalis* is one of the most destructive pests in rice in China and other Asian countries. The aim of this study was to investigate the potential of applied silicon in mediating rice plant resistance to first and third larval instars of *C. suppressalis* in a susceptible (Shanyou 63) and a moderate resistant (Yanfeng 47) rice cultivar.

Potted rice plants were treated with calcium silicate at rates of 150 kg/ha (SiO_2) or 600 kg/ha (SiO_2) or left untreated (the control). Si amendment significantly increased Si content in rice stems and leaf sheath, rice cultivar and interaction between Si treatment and rice cultivar also significantly influenced stalk SiO_2 content. Percentage of larvae bored (PLB) decreased 5%-28% with increase in Si addition. Percentage of larvae penetrated (PLP) did not differ among Si treatments or between rice cultivars for the first instars; for the third instars, PLP significantly decreased 10%-40% with increase in Si supply and was 10% to 30% lower on Yanfeng 47 than on Shanyou 63. Si addition significantly prolonged penetration duration (PD) in the first instars and Yanfeng 47 compared to Shanyou 63 extended PD in the third instars. Analysis showed that increased SiO_2 content in rice culms due to Si addition contributed to the reduction in PLP and prolong in PD of the third instar larvae. Silicon treatment significantly decreased larval development in the first instars, and weight gain and stem damage in the third instars. Some of the effects were manifested more strongly in the susceptible rice cultivar compared with the moderate resistant cultivar.

The current results indicate that Si amendment may contribute to the suppression of C. suppressalis directly through impeding larval penetration and performance, and

indirectly by delaying penetration, resulting in prolonged exposure of larvae to other control measures; Si supply impairs penetration more strongly in the third instars than in the first instars; and, susceptible rice cultivar benefits more from Si addition than resistant one in deterring boring by RSB larvae.

Keywords: Boring behavior, *Chilo suppressalis*, Performance, Plant resistance, Silicon, Rice.

Soil and crop responses to silicon supplements in New Jersey

Heckman JR, Provance-Bowley M

Department of Plant Biology & Pathology, Rutgers University, Foran Hall/ Cook Campus, 59 Dudley Rd. New Brunswick, NJ 08901, USA.

Email: heckman@aesop.rutgers.edu

Abstract

Silicon added to a Quakertown silt loam as calcium silicate slag (Excellerator (TM), Excel Minerals, Sarver, PA) was evaluated on selected crops grown in New Jersey. Field experiments were conducted with pumpkin (*Cucurbita pepo* L.) in years 2000 and 2001.The initial soil pH was 5.7. Liming materials calcium silicate slag or limestone each applied at the rate of 7840 kg/ha of calcium carbonate equivalent was compared. Each liming agent raised soil pH to 6.8.Silicon from the calcium silicate slag suppressed powdery mildew disease and delayed senescence of pumpkin foliage. In year 2000 only, pumpkin yield was increased by 60%. In year 2001, yield was not different. Adding silicon to soil increased in pumpkin foliage Si concentration 5 fold. In years 2002 and 2003, the same research plots were used to determine if increasing the concentration of Si in corn (*Zea mays* L.) plant tissue could decrease European corn borer (ECB) *(Ostrinia nubilalis* / Hubner), larval boring and feeding activity. Corn stem tissue Si increased from 1.3 to 1.7 g/kg in 2002 and 1.8 to 3.3 in 2003 in silicon amended compared to limestone plots. Silicon tended to decrease the amount of damage to the stem both years but this protection from European corn borer did not translate into a significant grain yield increase. In years 2006 to 2008, the plots were cropped to winter wheat (*Triticum aestivum* L.) to evaluate silicon for effects on powdery mildew disease and grain yield. In each of these three years additional calcium silicate slag or limestone was applied at the calcium carbonate equivalent rate of 4480 kg ha^{-1}. In 2006, powdery mildew lesions were reduced 29% on wheat foliage in the silicon amended plots. In 2007, powdery mildew was not diagnosed, but non–pathogenic *Alternaria* spp. leaf blotch was observed late season and lesions were reduced 16% on the foliage in the silicon amended plots. During 2008, powdery mildew lesions on foliage were 44% less and yields were 10% greater in plots amended with silicon. Current investigations are examining forage crop responses to silicon. A decade of research suggests that silicon from calcium silicate slag may suppress plant disease and increase crop yield.

Recent progress on aluminium/silicon interactions in higher plants

Hodson MJ

School of Life Sciences, Oxford Brookes University, Gipsy Lane, Headington, Oxford, OX3 0BP, UK Phone: +44-(0)-1844-291244; E-mail: mjhodson@brookes.ac.uk

Introduction

Aluminium (Al) toxicity is an important factor in decreasing plant growth in both naturally occurring acid soils and in soils that are affected by acidic precipitation. The amelioration of Al toxicity by silicon (Si) under some circumstances is now a well established fact. It is nearly 25 years since the first paper in the "modern era" addressing Al/Si interactions in plants was published.[1] This paper, together with observations suggesting that Si could reduce Al toxicity in animal systems, led to a flurry of activity by plant scientists in the 1990s, which we documented in two reviews.[2,3] At the "2nd Silicon in Agriculture" conference in Japan in 2002, I was able to report that we knew more about the amelioration of Al toxicity by Si than we did about the effects of Si on any other abiotic stress.[4] Here we will confine our discussion to work on Al/Si interactions in higher plants in the last decade.

The Chemistry of Al/Si Interactions

The chemistry of Al/Si interactions in solution, at least in simple solutions, has become clearer in the last ten years. The use of equilibrium speciation models (e.g. EQ3NR), can predict the behaviour of Al and Si in growth solutions.[5] For example, the addition of 1000 µM Si to 100 µM Al solutions caused a reduction in Al^{3+} content between pH 4.0 and 5.0. At pH 4.0 Al^{3+} fell from 92.4 to 83.3% in the presence of Si; and at pH 5.00 the fall was from 54.6 to 17.7%. These falls were attributed to the formation of hydroxyaluminosilicate (HAS) species. HAS are believed to be non-toxic to plants, and their formation is thought to be at least partly responsible for the amelioration of Al toxicity by Si.

Uptake of Al and Si

There has been further advancement in determining the range of Al and Si contents in plants. In 1995 we asserted that, "very high Si accumulation and very high Al accumulation are mutually exclusive",[2] and there has been little to change this assumption. Comparing an analysis of Al accumulator plants[6] with a meta-analysis of the silicon contents of the shoots 735 plant species[7] strongly suggests that there are no extreme accumulators of both elements. The nearest to an exception so far reported is

Faramea marginata, an Al accumulator in the Rubiaceae, which uses HAS to detoxify Al in its leaves, but it is only a moderate Si accumulator.[8] In the last decade there has been considerable progress in isolating transporters for both Si[9] and Al[10], but as yet the significance of this work to Al/Si interactions is unclear.

Amelioration of Al Toxicity by Si

There have been relatively few papers in the last ten years where the amelioration of Al toxicity by Si has been investigated at the whole plant level, probably because this had been intensively studied in the 1990's. However, we were able to demonstrate amelioration in a conifer[5], and probably the most comprehensive study ever was conducted on maize.[11]

Al/Si Codeposition

It is now clear that codeposition of Al with Si in solid phytoliths is a relatively widespread phenomenon in higher plants. The two areas where such codeposition has been most studied are in roots and in conifer needles.[12] In roots Al is often codeposited with Si in epidermal and cortical cells. Codeposition in the shoots of higher plants depends on two factors occurring together: the plant must have the capability to transport both Al and Si in reasonable quantities; and Al must be available for uptake from the soil.

Is there an *in planta* Component to Amelioration Effects?

Although it is now obvious that bulk external solution effects, and the formation of non-toxic HAS are often a key component in amelioration effects, it is equally certain that *in planta* phenomena are also often involved. In addition to the deposition of Al within phytoliths, there have also been cases where soluble HAS have been invoked in detoxification of Al in the leaves of *Faramea marginata*[8] and in the apoplast of the maize root apex.[11] Another approach has been to investigate Al/Si interactions in plant suspension cultures of Norway spruce.[13] Again the results strongly suggested that the formation of HAS in the cell walls led to increased Al tolerance.

Conclusions

There is little doubt that there has been less work on Al/Si interactions in the last ten years. The reasons for this are not entirely clear, but may be related to difficulties in applying work carried out in simple solutions in the laboratory to much more complex field situations. Although Si is sometimes invoked as one factor in decreasing Al toxicity in soil experiments, it is frequently one among many.[14] It may also be that workers in this area reached the limits of the available technology. With the discovery of both Al and Si transporters in plants a new phase of investigations into Al/Si interactions should be possible.

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Study on soil silicon status in Indonesia

Husnain [1], Aflizar [2], Darmawan [3], Masunaga T [4]

1.Indonesian Soil Research Institute, Jl. Ir.H. Juanda No. 98 Bogor, Indonesia Telp/Fax. +62 251 8321608, E-mail: husnain.isri@gmail.com

2.Payakumbuh State Polytechnic for Agriculture, Jl. Raya Negara KM.7 Tanjung Pati Kec.Harau, Indonesia, Telp/Fax. +62 752 7754192, E-mail: aflizar_melafu@yahoo.com

3.Faculty of Agriculture, Universitas Andalas. Kampus LImau Manis. Padang. E-mail darmawan_darma@yahoo.com

4.Fac. of Life and Environment Science, Shimane University, Nishikawatsu cho 1050 Japan

Telp/Fax. +81 852 326066, E-mail: masunaga@life.shimane-u.ac.jp

Introduction

Indonesia is one of the biggest rice producing countries in the world after China and India (FAS-USDA 2010). In fact, as much as 1.750 thousand MT rice was imported in 2010 (FAS-USDA 2010). Despite of political concern, decreasing arable land for agriculture and degradation of soil fertility might be responsible for the deficit of national rice supply.

Since the last 10 years, government has implemented the balance fertilization by recommended site specific fertilization of N, P and K for rice plant. However, maintaining N, P and K alone without consider other nutrient such as Silica (Si) and micro elements has led imbalances of nutrient in soil. Moreover, high intensity of rice cultivation (mostly 2-3 times a year) without sufficient nutrient replenishment is also responsible for the degradation of soil productivity.

Rice plant obviously required Si to maintain healthy growth and high productivity. Although Si was recognised as the non essential element for rice plant, but rice plant uptake Si ranged from 230 to 470 kg Si ha^{-1}, two times higher than N uptake (Savant *et al*. 1997). The main role of Si for rice plant has been reported including its role against plant disease (Ishizuka and Hayakawa 1951; Kawashima 1927; Miyake and Takahashi 1983). However, the function of Si in soil fertility and plant physiology is not fully recognized.

In case of Indonesia, the survey of available Si in soil and irrigation water were recently reported. Darmawan *et al*. (2007) reported that available Si in rice soils in Java Island over the past three decades has decreased by approximately 11-20%. In addition, Husnain *et al*. (2008) has found that lower soil Si content was found in intensive rice field where enormous Si uptake was not following by sufficient Si replenishment. Although there was no report on the deficiency of Si in Indone sian sawah soil, the huge loss of rice production due to plant diseases and failed to harvest might be an indication of the imbalance of nutrients, particularly Si.

In this paper we discussed about soil Si availability in Java and Sumatra Islands in relation to the parent material and the relationship of Si in soil and rice plant. This paper may provide the information on how to manage Si as nutrient for rice and other Si accumulated plants in term of sustainability of food crop production in Indonesia.

Methodology

The survey was conducted in the four provinces including West Sumatra, West Java, Central Java and East Java, Indonesia. Soil samples were taken from 92 sites of rice field in West Sumatra, 59 sites in West Java, 28 sites in Central Java and 15 sites in East Java. The rice flag leaves were taken from several sites where the soil has been taken in Java Island. Soil available silica was determined using ammonium acetate buffer method (1 N NH_4OAc, pH 4.0) (Imaizumi *et al*. 1958). The Si content in plant sample was measured using gravimetric method. To studying the silicon supply from the common extraction method (1 N NH_4OAc, pH 4.0), the incubation and extraction were repeated extraction process eight times.

Results and discussion

Soil Silica Availability

The soil available Si in Indonesia ranged from 46 to 1,115 mg SiO_2 kg^{-1}. The distribution of available Si content in soil under rice field was varied. In general, from total 194 sites of rice field, available Si tend to be low in West Java and West Sumatra provinces (Tabel 1). These trend might be related to the high precipitation and wet climate that enhances desilication process compare than eastern part of Java Island.

Since there have been no studies examining the Si status of rice in Indonesian soil, we refer to the criterion proposed by Sumida *et al*. (1992). According to the Sumida *et al*. (1992) the critical level of Si content in rice soil is 300 mg SiO_2 kg^{-1}.

The result of soil Si content in soil and its distribution were presented in Tabel 1. The soils contained less than 300 mg SiO_2 kg^{-1} were distributed about 76% of total 92 sites in West Sumatra, 22.5 % of total 59 sites in West Java while in Central Java and East Java less than 3% of total sites in both provinces. From these result, there were many sites contained less Si for rice plant.

Tabel 1 The distribution of Si content in rice soils in Indonesia

Location	Number of sampling site (n/site)	Available Si (mg SiO_2 kg^{-1})	Percentage
West Sumatra	92	<100	1 (1%)
		100-200	30 (32.6%)
		200-300	39 (42.4%)
		300-400	15 (16.3%)
		>400	7 (7.6%)
West Java	59	<100	2 (3.4%)
		100-200	1 (1.7%)
		200-300	10 (16.9%)
		300-400	13 (22.0%)
		400-600	21 (35.6%)
		>600	12 (20.3%)
Central Java	28	<100	0 (0%)
		100-200	0 (0%)
		200-300	1 (3.6%)
		300-400	5 (17.9%)
		400-600	15 (53.6%)
		>600	7 (25.0%)
East Java	15	<300	0 (0%)
		300-400	1 (6.7%)
		400-600	6 (40.0%)
		>600	8 (53.3%)

Available Si in soil is related to the parent material. The soil derived from volcanic ash contained high available Si (Figure 1). Alluvial soil showed less available Si. Soils derived from volcanic ash contained higher Si other than other parent materials, including shale, quartz, granite and peat (Imaizumi and Yoshida, 1958). Husnain *et al*. (2008) reported that soils in West Java derived from volcanic ash and tuff volcanic in upper topographical position, and alluvial in lower topographical position, while in Central Java, volcanic ash and tuff volcanic were distributed from upper to lower topographical position. In West Java, rice field were mainly located in the lower topographical position. This means that potential Si in lowland rice fields on West Java were originally low compare than that in Central Java as well as East Java.

These results confirmed with Si content in rice plant where the soil samples were taken. The Si content in rice plants were varied following the trend of Si content in soil (Figure 2). As the rice harvest, Si and other micro nutrients would remove from soil. The N, P and K fertilizer may return as the fertilizer input but it is not the case for Si. The Si input may return as the rice straw decomposed in soil, but farmer prefer to burn the rice straw that caused the loss of nutrient including Si (Husnain, 2009). Therefore sufficient Si input is required to compensate it loss through rice harvest.

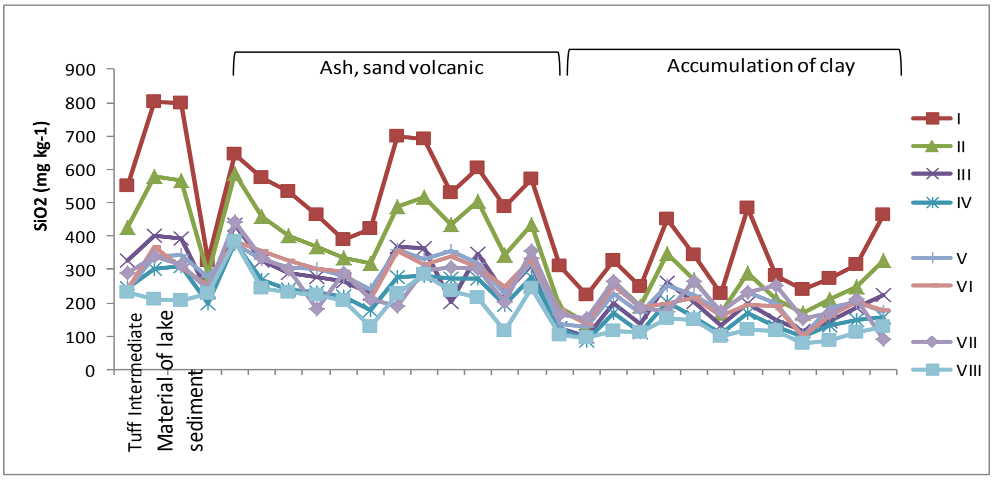

Figure 1 Silica supply under subsequently extracted soil as effect of parent material

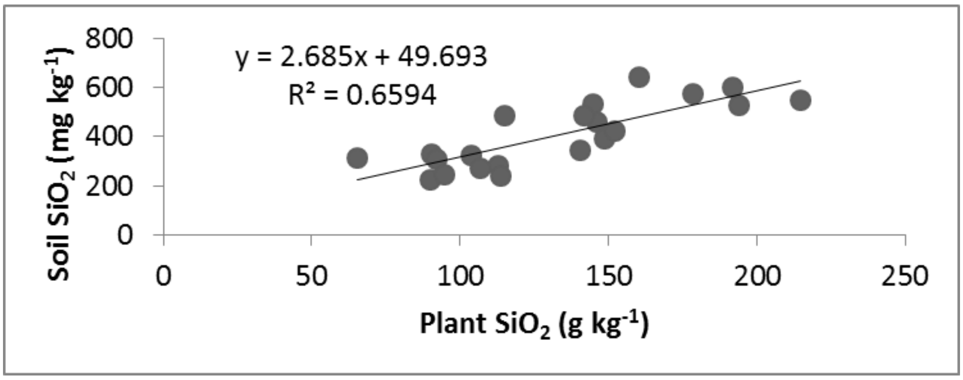

Figure 2 Relationship of silica in soil and rice plant

Methodology of soil Si extraction

Ammonium acetate buffer method (Imaizumi *et al*. 1958) is a common extraction method and has been widely used to determined available soil Si. There are several methods have been developed to extract available Si considering the silica fertilization and parent material. As there were no silica fertilization had been applied so far in Indonesian soil, we used the common extraction method using NH_4OAc 1 N pH 4.0 as described in Imaizumi *et al*. (1958). This method refers to the natural field condition such as submerge condition. The result of subsequently extracted soil Si using this method showed that the silica has continuously supplied at least up to three times incubation (Figure 3). Nevertheless, extractable silicon has been correlated with the plant yield (Figure 2). Therefore, soil Si extraction with NH_4OAc 1 N pH 4.0 still needs to be confirming in Indonesian soils.

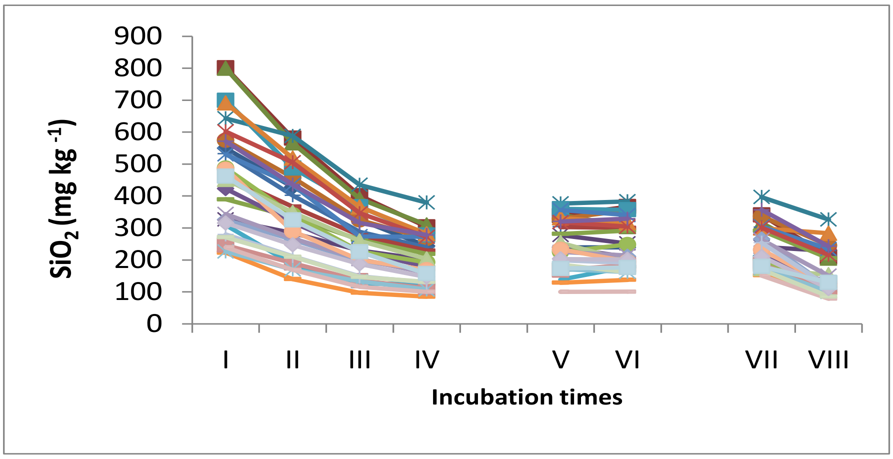

Figure 3 Soil Silica supply from subsequently extracted soil

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Effect of silicon on formation of cell wall in rice and tomato plants

Inanaga SJ [1]*, Chen NC [1, 2], Chishaki N [1]

1.Lab of Plant Nutrition and Fertilizers, Faculty of Agriculture, Kagoshima University, Kagoshima 892-0065, Japan

2.Lab of Pollution Control and Remediation, Guangdong Institute of Eco-environmental and Soil Sciences, Guangzhou 510650, China

** Corresponding author: inapi02@yahoo.co.jp*

Abstract:

The effects of silicon on cell wall formation in rice (*Oryza sativa* L.) and tomato (*Solanum lycopersicum* L.) plants were determined. Rice or tomato plants were grown in culture solution without silicon or with 50 mg L^{-1} silicon, and then the cell wall was extracted from the rice straw and 3 plant parts of tomato (roots, upper leaves and stem, lower leaves and stem). The cell wall was fractionated into soluble pectin substances in hot water (F1), pectin (F2), oxidized lignin (F3), hemicellulose (F4) and cellulose (F5). In rice straw, silicon addition increased F2 weight after heading. In all plant parts of tomato, silicon supply increased F2 and F3 weights. In spite of silicon deficiency, silicon content of rice straw cell wall before heading and those of F2 and F3 at heading were higher in silicon deficiency than in silicon supply. Addition of silicon markedly increased silicon content of F1. In all plant parts of tomato, silicon supply markedly increased total cell wall silicon content, as shown by the increase in F1. The silicon content of F2 was higher with than without silicon addition. The absorption bands of infrared spectroscopy of F1 from roots of rice plant by silicon addition showed a shoulder at 940 cm^{-1} and an increase in intensity at 465 cm^{-1}, indicating an association of Si-O with $–CH_2$-CH_2-, and the existence of silicon, respectively. These results suggest that the later growth of rice straw and curling of tomato leaves as a result of silicon deficiency may be due to insufficient formation of primary cell wall, pectin and lignin, and that silicon absorbed during plant growth accumulates in F1, binding with organic compounds.

Key words: Cell wall, Lignin, Pectin, Plants, Silicon.

Effect of silicon application on preseasonal sugarcane in an inceptisol

Jagtap JB [1], Rathod PK [1], Mote PU [1], Thorat SB [2]

1.Krishi Vigyan Kendra, Kalwade, Dist. Satara-415110,

2.*Vedant Agrotech, 221Mahalaxmi Market, Market Yard,*

Pune 411037, India

Email: vedantagro@yahoo.com

Abstract

Six field demonstration trials were conducted on preseasonal sugarcane (cv.86032, October-November planting) at Shere in Satara District of Maharashtra during the year 2009-2010. The soil was Inceptisol (Vertic Ustropept). There were two treatments viz., 0 and 400 kg ha^{1} silica applied through calcium silicate (48 % silica). Recommended levels of NPK fertilizers were applied to both the plots (N 250 kg ha^{1}, P_2O_5 115 kg ha^{1} and K_2O 115 kg ha^{1}, respectively). Diameter and weight of canes and sugarcane yields were recorded at harvest.

Application of 400 kg ha^{1} silica increased cane yields from 123 Mg ha^{1} (without silica) to 153 Mg ha^{1} (with silica). The cane yield increase was 30 Mg ha^{1} by application of 400 kg ha^{1} silica. This increase in sugarcane yield was due to increase in average cane weight (from 1.280 to 1.480 kg) and diameter of cane (from 8.25 to 9.43 cm) as result of silica application. It was noted that silica application also reduced attack of stem borer, wooly aphids and leaf freckling in sugarcane. The benefit / cost ratio was found to be increased from 2.71 to 3.03 as a result of silica application. It can be concluded that 400 kg ha^{1} silica applications are beneficial for sustainable sugarcane yield production.

Keywords: Calcium silicate, Preseasonal sugarcane, Sugarcane yield.

Improvement of crop quality by silicon fertilizers: Effects and its possible mechanisms

Jia JX

Bureau of Science and Technology, Jiaxiang County, Shandong Province, Jiaxiang 272400 Shandong, P.R. China.

Email: jxkjzxs@163.com

Abstract

The article summarized the effect of silicon fertilizer on quality improvement in 13 crop species. The percentages of brown rice and polished rice were improved after application of silicon fertilizers, and the quality of rice was upgraded by 1-2 levels. The inner quality of tobacco was enhanced. The sugar contents of sugarcane, apple, grape, watermelon, strawberry, scallion etc. were increased. The hardness and antistress abilities of apple, grape and tomato were improved. The contents of vitamin C in nectarine, strawberry, aubergine and celery were increased. Protein contents in nectarine and scallion were upgraded. The soluble solids in the petiole of strawberry, aubergine and greenhouse celery were raised, whereas nitrate content of greenhouse celery was decreased. The possible mechanisms of silicon-improved crop quality were analyzed intensively in the present paper in the following aspects: acquisition of silicon and other trace elements, harmonization of nutrition provision, enhancement of resistance to stressful conditions. Finally, the research perspectives were also discussed on agricultural application of silicon fertilizers and silicon-enhancement of crop quality.

New progress in silicon-improvement of quality of crops

Jia JX [1], Cai DL [2], Liu ZM [3]

1.Bureau of Science and Technology, Jiaxiang County, Shandong Province, Jiaxiang 272400 Shandong, P.R. China,

2.Institute of Geography, Academy of Sciences of Henan Province, Zhengzhou, China,

3.Shengyuan Bio-fertilizer Company, Jinin, Shandong Province, China

Abstract

This article summarized the effects of silicon fertilizer on silicon-improvement of quality in 20 crop species according to filed trials and reference. After application of silicon fertilizers, the rates of brown rice and polished rice were improved, the inner quality of tobacco was enhanced, and the sugar contents of sugarcane and grape were increased. Silicon fertilizer could enhance hardness and pressure-resistance of apple, grape and tomato, and increase vitamin C of nectarine, strawberry, eggplant and celery. Silicon fertilizer could increase protein content of nectarine and scallion, soluble solids of strawberry, eggplant and greenhouse celery, and reduce nitrate content of greenhouse celery. The possible mechanisms of silicon-improvement of crop quality were analyzed in the present paper and summarized in the following aspects: silicon provision, improvement of micro-nutrient supply, coordination of nutrition supply and enhancement of resistance to stressful conditions. Finally, the research perspectives were also discussed on trends of silicon fertilizer for improving crop quality and silicon fertilizer application.

Key words: Crops, Silicon fertilizer, Quality.

The silicon: nitrogen interaction in relation to infestations of the stalk borer, *Eldana saccharina*, in sugarcane

Keeping MG, Miles N, Sewpersad C, Sithole S

South African Sugarcane Research Institute, Private Bag X02, Mount Edgecombe 4300, KwaZulu-Natal, South Africa;
e-mail: malcolm.keeping@sugar.org.za

Abstract

The stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) is a major limiting factor in South African sugarcane production. One option to reduce the intensity of borer infestations has involved a reduction in nitrogen (N) fertiliser applications, according to soil type and other growing conditions. However, soil amendments with silicon (Si), where this element is deficient, can significantly increase plant resistance to *E. saccharina* and mitigate the effects of high plant N levels in promoting borer damage. More recently, we tested the independent and interactive effects of these nutrients, in combination with resistant (N33) and susceptible (N27) cultivars, on *E. saccharina* infestation and stalk damage. A pot trial was established with three levels of N, two levels of Si (5 t/ha, 10 t/ha calcium silicate), and two levels of dolomitic lime (5 t/ha, 10 t/ha) as controls. The mass of washed river sand in which the plants were grown was 31 kg/pot and N was supplied in solution at rates of 4.5, 8.9 and 16.6 g/pot every 2 weeks, to provide the three N levels. The trial was artificially infested with *E. saccharina* eggs and survival of and stalk damage due to emerging larvae assessed after 2 months. Overall, increasing levels of N significantly increased larval survival, percentage internodes bored and percentage stalk length bored, while calcium silicate at both application rates significantly reduced these compared with lime at both rates. A significant interaction between cultivar and N revealed that increasing N did not significantly affect larval survival in N27, but did increase it in N33. The interaction between cultivar and Si for percentage joints bored and percentage stalk length bored showed that Si significantly reduced stalk damage in N27 but did not do so in N33. This supports previously published observations that Si provides relatively greater protection for susceptible cultivars (particularly when water stressed) than for resistant cultivars. The reduction in borer survival and stalk damage through Si application, at all levels of N, and in a

susceptible variety, holds promise that under field conditions, sugarcane yields could still be optimised through adequate N fertilisation, while reducing populations of *E. saccharina* to acceptable levels using an integrated pest management (IPM) approach that incorporates Si nutrition of the crop.

Leaf silicification, covariations with minerals concentrations and forage value of three tropical miscellaneous species from sudanian Benin

Kindomihou V [1, 2,*], Téka OS [1], Adjolohoun S [2], Holou RAY [1, 3], Houessou L [1], Dagbénonbakin G [4], Agbangba EC [5], Gruber W [6], Adandédjan C [2], Sinsin B [1], Lejoly J [7], Meerts P [6]

1. Laboratoire d'Ecologie Appliquée, Faculté des Sciences Agronomiques, UAC.

2.Laboratoire de Recherche Avicole et Zoo-économie, Faculté des Sciences Agronomiques, UAC.
3.Mosanto, 67760 US 131, Constantine, MI, USA.
4.Institut National des Recherches Agricoles du Bénin, CRA-RCF, Cotonou, Bénin.
5.Laboratoire des Sciences du sol, Faculté d'Agronomie, Université de Parakou, Bénin.
6.Laboratoire d'Ecologie végétale et de Biogéochimie, Faculté des Sciences, CP244, Boulevard du Triomphe, 1050 Bruxelles, ULB, Belgique.
7. Herbarium de l'ULB, CP 169, 50 Avenue F. Roosevelt, 1050 Bruxelles – Belgique.
**E-mail:kindomihou@gmail.com;*

Abstract

Miscellaneous species, as the third forage resources (apart from gramineous and legumes), highly contribute to herbivorous feeding in tropics. The present study examine mineral profile, forage value and covariations with silica concentration to state on their silicification pattern in relation with nutritive performance. Eight traits (mineral: 7; fodder value: 1) were analyzed for 3 species (*Sida rhombifolia, Spermacoce stachydea* and *Spermacoce quadrisulcata)* grown in native sudanian conditions. Leaves were sampled in 3 replications on individuals' shrubs among the native pastures around the Sota forest (Gogbèdè-Kandi) in July, August and October 2003. Silica and ashes concentrations were dry way analyzed, N by Kjeldahl and the other (Na, Ca, P, K, and Mg) by spectrophotometer (Belgium). Digestible Nitrogen Matter (MAd) was calculated using Demarquilly formula. Effects of species and season were tested by a 2-way ANOVA. Correlations were analyzed using Pearson correlation at 5%. Results showed SiO_2 concentration ranging from 0.53 to 7.24% DM depending on species. *Spermacoce quadrisulcata showed* the highest SiO_2

concentration and *Sida rhombifolia*, the lowest. The higher value with *S. quadrisulcata* reflects an ability to actively accumulate silicon, which was particularly known for some gramineous (rice, bamboo) and *Stereospermum kunthianum* (Bignoniaceae). Interaction species*season is highly significant. The most silicified species (i.e. *S. quadrisulcata*) showed the lowest and the highest K concentration depending on season (1.65 vs 3.71% DM), the lowest Ca, Mg, P and N concentrations. *S. rhombifolia* expressed higher concentrations for N (1.31% DM), Ca (1.76% DM) and MAd (40.42 g/kg DM) early in the season, but the lowest Na concentration (67 ppm). Na concentrations are the lowest in August. These results showed that mineral accumulation is season and species dependant. SiO_2 is positively correlated to P ($R_{SiO2/P}$= 0.518; p=0.006) and Mg ($R_{SiO2/Mg}$= 0.594; p=0.001) but negatively to Ca ($R_{SiO2/K}$=-0.592; p=0.001). Globally, these results indicate that silica accumulation pattern should be similar to those of P and Mg, while antagonist to Ca. The positive correlation between SiO_2 and P at the only pooling stage suggests that silica concentration pattern is complex with tropical miscellaneous species. No correlation appeared between SiO_2 and N and MAd, making inconclusive the relationship between silicification and nutritive value. Further studies are needed to analyze SiO_2 correlation with organic structural compounds for a well characterization of tropical miscellaneous species silicification and modelling their nutritive performances.

Key words: Benin, Forage value, Miscellaneous species, Mineral, Silica accumulation, Sudanian.

Cationic resin and plant bioassays to assess suitability of silicated fertilisers

Kingston G

Sugron Pty Ltd – Queensland Australia

Email: sugronomo@gmail.com

Introduction

A wide range of products have been marketed as silicon fertilisers, but there is large variation in their capacity to release agriculturally significant quantities of mono-silicic acid for uptake by plants. Ma and Takahashi (2002) noted that a standard was established in 1955 in Japan for blast furnace slag as a calcium silicate fertiliser. The product was required to contain more than 20% soluble SiO_2 when extracted with 0.5 N HCl. Products assayed by this method did not always correlate well with Si uptake by rice (Takahashi 2002). Thus the range chemical methods have since been proposed to index the suitability of a silicated material for use as silicon fertilisers. Ammonium acetate (0.5 M) was used by Bair (1996); amberlite resin (Kato and Owa (1990); Na_2CO_3 (0.3 M) + NH_4NO_3 (0.2 M), Pereira *et al.* (2003); 0.01 M $CaCl_2$, water and water + resin (Berthelsen *et al.* 2003). The latter authors concluded there was no proven or reliable method that indexed silicon availability across all sources, but the Amberlite resin method of Kato and Owa (1990) did give best correlations with silicon levels in rice plant bioassays and mono-silicic acid in soils.

This paper reports on application of the resin solubility method of to a range of products of potential interest as silicon fertilisers for the Australian sugar industry and the impact of particle size on release of mono-silicic acid to enable derivation of a raw product solubility ranking, based on the weighted solubility of the separate size fractions. Several products were also assessed with rice and sugarcane bioassays

Methods

Silicated materials were screened into <105, 105-250, 250-500, 500-1000, 1000-2000 and >2000 µ fractions to determine particle size distribution. The Kato and Owa (1990) method as modified by Furukawa and Tomita (2002) was applied to the <105µ fraction, as it is not possible to select a representative 0.2 g sample of a raw product Amberlite FPC3500 resin was used in place of IRC-50 as the latter is no longer available. Aliquots were extracted for analysis of mono-silicic acid at 48 hours and 8 weeks after the initial mixing and analysed for soluble silicon.

Materials shown in Table 1 were subjected to the resin solubility and / or bioassay tests with rice and sugarcane.

Table 1 Materials subjected water solubility testing in the presence of Amberlite FPC3500 resin and solubility results

Product	Si%	Soluble Si (mg/kg)		% Soluble at 8 wks
		48 hours	8 weeks	
Thermo-phosphate**	12.2	112845	150012	100
Water cooled calcium silicate slag (Sunstate average)	15.4	45996	108188	70.3
Water cooled calcium silicate slag (Cement Australia)	19.2	57333	104500	54.4
Air cooled blast furnace slag (ACBFS) **	18.4	41183	98000	53.3
Water cooled calcium silicate slag _IPL	16	41067	73368	45.9
Water cooled calcium silicate slag (Port Kembla)	17.5	47300	64403	37.9
Miriwinni geologic calcium silicate & limestone *	9.8	9200	64300	65.6
Water cooled calcium silicate slag _IPL (raw material)***	16	8064	+-	
Silica Gel *	46.7	ND	18800	4.0
Diatomaceous earth (DE) **	32.4	ND	8867	2.7
Crushed rock product (Natramin)**	25.0	ND	5883	2.4
Composted sugar mill filter mud	24.4	1433	4182	1.7
Potassium silicate (pyrophyllite - biotite mica)	21	2903	3250	1.5
Amorphous silicon product 1	32.4	ND	1788	0.6
Amorphous silicon product 2* (MaxSil 2)	46	ND	1750	0.4

Where * material also subjected to a rice bioassay, ** denotes materials also in rice and sugarcane bioassay and *** also in sugarcane bioassay only; ND= Not detectable; + available mid-April.

For the rice bioassay, silicated products (as supplied) were applied and mixed with dry and silicon deficient soil (Haysom and Chapman, 1975) at the rate of 736 kg Si/ha, equivalent to the silicon supplied from 4 t/ha of air cooled blast furnace slag. Each bulk soil sample was moistened to field capacity and incubated at 25°C for 50 days before rice was planted in duplicate 0.13 m diameter pots, with four replications of each treatment. Four rice plants per pot were allowed to grow for 68 days after which a harvest was conducted for determination of above ground biomas and its Si%.

Replicated field experiments for the sugarcane bioassay were conducted in silicon deficient soil where silicated products were broadcast on the soil surface at rates indicated in Figure 1 and incorporated in the surface 20cm of soil with either a rotary hoe or disc harrows. Leaf samples were taken from the top-visible dewlap leaf during the peak growth period and were analysed for silicon.

Results and discussion

Resin solubility

Data in Table 1 clearly show the silicon content of products was not an indicator of the release of mono-silicic acid at 48 hours or at 8 weeks. In fact there was no detectable release of soluble silicon from silica gel, diatomaceous earth (DE), crushed rock and amorphous silicon products at the 48 hour sampling. Soluble silicon extracted from the silica gel at 8 weeks represented only 4% of its total silicon content.

Naturally occurring silicate minerals in the crushed rock and phyophyllite had much lower solubility than the wollastonite in the Miriwinni calcium silicate – limestone mixture. Thermo-phosphate is a manufactured silicate-phosphate fertiliser and showed the highest solubility of all materials tested. This material returned 91% solubility in the 48 hour aliquot and 100% at 8 weeks (note the resin solubility of 150,012 mg Si/kg at 8 weeks in Table 1 exceeds the “typical analysis” supplied by the manufacturer). Calcium silicate blast furnace slags, either air or water cooled, were the next most soluble group of materials, with most samples returning 38-54% solubility by 8 weeks, which is in close agreement with data published by Furukawa and Tomita (2002). While there was some variation between the 8 week solubility results of the various water quenched slags, solubility of water and air cooled materials was similar.

There was a clear and expected impact of particle size on the solubility of silicon in the non-milled water cooled slag (Table 2). The whole product 48 hour solubility index, based on the weighted average of the various size fractions, suggests this 16% silicon material without additional milling might release similar quantities of silicon to the Miriwinni calcium silicate / limestone mixture that contained only 9.8% silicon (8 week data will be available 20th April). This type of assessment was explored as the additional cost of grinding slag to meet particle size distributions similar to those for agricultural limestone or for slag (Owa (2002), makes the cost of very unattractive to Australian growers of sugarcane. Results in Figure 3 confirm the lower release of plant available silicon from this material.

Table 2 Impact of particle size on release of soluble silicon from water cooled blast furnace slag and a whole product solubility estimate

Particle size	% by weight	Si (mg/kg)	
		48 hours	8 weeks
<105µ	0.71	38600	Avail April
105-250µ	3.65	19500	
250-500µ	10.23	12483	
500-1000µ	32.38	8433	
1000-2000µ	45.44	6100	
>2000µ	7.6	3925	
Weighted av.	-	8064	

Bioassays

The rice bioassay showed that only air cooled blast furnace slag (ACBFS) had a significant impact on elevating the Si% in rice biomass above that of the untreated control (Table 3). Regression of Si% in biomass on the 48 hour and 8 week resin soluble silicon produced coefficients of determination of 0.88 and 0.96, respectively. Similarly only the air cooled blast furnace slag produced more biomass than the untreated control, indicating that the resin solubility provided a good index of plant available silicon.

Table 3 Silicon content of rice biomass at 68 days after planting

Treatment	Silicon in biomass	
	Si%	Homogeneous groups
ACBFS @ 4 t/ha	0.92	A
DE_1 @ 2.27 t/ha	0.18	B

Amorphous Si_2 @ 1.6 t/ha	0.16	B
Untreated control	0.14	B
Amorphous Si_1. Si @ 2.27 t/ha	0.20	B
P value		0.01

Means followed by the same letter are not significantly different (p=0.01)

Bioassays were conducted across three field experiments with sugarcane to examine availability of silicon from milled air cooled blast furnace slag (CalSil), non-milled ground granulated blast furnace slag (GGBFS), Cement, diatomaceous earth (DE), a geologic calcium silicate / limestone mixture, a crushed rock product and a thermophosphate. There was a non-significant trend (r^2=0.40) to response in leaf silicon in relation to the quantum of soluble silicon (% solubility x application rate) indicated by the 8 week resin test for those products subjected to both the resin solubility test and the field bioassay.

The field experiment that included diatomaceous earth, non-milled GGBFS, CalSil and Cement (Figure 1) clearly demonstrated the non-availability of silicon in diatomaceous earth and that coarser particles in the GGBFS did not have a significant effect on leaf silicon status until the third crop (second ratoon).

Conclusion

The cationic Amberlite resin test for solubility of silicated products allows materials to be ranked in order of capacity to supply plant available silicon to both rice and sugarcane. Replication within assessments and across time has demonstrated the repeatability of the test. The test was applicable across a range of materials including calcium silicate slags, naturally occurring silicates in rocks, micas, wollastonite, diatomaceous earths and manufactured thermophosphate. The weakly acidic resin provides an environment somewhat similar to that found in soils and the adsorption of dissolved calcium and magnesium prevents later precipitation of cationic silicates. The resin solubility test can be completed in as little as 8 weeks and is much cheaper than pot or field bioassay tests.

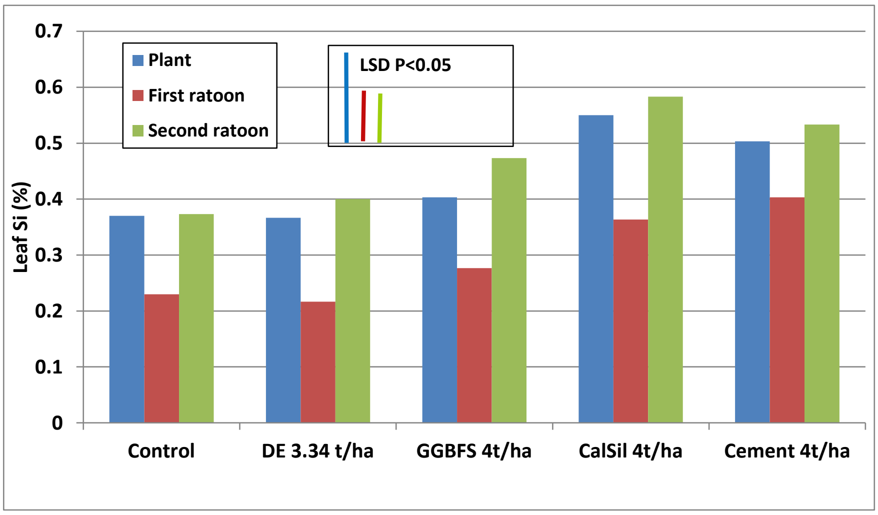

Figure. 1 Leaf silicon % for three field grown crops of sugarcane in relation to unamended soil and three silicated materials

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Silicon testing, silicon fertilizer manufacturing techniques and standards

Korndörfer GH *, Pereira HS *

Universidade Federal de Uberlândia (UFU), Instituto de Ciências Agrária (ICIAG), Uberlândia - Brazil. CNPq felowship.

Introduction

Silicon helps plants to overcome various abiotic and biotic stresses. In the field where plants are constantly exposed to different stresses, especially in soils that are deemed to be low or limiting in plant available silicon, the awareness of silicon deficiency in soil has become recognized as being a limiting factor for crop production.

Although silicon still is not recognized as an essential element for plant growth, its beneficial effects on growth, development, yield and disease resistance have been observed in a wide variety of plant species and countries.

Recently, Si has become globally important because it may contribute to reduced rates of application of pesticides and fungicides. Silicon is also now considered as an environment-friendly element. Research on the importance of silicon (Si) nutrition in plants to promote plant growth and development have been reported in a number of countries including Australia, Brazil, India, China, Japan, Mauritius, Puerto Rico, South Africa, Taiwan and the United States of America (Datnoff et al., 2001).

Silicon fertilizer testing

Silicon (Si) is abundant in nature, and as such, the total silicon content of soils, plants and materials suitable for use as soil amendments for agricultural purposes, can be high. Therefore, to develop recommendations for field applications of silicate materials, knowledge of the soil Si status and the availability of Si in the amendment are essential.

Unfortunately selecting a suitable silicate materials and assessing it efficacy is difficult. While a number of chemical extractants methods have been used to estimate both total and soluble Si in silicate materials, often the results obtained do not correlate well with plant uptake of Si, once the material is applied to the soil.

In addition to the effect on particle size on solubility, other chemical characteristics of the material such as pH, molar ratio of CaO: SiO_2 have been shown to influence Si availability (Ma and Takahashi, 2002). Once a product is added to the soil, soil chemical reactions, for example, the increase in soil pH due to the dissolution of Ca and Mg from the material can further influence the solubility and hence availability of Si (Ma and Takahashi, 2002). Consequently, it is possible that there is not a universal extractant that is suitable for determining available Si that will cover all types of materials, and for all soils and soil conditions (Gascho, 2001).

Currently in Brazil, as has been established for micronutrients [copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), boron (B), chloride (Cl), and molybdenum (Mo)], the guaranteed Si content in fertilizers is expressed according to its total elemental content. However, this approach may be inadequate in expressing the plant available Si content of a fertilizer. For example, many Si-containing industrial by-products (slag) have been used as Si fertilizers, but there exists a high variation in the composition and availability of Si from these materials to the plant (Datnoff et al., 2001; Ma and Takahashi, 2002). Takahashi (1981) determined that the availability of Si to plants was greater from Si slag that had been cooled slowly compared with slag that were more rapidly cooled in water. The availability of Si was also shown to increase with decreasing granular size of the material (Takahashi, 1981; Datnoff et al., 1992).

In Japan, evaluation of available Si from slag has been done using hydrochloric acid (HCl 0.5N) (NIAES, 1987). However, this extraction method tends to over- or under-estimate the amount of Si that is available to the plant. Other acid extractors, such as citric acid, acetic acid, and the acetate of ammonium buffered to pH 4.0, were also found to be inefficient in accurately estimating plant available Si (Takahashi, 1981; Kato and Owa, 1997). Kato and Owa (1997) suggested using the cation-exchange resin as an extraction method might be superior to past methods for estimating plant available Si from fertilizers.

Another method that had a high correlation between the amount of Si supplied by the source and the amount of the element absorbed by the plant was the leaching column method (Snyder et al., 2001). However, this method only provides an estimate of which source will provide the greatest amount of plant available Si in a short period of time and does not quantify the percent plant available Si in fertilizers. In the US, some products are marketed as being reliable sources of plant available Si. However, no official method exists for guaranteeing that these materials will supply plant available Si to plants.

Berthelsen *et al.* (2003) compared the effectiveness of a number of chemical extraction methods described in the literature on a diverse selection of silicate materials (including calcium silicate slag, cement, wollastonite, olivine, diatomaceous earth, fly ash and filter cake scrubber waste). These same materials were then compared through indirect chemical extraction after soil incubation, and then an assessment of plant Si uptake and changes in soil Si status was undertaken following glasshouse pot studies. This series of experiments indicated that the extraction method developed by Kato and Owa (1997), using the addition of a weakly acidic cation exchange resin in the H+ form (Amberlite IRC-50) to the extraction medium, provided the best indicator of plant-available Si, which correlated well with both the indirect chemical extraction results and also soil and plant Si and yield when the materials were used in the glasshouse pot studies. These results are supported by recent work by Pereira *et al*. (2003) who compared a similar range of extraction methods and tested them against 12 different sources of Si material and also found a high correlation with Si content and Si uptake in rice using this 'resin' method.

Buck *et al.* (2011), using ten different Si sources [Wollastonite W10; calcium silicate slag from US; calcium silicate from Canada; magnesium silicate; Excellerator; silican gel; 00-00-12 and three types of potassium silicate with different concentrations in the liquid form, K53; K120 and AgSilTM25] and seven extracted methods: hydrochloric acid (HCl) plus hydrofluoric acid (HF) extraction, leaching column; sodium carbonate (Na_2CO_3 –10 g L^{-1}) + ammonium nitrate (NH_4NO_3 –16 g L^{-1}); citric acid (50 g dm^{-3} or 5%); hydrochloric acid (0.5 N); neutral ammonium citrate (NAC); and resin (Amberlite IRC-50, pK 6.1), concluded that based on the correlation coefficients, the best extractor for available Si in solid fertilizer was determined to be Na_2CO_3 + NH_4NO_3 (Figure 1), while for liquid fertilizers, the total Si (HCl + HF) was found to be the best. Consequently, regulatory agencies in USA now have two extractors for estimating the plant available Si from fertilizers depending on the physical property of the material (solid or liquid).

Using these same sources Pereira et al. (unpublished) proposed an evolution of the method by adding EDTA and the use of autoclave. The results showed a higher correlation with the silicon absorbed by plants, nearly tripled the Si extraction of sources, demonstrating the high capacity of the extractor. Evaluating other variations of this method with the application of the autoclave in 19 Si sources applied in sandy soil Pereira et al. (unpublished) confirmed the results showed in Figure 2.

As various forms of calcium silicate materials are the most widely used Si fertilizer, most proposed methods are based on estimating available Si from this source. Other silicate materials may possibly behave quite differently. Whatever method is used, it is important to keep a wide product to solution ratio, to keep the concentration of monosilicic acid low and prevent polmerization from occurring. In addition, as generally Si availability increases with decreasing particle size, it is important to define and standardize particle size when attempting to determine their reactivity and Si availability.

Therefore, methods to quantify plant available silicon (Si) from Si-based slag for use as fertilizers are not well defined. Although it is possible to estimate total Si from a potential Si fertilizer source, this approach does not represent how much Si is available for uptake by the plant.

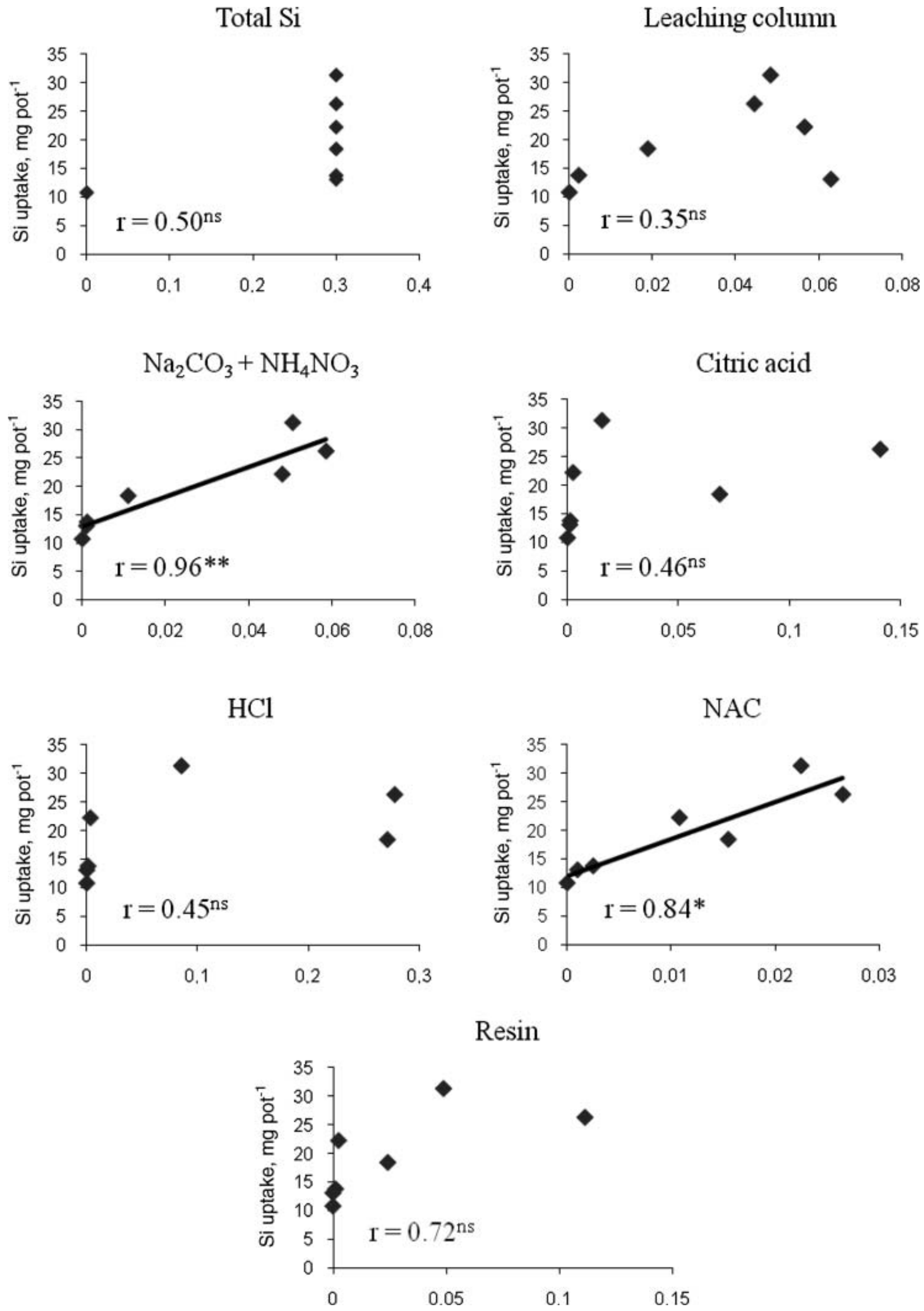

FIGURE. 1 Relationship between Si uptake in *Poa trivialis* and soluble Si added in the soil from solid fertilizers by each extractor. ns, $*$, $**$ = non-significant, significant at 1% and 5%, respectively.

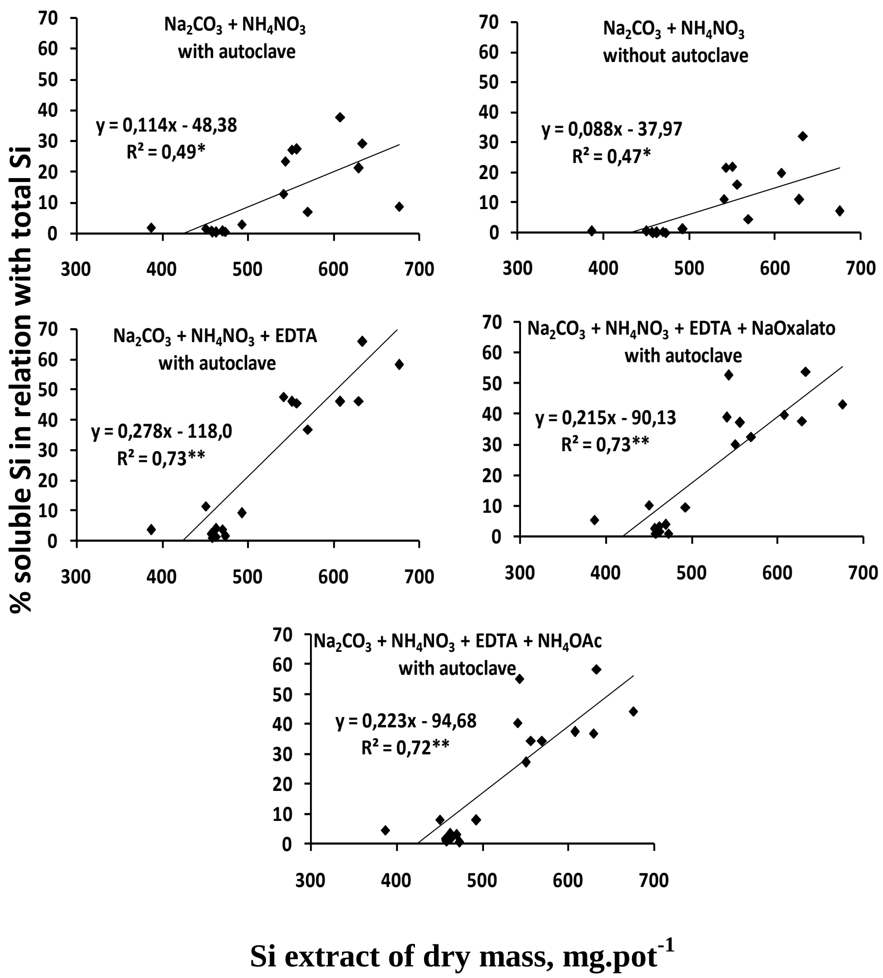

FIGURE. 2 Correlation between Si extract of dry mass and percentage of soluble Si in relation with total Si of the sources. ns, ∗, ∗∗ = non-significant, significant at 1% and 5%, respectively.

Silicon fertilizer manufacturing

The number of suppliers of silicon-based fertilizer products is not very big and most of them have a national, sometimes regional marketing approach.

There are many types of silicate materials suitable for use as soil amendments/fertilizers, however, their effectiveness is more dependent on their reactivity rather than total Si content. An excellent review of sources suitable for agriculture is provided by Gascho (2001). As mentioned plant material can have high concentrations of Si, and crop residues (e.g. rice hulls and sugar mill wastes) are commonly used, although high rates are usually necessary. There are a few naturally occurring mineral materials, such as wollastonite ($CaSiO_3$), olivine ($MgSiO_3$) and diatomaceous earth, which can have total silicon contents of approximately 55%, 30% and >70% SiO_2 respectively, but often availability limits their potential use. By far the most common forms of silicate materials used as soil amendments are various industrial by-products, for example, slag from iron steel production (calcium silicate slag) and a by-product from the production of elemental phosphorus.

The metallurgy slag is basically composed of calcium and magnesium silicates. So long as they do not contain heavy metals in their composition, they can satisfactorily meet the requirements of a good Si source for agricultural use, such as: high soluble Si content, easy mechanized application, balanced ratios and amounts of calcium (Ca) and magnesium (Mg), low cost, and low soil contamination potential with heavy metals (Korndorfer *et al.*, 2004a).

Considering that part of Si absorbed/accumulated by plants comes from the soil and another part comes from Si applied in the form of fertilizer, it is necessary to evaluate varietal differences with regard to Si absorption and the amount of accumulated Si in the above-ground part that is derived from metallurgy slag.

According to Sousa & Korndörfer (2010) in a randomized experimental design with eight treatments (0, 100, 200 and 400 kg ha^{-1} Si, and two cultivars of sugarcane: SP81-3250 and RB86-7515) the application of metallurgy slag increased the amount of Si available in the soil and result in a larger accumulation of Si in the sugarcane plants. The silicon mean recovery from slag (mean of two sugarcane cultivars) was 39.4%, varying from 22.9 to 55.8% depending on the Si rate used (FIGURE 2). Cultivar SP81-3250 had the highest Si recovery capacity (Recovery Index equal to 55.8%), which means that of all absorbed Si more than one half came from the fertilizer. The variety SP81-3250 showed a greater capacity of utilizing Si from the fertilizer (slag) when compared with variety RB86-7515.

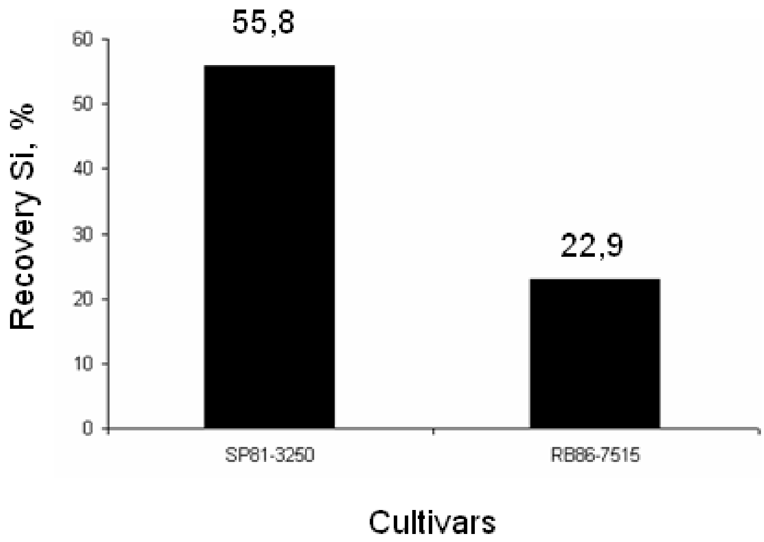

FIGURE. 2 Silicon recovered from the fertilizer by two sugarcane cultivars.

Si fertilizer standards

Silicon sources vary around the world. For example, in Japan, steel mill waste is the most important, while in the United States, waste from elementary phosphorus manufacturing is used, and in Brazil the source with the greatest potential for increased crop quality and yield has yet to be identified.

In the US, some products are marketed as being reliable sources of plant available Si. However, no official method exists for guaranteeing that these materials will supply plant available Si to plants. As the demand for Si in the agricultural market grows, it is necessary to establish reliable methods of Si analyses of fertilizers so that they can be approved by the Association of Official Analytical Chemists (AOAC International) and Association of American Plant Food Control officials (AAPFCO). Once approved, companies marketing these fertilizers can establish and maintain quality control of their products.

In Brazil, the soil incubation test of fertilizers containing Si is to determine the potential reactivity and release rate of Si, Ca and Mg, from silicate materials. The incubation is done at two different soil types, clay (> 60% clay) and sandy (<15% clay). The soils receive increasing doses of Si (0, 100, 200, 400 and 600 kg ha^{-1} Si) from a source considered a Si standard (Wollastonite).

The sources of Si to be tested are characterized according to their total Si contents, and according to methodology described by Korndörfer et. al. (2004, a). Before running the incubation test, the products (fertilizers containing Si) should be milled to pass 100% on 50 mesh sieve (mesh/inch). After that, the sources of Si and

Wollastonite are mixed with 300g of dry soil, inside a plastic bag (Figure 1). The soil should be placed in plastic containers (Figure 2) and distilled water to 80% of water holding capacity should be added (Figures 2 and 3).

FIGURE 1. Mixing the soil and the Si source in a plastic bag

FIGURE 2. Water added to plastic containers with soil

FIGURE 3. Soil incubated in plastic containers capped.

After 60 days of reaction (incubation period) soluble Si in soil with $CaCl_2$ 0.01 mol L^{-1} extractor is determined, according to methodology described by Korndörfer et al. (2004).

After completing the laboratory procedure for Si in the soil the equivalent in calcium silicate (Eq.SiCa) is calculated based on the formula below. The calculation of Eq SiCa (%) should be done individually for each soil type (clay and sandy).

$$\mathbf{Eq.SiCa\ (\%)} = \frac{\sum [(Xf200 - Xt) + (Xf400 - Xt)]}{\sum [(Xw200 - Xt) + (Xw400 - Xt)]} \times 100$$

Where:

Xf200 = Si content in the soil from the Si source in the test – rate of 200 kg ha^{-1} of Si

Xf400 = Si content in the soil from the Si source in the test – rate of 400 kg ha^{-1} of Si

Xw200 = Si content in the soil of wollastonite ($CaSiO_3$) - rate of 200 kg ha^{-1} of Si

Xw400 = Si content in the soil of wollastonite ($CaSiO_3$) - rate of 200 kg ha^{-1} of Si

Xt = Si content in the soil of the control (corresponding to the soil content used without Si application).

Si-containing fertilizers that reach Eq.SiCa value of less than 45%, calculated with the formula specified above in each of the soils (sandy and clay) simultaneously, will be able to get certification from the Agriculture Department to commercialize legally and does not need to be submitted to any other biological or agronomic test.

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Foliar silicic acid technology for plants

Laane HM

SiLife Ltd, the Netherlands

Abstract

The importance of silicon for living organisms is still underestimated although a growing number of publications showing the beneficial effects on plants. Nevertheless up till now silicon deficiency in plants is supposed to be 'a limited problem'. For example in the Rice Knowledge Bank of the IRRI (International Rice Research Institute) the symptoms and effects of silicon deficiency are mentioned: "not very common in irrigated rice".

This view is based on the presence of large quantities of SiO_2 & silicates in most soils. Nevertheless most plants do have '*a silicon problem'*. This deficiency is the result of the inadequate uptake of bioavailable silicic acid despite the quantities of silicon in the soil.

The reasons for this plant silicon deficiency problem are:

1. Plants need silicic acid and not 'silicon';
2. Transformation from silicates and SiO_2 into silicic acid is a (very) limited process;
3. The concentration of (mono) silicic acid (= SA) in the soil is very low;
4. Moreover silicic acid is an instable molecule with high tendency to aggregate/polymerize;
5. Due to crop removal (harvesting) each year substantial amounts of 'silicon' are removed.

To overcome the problem of silicon deficiency so far silicates are used as fertilizers showing beneficial effects like higher yield and lower infection rate, but due to the restricted transformation into silicic acid the advantages of extra silicates are limited. This problem can be overcome nowadays by the use of concentrated, stabilized and bioavailable silicic acid. The invention of this product makes it possible to study the (direct) effects of silicic acid itself. To prove the hypothesis of 'the silicon deficiency in plants' trials with foliar stabilized and concentrated silicic acid and low dose boric acid ($OSAB_3^R$) were carried out on potatoes and onions in clay soil (with high silicon content) in a randomized block design with three replications (the Netherlands, 2003). $OSAB_3$ (0,9% concentrated silicic acid and 0,1% boric acid)

was diluted 250 times and 6 x sprayed during growth cycle. Compared with the conventional growth (with NPK, pesticides, etc.) the $OSAB_3$ sprayed potatoes and onions showed higher yields (6,3% and 4,5%). At the same time a significant reduction in infection rate was noticed. Also other crops were tested like rice (Panama, 2005) and papayas (Columbia, 2007). These crops showed similar effects like higher yields (10 - 19%) and significant lower infection rates.

In cooperation with the University of Karnataka, India, large scale scientific trials were started on rice, finger millet, tobacco, grapes and other crops (2006-2011). Application of 3-6 foliar sprays $OSAB_3$ (diluted 250 -500 times) significantly influences many growth and yield parameters over control (with NPK and normal quantities of pesticides). Also a significant reduction in infection rates was noticed.

The effect of foliar spray with $OSAB_3$ on grapes showed a significant increase of the uptake of nutrients (like Si, P, K, Ca and Bo) from the soil (compared to control).

Summary

The use of 3-6 foliar sprays with silicic and boric acid ($OSAB_3^R$) on plants shows that plants have a silicon deficiency. Since 2001 all tested crops (also in soils with high silicon content) showed significant increases in many growth and yield parameters and a reduction of infection rates.

This is due to a new physiological mechanism of silicic acid foliar sprays. The underlying mechanism of this ‘foliar silicic acid technology’ on plants needs more clarification.

Localization of Si on tissue level in rice, maize and wheat

Landberg T, Greger M

Department of Botany, Stockholm University, 106 91 Stockholm, SWEDEN

Abstract

Silicon is known to be beneficial in several plant genera, e.g. *Poaceae*. In Rice the Si content can reach 10 % of the plant dry weight and enhances the tolerance to a range of stresses. The aim of this study was to investigate pathways and final destination of Si in plants on the tissue level.

Three species, rice (*Oryza sativa*), maize (*Zea mays*) and wheat (*Triticum aestivum*), all from the *Poaceae* family, were cultivated in nutrient solution. At the 2 – 3 leaf stage plants were treated with different concentrations of Si (0 – 35 mM K_2SiO_3) for different time periods (30 min – 96 h). Stems and leaves were analyzed on Si using ESEM (energy-dispersive X-ray Scanning Electron Microscopy) on tissue surfaces and cross sections (at 80x – 2000x).

Silicon was mainly localized to silica bodies cells in epidermis that develops "scale"-like structures on the plant surfaces filled with Si and finally contained >99% SiO_2. These structures were deposited with Si during 4 – 12 h; the deposition rate decreased in the order rice > maize > wheat. The geometry pattern of the SiO_2-structures differed slightly between the species but they were all distributed as strings along the veins. In the other parts of the tissue, Si concentration was much lower e.g. after 72 h treatment with 5 mM about 1 % of the total element content in cell walls was Si. The Si was evenly distributed within the xylem, parenchyma and fiber cells. However, the Si level was 2-3 times higher in the phloem (sieve cells and companion cells). The role of phloem is unclear but the elevated Si-levels may indicate a translocation of Si in the phloem. The results suggest that *Poaceae* has a well-developed mechanism for translocating Si. Silicon is included in the cell wall in the whole tissue but is to the highest extent distributed to certain structures on the plant surface where it probably serves as protection against the environmental stressors.

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Silicate-mediated alleviation of Pb toxicity in banana grown in Pb contaminated soil*

Li LB, Zheng C, Shen H**

College of Resources and Environment, South China Agricultural University, Guangzhou, 510642

*** Corresponding author: hshen@scau.edu.cn*

Abstract

Silicate (Si) can enhance the plant resistance or tolerance to the toxicity of heavy metals. However, it remains unclear whether Si can ameliorate lead (Pb) toxicity in banana (*Musa xparadisiaca*) roots. In this study, treatment with 800 mg kg^{-1} Pb decreased both shoot and root weight of banana seedlings. The amendment of 800 mg kg^{-1} Si (sodium metasilicate, $Na_2SiO_3 \cdot 9H_2O$) to the Pb-contaminated soil enhanced banana biomass at two growth stages significantly. The amendment of 800 mg kg^{-1} Si significantly increased soil pH and decreased exchangeable Pb, thus reducing soil Pb availability, while Si addition of 100 mg kg^{-1} did not influence soil pH. Results from Pb fractionation analysis indicated that more Pb was in the forms of carbonate and residual-bound fractions in the Si-amended Pb-contaminated soils. The ratio of Pb-bound carbonate to the total Pb tended to increase with increasing growth stages. Treatment with 100 mg kg^{-1} Si had smaller effects on Pb forms in the Si-amended soils than that of 800 mg kg^{-1} Si. Pb treatment decreased the xylem sap greatly, but the addition of Si at both levels increased xylem sap and reduced Pb concentration in xylem sap significantly in the Si-amended Pb treatments. The addition of Si increased the activities of POD, SOD and CAT in banana roots by 14.2 to 72.1% in the Si-amended Pb treatments. The results suggested that Si-enhanced tolerance to Pb toxicity in banana seedlings was associated with Pb immobilization in the soils, the decrease of Pb transport from roots to shoots and Si-mediated detoxification of Pb in the plants.

Keywords: Banana seedling · Pb fractionation · Pb toxicity · Si alleviation · Xylem sap

Acknowledgement

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Silicon ameliorates manganese toxicity by regulating physiological processes and expression of genes related to photosynthesis in rice (*Oryza sativa* L.)

Li P [1,2], Song AL [1], Li ZJ [1], Fan FL [1], Liang YC [1*]

1.Ministry of Agriculture Key Laboratory of Crop Nutrition and Fertilization, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, P.R. China,

2.College of Agriculture, Shanxi Agricultural University, Taigu 030801, China

* Corresponding author: Prof. Yongchao Liang, Email: ycliang@caas.ac.cn

Abstract

The effect of silicon (Si) nutrition on chlorophyll (Chl) content, photosynthesis and the expression of genes involved in manganese (Mn) toxicity were investigated in hydroponically-grown rice seedlings to elucidate the possible physiological and molecular mechanisms of Si-mediated alleviation of excess Mn toxicity. Rice seedlings were cultured in modified Kimura B nutrient solution containing normal Mn (6.7 μM) and excess Mn (2 mM), respectively, both without or with supply of 1.5 mM Si. Influence of Mn and Si on photosynthesis in rice was studied by the measurement of gas exchange characteristics. The expression of genes was examined by quantitative reverse transcription-polymerase chain reaction (RT-PCR). The results showed that the contents of Chl a, Chl b, carotenoids and Chl 'a+b' were significantly decreased by excess Mn treatment, while they were significantly enhanced by addition of Si. Net photosynthesis (P_n) was seriously inhibited by excess Mn, but was significantly increased by Si. Our studies showed that a group of genes responsible for photosynthesis showed differential expression in rice under excess Mn treatment. Expression levels of *PsbP* and ATPase protein genes were significantly increased in plants treated with excess Mn, but were maintained either high levels or even higher levels in plants treated with both excess Mn and Si. In contrast, expression levels of *HemD, Lhcb,* pyrophosphatase, phosphoribulokinase and pyruvate kinase were significantly decreased under excess Mn, while the addition of Si significantly increased the expression level of these genes. Expression levels of *PsaH* was significantly increased by excess Mn, but was significantly reduced by Si. The results suggest that Mn-induced inhibition of photosynthesis can be attributed to the

inhibition of the chlorophyll biosynthesis and the light-harvesting process, the impaired stabilization of the structure of PSI, inhibition of ATP synthesis, and reduction of the acceptormolecule for CO_2 fixation of the Calvin cycle. Si apparently allows plants to more efficiently respond to Mn toxicity by increasing chlorophyll content, light-use-efficiency and ATP quantity, by stabilizing the structure of PSI, and promoting CO_2 assimilation. Our findings suggest a more active involvement of Si in Mn detoxification ranging from physiological responses to gene expression.

Key words: Manganese, Photosynthesis, Rice, Silicon.

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Effect of silicates on the physiology and toxicity of *Brassica Chinensis* under Cr and Pb stress

Li SY [1], Liao XR [1], Wang RP [1], Luo XL [2]

1.Guangdong Institute of Eco-environmental and Soil Science, Guangzhou, Guangdong, 510650,

2.Guangdong Institute of Eco- Science，510650

Abstract

Pb pollution in soil was very severe in Guangdong. Cr concentration was less than the background value in most soil, but it exceeded standard in suburb cultivated land. The situation of soil heavy metal pollution was threatenning the quality and safety of vegetable production in Guangdong. Aiming at optimization of manuring level of silicates and humic acid, pot experiments were carried out to study the effects of silicates and humic acid on growth and physiology of *Brassica Chinensis* which were growing up in Cr, Pb and Cr-Pb contaminated soil. The results indicated that, the inhibitory effect of silicates on toxicity of Cr-Pb pollution was better than humic acid's, and 1.0mg·kg^{-1} silicates has the best effect. That mass fraction of silicats could improve the growth of unpolluted *Brassica Chinensis*, and promote the SOD activity of *Brassica Chinensis* polluted by Cr-Pb, alleviate the damage of membrane lipid peroxidation of root's plasma membrane. While high level silicates (2.0mg · kg^{-1}) or interaction between Pb and high level silicates (above 1.5mg·kg^{-1}) would inhibit the growth. Humic acid could also promote SOD and POD activity in a certain degree, but its detoxification and promoting effect on growth were not significant.

Key words: *Brassica Chinensis*, Cr-Pb compounded pollution, Humic acid, Silicon.

Effect of silicon fertilizer on nutrition and yield of rice under the condition of iron and manganese stress

Li YY, Liu SQ, Ji JH, Tong YX, Liu Y, Zhang MY

Soil Fertilizer and Environment Resources Institute of Heilongjiang Academy of Agricultural Sciences, Harbin, 150086

Abstract

The result of pot experiment showed that silicon had a positive effect on the seedling quality, nutrient absorption and yield of rice under the condition of high iron and manganese stress. The indexes of seedling quality in the treatment without silicon application were worse, and the treatment of medium- and high-dose silicon application was best. The appropriate rate of silicon (SiO_2) application was 0.3~0.6 mg/kg. It is shown that the nutrient elements of rice plant and grain have been increased, using different concentrations of iron, manganese and silicon. When the soil is deficient in the element, be helpful for rice growing development. No silicon fertilizer or low quantity of the siliceous fertilizer affect the absorption of nitrogen, phosphor and potassium under the condition of high iron and manganese stress, thus affecting normal growth and development and yield. The yield in the combination treatment of high silicon, low iron and manganese application was increased by 15.2% and 3.4%, respectively over that of control. The yield in the treatment of high iron and manganese without silicon application was decreased by 72.7% over that of control. The yield in the treatment of low iron and manganese without silicon application was decreased by 20.5% over that of control. Under high iron and manganese stress with silicon application the yield increased by 20.5%~72.7%. The appropriate rate of silicon (SiO_2) application was 0.3~0.6 mg/kg. The field experiment showed that the optimum rate of silicon fertilizer for rice in Heilongjiang province was 450~900 kg/hm^2 and the yield increased by 840 kg/hm^2 and on the average, the yield increase was 11.4%.

Key words: Iron and manganese stress, Nutrition situation, Rice, Silicon fertilizer, Yield.

Effects of slag-based silicon fertilizers on the improvement of photosynthesis, growth and yield in rice

Li ZQ [1], Chu GX [1], Zhao YY [1], Ye J [1], Liu Q [1], Liang YC [1,2]*

1.Key Laboratory of Oasis Eco-Agriculture, College of Agriculture, Shihezi University, Shihezi 832003, P.R China,

2.Ministry of Agriculture Key Laboratory of Crop Nutrition and Fertilization, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, P.R. China.

**Corresponding author: Email: ycliang@caas.ac.cn*

Abstract

Furnace slag from iron & steel industries has been widely used in agriculture, especially in rice and sugarcane field in many countries including Southeast Asia, South and North America and Africa. Slag-based silicon fertilizers have been documented to improve soil physical conditions such as soil acidity and structure and to enhance the growth, yield and quality of crops. However, studies on slag-based fertilizers have been performed mainly in acidic soils in tropical and subtropical areas as slag-based fertilizers are basic with high pH. Information is still not available on the responses of crops grown in the calcareous soils to slag-based fertilizers. On the other hand, the efficacy of slag in promoting the growth and yield of crops depends on the types and application rates of slag used. In the present study pot experiments were conducted by amending both blast furnace slag and copper-nickle slag at varying rates to study their effects on rice photosynthesis, growth and yield in a desert grey soil in the arid region of Xinjiang, China. The results showed that soil pH value was increased from 8.05 to 8.18 by the application of blast furnace slag and from 8.05 to 8.31 by application of copper-nickle slag. Electrical conductivity (EC) was increased from 0.261 to 0.346 ms/cm by blast furnace slag and from 0.261 to 3.58 ms/cm by copper-nickle slag at the harvest stage of rice. The photosynthesis rate, transpiration rate and stomatal conductance were increased by the addition of slag at the flowering stage, but the intercellular CO_2 concentration was decreased. Soil available silicon content and silicon supplying capacity were increased by the slag-based fertilizers. Application of the slag-based fertilizers promoted silicon uptake by rice, and enhanced SiO_2 content in stem and leaves of rice at the harvest stage. Application of

both kinds of slag not only enhanced rice height, tiller number and shoot dry weight biomass, but also improved yield components including the weight per spike, 1000-grain weight and rough rice weight. However, it should be stressed that application of copper-nickle slag could increase the rice yield at lower application rates (i.e. 1.0 and 2.0 $g \cdot kg^{-1}$), but decrease the rice yield at higher application rates (i.e. 4.0 and 8.0 $g \cdot kg^{-1}$) due to copper toxicity caused by the high copper content in copper-nickle slag. To summarize, application of the slag-based silicon fertilizers could increase the productivity of rice in the calcareous soils. The mechanism of yield-increasing might contributed to more soil available silicon provided by the types of slag tested for rice uptake and the improved growth and photosynthetic parameters. However, the rice production was reduced at higher rates of copper-nickle slag, which needs further study in the future.

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The roles of silicon in agriculture---from laboratory to field

Liang YC *, Song AL, Li P, Sun WC, Xue GF, Li ZJ, Fan FL

Ministry of Agriculture Key Laboratory of Crop Nutrition and Fertilization, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China

** Corresponding author. Email: ycliang@caas.ac.cn*

Abstract

Although silicon (Si) is the second most abundant element both on the surface of the Earth’s crust and in soils, it has not yet been listed among the essential elements for higher plants. The beneficial role of Si in stimulating the growth and development, particularly in sustaining agriculture, has been well documented. Silicon is known to effectively mitigate various forms of abiotic stress such as salinity, drought, chilling, freezing, high temperature and UV radiation stresses and excess metal toxicities including aluminum, iron, manganese, cadmium, arsenic and zinc toxicity etc. and biotic stress such as fungal and bacterial diseases and pest damage. Silicon is also known to enhance the resistance to lodging in rice and wheat. Although numerous studies have been done aimed at understanding why and how Si enhances plant resistance to such biotic and abiotic stresses, the mechanisms underlying are still not fully understood. On the other hand, field application of Si fertilizer such as slag-based silicate fertilizers is a rather common agricultural practice in Southeast Asia, North and South America, Australia and Africa. Numerous field trials prove that silicon application to Si-deficient soils usually significantly increases crop yield and quality and improve environmental quality and health. More recently, rapid progress and great breakthrough have been made in understanding mechanisms of silicon uptake, transport and distribution in plants through isolating, cloning and functional analysis of a series of silicon-relevant genes in rice, barley, maize and pumpkin plants. Meanwhile, progress has also been made in physiological and molecular understanding of Si-mediated alleviation of abiotic (e.g. excess zinc and manganese stress) and biotic stresses (e.g. rice blast and bacterial blight). In the present paper, we reviewed the updated knowledge of the roles of silicon-enhanced resistance to both biotic and abiotic stresses in plants coupled with the current research status of silicon fertilizer research and development, field application and management for high crop

productivity and quality, and environmental health in China. Based on the most current research findings, we believe deeply that silicon is an important player more than a beneficial element and its essentiality in higher plants will be recognized. Finally we discussed future research needs for Si-mediated alleviation of biotic and abiotic stresses, and for Si-enhanced crop productivity and quality and environmental health.

Acknowledgement

This work is jointly supported by the Intergovernmental Science & Techonology Co-operative Project between China and Serbia granted to Y.C.L. (2011-2013), This Ministry of Science and Technology (2006BAD02A15) and the Distinguished Talent Program from the Chinese Academy of Agricultural Sciences.

The mechanism of Si foliar application on alleviation As and Cd combined toxicity to rice

Liu CP, Li FB *, Wu CG, Li HM, Xu XH

Guangdong Open Lab of Environmental Science & Technology, Guangdong Institute of Eco-Environmental and Soil Sciences, Guangzhou 510650, China

**Corresponding author: E-mail: cefbli@soil.gd.cn*

Abstract

In the present study, two silica sols, in nanometer particle size, were prepared using hydrothermal method for As and Cd combined contaminated paddy soil control. Pot and field experiments were conducted to investigate the effects of foliar application of two silica (Si) sols on the alleviation of Cd and As toxicity to rice. Results showed that Si foliar application reduced As and Cd accumulation in rice grain. For the optimal effect, Si should be foliar applied at the tillering stage during rice growth. Cd concentration in grain of rice grown on 10 mg kg^{-1} Cd contaminated soil dropped from 0.71 to 0.09 mg kg^{-1} with Si-Sol –B foliar application. Compared with control, the Si foliar application led to increase in production of rice in 29.6% and a decrease in As or Cd concentration in grain of rice with 28.0% or 28.2%, respectively, when the soils were contaminated with As and Cd combination. In the filed experiments, the production of rice with Si foliar application was 22% higher than that of control and the As or Cd concentration in grain of rice treated with Si foliar application was 40.2% or 28.2% lower than that of control.

The mechanism of Si foliar application to alleviate the toxicity and accumulation of As or Cd in grains of rice were studied in hydroponic solution culture. Results showed that Cd sequestration in the shoot cell wall may be related to alleviate Cd toxicity and to reduce Cd transport from shoot to grain. Under 50 μM Cd treatment, the Cd concentration in rice shoot or root applied with Si-sol-B was 61.4% or85.1% of the control, respectively, while the Cd contents in rice shoot or root were not affected significantly. Compered with the control, the Cd percentage in shoot cell wall of rice applied with Si-sol-B increased by 123%. Si foliar application reduction in As uptake by rice is due to competition of the Si/arsenite efflux transporter Lsi2 duringthe As (III)-transportation process. Under 100 μM Na_2HAsO_4 treatment, the As concentration in shoot or root decreased by 41.3% or 22.3% with Si foliar applicaiton, and the As content in shoot decreased by 30% with Si foliar applicaiton. In addition,

the Si foliar application enhancement of antioxidant defense capacity of rice under As or Cd stress may be contribute to As or Cd toxicity alleviation. With 100 μM Na_2HAsO_4 treatment, the activities of SOD, POD and APX in rice root foliar applied with Si increased by 54.0%, 41.9% amd 16.8% respectively, while the content of MDA and the ELR decread with 130.2% and 33.8%. Under 10 μM Cd treatment, the activities of SOD, POD, APX, the content of ASA and GSH of rice root foliar applied with Si increased by 65.8%, 12.9%, 8.5%, 15.9% and 13.1% respectively, while the content of MDA and the ELR decread with 21.4% and 31.9%.

The effect of different physical-chemical treatments on Si promoted-release of sand

Liu H, Wang J, Li HS, Liao ZW *

New Fertilizer Research Center, College of Resources and Environment, South China Agricultural University, Guangzhou510642

** Corresponding author: Email: zwliao@sohu.com*

Abstract

Slags and sands with high content of silicon are good sources for Si fertilizer, providing a new way of comprehensive utilization for mining tailings and slags. Therefore, promoted-release technology is developed for this purpose. This technology has been successfully applied in treating phosphor rock and magnesium ore. This paper is to study the effect of promoted-release with different physical-chemical treatments on Si availability in sand.

Materials and methods

The promoted-release effect of different activators on sand

Material sand (passing 0.15mm sieve), activators: WZ, JMY, YY and QN, made in new fertilizer resources research center, South China Agriculture University.

Methods

Firstly quartz sands were mixed with different activators, then grinded completely and dried under 35℃ and 60℃. All treatments are shown in the following table.

Table 1 Treatments of different activators & different temperatures

Code	CK	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Activator,temperatures		5% WZ, 35℃	6%JMY, 35℃	6% YY, 35℃	5% WZ, 60℃	6%JMY, 60℃	6% YY, 60℃	5% QN, 35℃	10% QN, 35℃	1.2% QN, 60℃	5% QN, 60℃

(% proportion by weight)

Dynamic extraction of activated sand

Si was continuously extracted three times from samples by distilled water and analyzed using molybdenum blue spectrophotometry.

Results

The promoted-release effect with different physical-chemical treatments on water-soluble Si

As Table 2 showed, the total water-soluble silicon content of all activated sands was much higher than that of CK sand, ranging from 27.84% to 5000.00%. QN activator (5%and 60℃) was the highest, up to 1618.74mg/kg, 50 times higher than CK sand. The treatment of 10%QN was higher than that of 5%QN 2.72 times under the same temperature of 35℃. When temperature rose to 60℃, the promotion effect was better. However, for activators of WZ, JMY and YY at 60℃, there was a decreasing trend in water-soluble Si when temperature rose to 60℃.

Table 2 The effect of activators on quartz sand for water-soluble silicon

treatments	*1st extraction（mg/kg）*	*2nd extraction（mg/kg）*	*3rd extraction（mg/kg）*	*total（mg/kg）*	*Compare to CK（%）*
sand	12.07±0.19	8.16±0.17	11.52±3.16	31.74±3.29	--
5%WZ 35℃	22.96±2.66	29.22±1.21	22.57±2.71	74.75±1.16	135.49
6%JMY 35℃	23.8±7.05	20.43±0.92	14.23±0.94	58.45±7.07	84.16
6%YY 35℃	18.19±0.5	24.1±1.26	21.54±0.63	63.83±1.39	101.09
5%WZ 60℃	3.16±1.23	33.86±3.53	32.05±6.99	69.07±11.76	117.59
6%JMY	6.38±8.06	14.72±1.68	19.48±1.16	40.58±7.53	27.84

60℃					
6%YY 60℃	6.63±2.27	13.48±1.95	22.42±1.38	42.53±1.06	33.98
5%QN 35℃	240.03±7.39	67.22±5.29	51.02±0.73	358.26±1.37	1028.74
10%QN 35℃	720.21±3.24	140.03±1.55	113.83±0.89	974.08±5.67	2968.93
1.2%QN60℃	106.08±14.92	42.23±8.77	31.3±0.69	179.61±6.84	465.88
5%QN 60℃	1255.62±53.54	256.64±26.49	106.47±9.15	1618.74±89.17	5000.00

Discussion

All four activators showed good promote release effect on Si in sand. The best is 5%QN at 60℃. It is concluded that the effect depended on tow factors: activators and temperatures. For activators of WZ, JMY, YY, better effects were obtained at lower temperature (35℃). However, as to activator QN, better effects were obtained at higher temperature (60℃).

Sharing the new concept of promoted-release which had been successfully applied to activate phosphate rock, this research showed a breakthrough from classical technology of Si fertilizer production featured of high temperature calcination. With gentle conditions of ordinary pressure and temperature, promoted-release technology will provide a new, low carbon way of manufacturing Si fertilizer.

Effect of organo-silicon stimulators on the frost resistance of rice

Loginov SV [1], Matichenkov VV [2], Matichenkov IV [3]

1.The State Scientific Center of the Russian Federation "State Research Institute for Chemistry and Technology of Organoelement Compounds", Moscow, Russia,

2. Institute Basic Biological Problems RAS, 142290, Pushchino, Russia,

3. Moscow State University, Soil Science department, Moscow, Russia.

Abstract

Short frost is one of the major forms of abiotic stress, which has negative influence on the cultivated plants and can dramatically reduce the efficiency of farms. Rice is very sensitive to frost. Numerous laboratory, greenhouse and field tests have demonstrated that active Si substances can dramatically increase the plant resistance against any type of the stress, caused by biotic and abiotic factors. However several subjective and objective reasons (for example the absence of the method for determination of active Si in plant tissue) results in critical poor investigation of function and role of this elements in plant physiology and biochemistry. Organo-silicon substances have extremely high activity and influence on the plant physiology. The application of the extremely low rate (several grams per hectare) has same effect as application of the tons per hectare of the traditional Si-rich soil amendments. The greenhouse tests with temperature control were conducted with rice. The several types of organo-silicon compounds were tested in this experiment. The frost simulation was initiated for 3 weeks old rice with level -4^{0}C during 4 hours. The control plants were died (95% of death). The application of the organo-silicon compounds protects the rice against frost (0-5% of death). The biomass of rice was tested 1 week after frost simulation. It is important that treated plant with frost had more biomass than control plants without frost simulation. The obtained data correlated with other our investigations which were conducted with citrus, sugarcane, grape, peaches and other cultivated plants. The application of the active forms of Si can protect plant against short time frost.

Silicon deposition in the apoplast and its effect on Si-mediated resistance to abiotic stress

Lux A, Vaculik M, Martinka M, Masarovic D, Bokor B

Department of Plant Physiology, Faculty of Natural Sciences, Comenius University in Bratislava, Mlynská dol. B2, 842 15 Bratislava, Slovakia

Abstract

Silicon mediated alleviation of abiotic stress in plants is already well known and widely documented phenomenon in many plant species. Several physiological processes occurring inside the cells (in the symplast) have been recognized. Plants exposed to drought, heat, salinity or toxic concentrations of metals exhibit improved assimilation, water use efficiency and various biochemical adaptations after Si treatment. Apart of these symplastic reactions there are also processes in the apoplast which are less studied and known. However, many stress induced reactions occurring in the symplast have their counterpart also in the apoplast. A number of stress induced and stress related metabolic changes take place in the apoplast. In addition, the cell wall as the first barrier of various environmental abiotic stresses posses specific tools for the protection against stress. The cell wall impregnation and early cell wall related changes, accompanying differentiation of various specific cell types, represent important factors of plant organs and tissues in reaction to the stress.

Silicon induced changes of visco-elastic properties of cell walls are one example illustrating positive effect of Si on plants exposed to abiotic stress. We have found increased cell wall elasticity in apical part of root after Si treatment, resulting in increased cell elongation and improved growth. On the other hand mature cell walls became more rigid and less elastic after Si exposure compared with Si deficient plants. Another example is Si induced change of differentiation of apoplastic barriers. Modified distance of apoplastic barrier formation from the root apex might accompany changes in the ion uptake by roots and thus translocation of these ions to above-ground plant parts. Co-deposition of some metals with silicon in the form of aluminosilicates or complexes of other metals with silicon deposited in the cell wall were also found. Intensive deposition of Si in root endodermis of several grass species including some important cereals represents specific site of barrier formation of Si towards some stress factors. All these processes underline the importance of apoplastic part of plant organs and tissues in Si mediated resistance to various abiotic stresses.

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Transport of silicon from roots to panicles in different plant species

Ma JF, Yamaji N, Mitani-Ueno N

Institute of Plant Science and Resources, Okayama University, Chuo 2-20-1, Kurashiki, 710-0046, Japan，Email: maj@rib.okayama-u.ac.jp

Abstract

The beneficial effects of silicon (Si) mostly rely on its deposition in different tissues. Therefore, understating how plants transport Si from soil to different tissues is a very important issue. At this symposium, I will present transporters involved in the uptake, translocation and distribution of Si in different plant species.

The uptake of Si by plant roots is mediated by two different transporters. Lsi1, belonging to NIP group of the aquaporin family, is an influx transporter of Si. This transporter is responsible for the uptake of Si from soil into the root cells and has been found in both dicots and monocots although the expression patterns and cellular localization differ with plant species. The subsequent transport of Si out of the root cells towards the stele is medicated by an active efflux transporter, *Lsi2*. *Lsi1* and *Lsi2* are polarly localized at the distal and proximal sides, respectively, of both exodermis and endodermis in rice root. Silicon in the xylem sap is presented in the form of monosilicic acid and is unloaded by *Lsi6*, a homolog of *Lsi1* in rice. The distribution of Si into the rice leaf sheath is largely dependent on *Lsi6*, but that into leaf blade is affected by transpiration. *Lsi6* is also involved in the inter-vascular transfer of Si at the node of rice and barley, which is necessary for preferential Si distribution to the panicles. All these transporters are required for Si functioning as a beneficial element.

Silica metabolism and silicification in sorghum wild type and mutant plants

Markovich O, Cohen D, Fridman E, Elbaum R

Institute of Plant Sciences and Genetics in Agriculture, R. H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, Rehovot 76100, Israel

Abstract

Sorghum (*Sorghum bicolor*) is a cereal originated from Africa, which is evolutionary related to sugarcane, maize, and rice. It ranks as the fifth most important grain crop, useful to food and fibers industries, animal feed, and lately utilized as a source for bio-energy. Sorghum is a C4 grass characterized by fast growth and high photosynthetic efficiency. Completion of the sorghum genome sequence and its high co-linearity (synteny) with other grasses has opened new avenues for utilizing sorghum as a model plant for functional genomics of cereal crops. Silicon oxide is known to increase the tolerance of grasses and other plants to biotic and abiotic stresses. Sorghum root silicification is well studied for many years. Accumulation of silica in root and leaves was correlated to the sorghum high resistance to drought, through maintaining high stomatal conductance, increased water use efficiency, increased net growth, and more efficient water uptake from the soil. In the last years, three silicon transporters were identified in rice, barley, maize, and cucumber. A search through databases of expressed sequence tags (EST) revealed that the transporters exist in sorghum as well. To study the proteins that are involved in sorghum silicification we scanned a fast neutron mutant population of 520 families, comprised of about 15,000 plants. We developed a hydroponic scanning method based on the application of poisonous germanium oxide to the plants, assuming it takes the same metabolic path as silica. The plants that absorbed silica in a similar manner to the wild-type (WT) sorghum, accumulated GeO_2 and developed necrotic brown spots on the leaves. We identified 37 families that showed either reduced number of necrotic spots, or that the spots pattern was different from the WT plants. Using PCR, we found one family to be mutated at the root silicon transporter, LSi1. Our initial observations show that in the WT sorghum silica accumulates at the older (distal) parts of leaves in dumbbell shaped silica bodies. These bodies are deposited in a sub-cellular compartment along the vascular bundles. Other epidermal cells

accumulate silica at the cell-wall, but the silica is expelled from guard cells. Next, we will compare the silicification pattern in the Lsi1 mutant to the WT pattern. Because LSi1 allows the entry of silica to the roots, we predict to find only smaller amount of silica bodies, but no effect on the deposition pattern. We will use this mutant to test the effect of silica on resistance to drought, salt, and aluminum stresses. We will conduct molecular biology tests, histological analysis of the silica localization, and biochemical and structural investigations. This data will enable us to decipher the mechanism in which silica increases the plant tolerance to a variety of environmental stresses. Our research may potentially link the physiological and anatomical observation to molecular mechanisms that will explain the way in which silica increases tolerance of plants to stresses.

Active Si as alternative for pesticides in organic farming

Matichenkov VV [1], Bocharnikova EA [2]

1.Institute of Basic Biological Problems Russian Academy of Sciences, Russia. E-mail: Vvmatichenkov@rambler.ru

2.Institute Physical-Chemical and Biological Problems in Soil Science Russian Academy of Sciences, Russia. E-mail: mswk@rambler.ru

Abstract

The possibility to reinforce the natural plant defense system against abiotic and biotic stresses can be successfully realized by application of monosilicic acid. Several mechanisms of direct active Si effect on plants were determined. There is mechanical effect, which realizes by the accumulation of Si in the epidermal tissue with the formation of double cuticle layer mechanically protecting plants. The physiological effect of Si on plants proceeds via the formation of better developed root system and the protection of chlorophyll molecules by monosilicic acid. The chemical protection realizes by blocking or precipitation of heavy metals, sodium, and other pollutants by mono- or polysilicic acids. Finally, the biochemical mechanism is related to the additional non enzyme synthesis of antioxidants and stress-proteins providing the reinforcement of the natural plant protection against biotic stresses. The active Si is able to increase the stability of RNA and DNA of plants. The greenhouse and field tests have shown that the application of monosilicic acid or natural sources of active Si, for example Diatomaceous Earth in combination with organic compounds reduced the level of diseases, fungi, nematodes, and insect attacks by 30 to 75%. Some Si-rich materials had more beneficial impact than commercial pesticides. The testing was conducted on the following plants: cauliflower, sunflower, rice, banana, barley, tomato, and cucumber. It is important to note that Si materials used were officially certificated for organic farming by European and American organizations.

Detoxification of heavy metals in industrial and municipal wastes by activated Si

Matychenkov IV [1], Pakhnenko EP [1], Bocharnikova EA [2], Matichenkov VV [3]

1.Moscow State University, Soil Science department, Moscow, Russia, e-mail: kwsm@rambler.ru
2.Institute Physical-Chemical and Biological Problems in Soil Science RAS, 142290, Pushchino, Russia, e-mail: mswk@rambler.ru
3.Institute Basic Biological Problems RAS, 142290, Pushchino, Russia, e-mail: vvmatichenkov@rambler.ru

Abstract

Numerous solid and water-based industrial wastes contain high amounts of heavy metals (HM) in active forms. Municipal sludge also can be rich in HM and active aluminum. The utilization of these wastes is restricted by environmental governmental organizations. The storage sites for the deposit of these by-products require special high-cost constructions to provide necessary level of protection against environmental pollution. In recent years, the technologies based on using active Si and organic substances have been elaborated for neutralization of heavy metal toxicity and elimination of pathogen microorganisms in industrial slag and municipal sludge. Industrial water-waters contaminated by Cr, Cd, Pb, Zn and Cu, slag from battery manufacturing, and municipal sludge were used to demonstrate the efficiency of the technology elaborated. Si-treated and untreated waste-waters were analyzed for HM by atomic adsorption method. The following standard EPA procedure for heavy metal extraction from soil and polluted ground was used for testing treated and untreated battery slag and municipal sludge: a) mobile heavy metals – 0.1 M $MgCl_2$; b) potentially mobile heavy metals – 0.1 n HCl; c) total extractable heavy metals – 2M HNO_3. All these extractions were conducted sequentially. Active Si significantly (up to 7-30 times for mobile forms, up to 4-5 times for potentially mobile forms and by 50 to 70% for total extractable forms) reduced the mobility of Pb, Cr, Cu, Cd, and Zn in solid and liquid wastes. The multi-application of this technology would allow to neutralize completely heavy metal toxicity and to utilize battery's slag and municipal wastes.

The potential of postharvest silicon dips to regulate phenolics in citrus peel as a method to mitigate chilling injury lemon

Mditshwa A, Bower JP, Bertling I, Mathaba N

Horticultural Science, School of Agricultural Sciences and Agribusiness, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209
E-mail: amditshwa@gmail.com

Introduction

South African citrus fruit is shipped at -0.6°C to meet the quarantine requirements for certain high paying markets. However, tropical and subtropical fruit suffer from chilling injury when held at temperatures below 12°C. Physiologically, chilling injury is induced by oxidative stress caused by reactive oxygen species (ROS) (Sala and Lafuente, 2000). One of the most effective anti-oxidants to scavenge these ROS and subsequently mitigate chilling injury is phenolics. Silicon (Si) has been proved to induce stress resistance in plants (Liang *et al*., 2008) and has been reported to increase phenolic concentration in tissue (Ma and Yamaji, 2006). The objective of this study was to evaluate the potential of Si dips to regulate phenolics capacity, thereby preventing chilling injury.

Materials and methods

Lemons (c.v. Eureka) were obtained in July 2010 from the UKZN Research farm, Ukulinga. Fruit was transported to the laboratory and treated with various concentrations (50, 150 and 250 ml/L) of K_2SiO_3 dips for 30 minutes. Fruit was left at room temperature to dry and subsequently stored at -0.5°C or 2°C for up to 7, 14, 21 and 28 days. Samples for phenolics evaluation were taken out of cold storage and stored for 5 days at room temperature. Phenolic compounds were determined spectrophotometrically according to Abeysinghe *et al*., (2007).

Results and discussion

Ukulinga lemon showed no chilling symptoms, neither at -0.5 nor at 2ºC, after 28 days of cold storage plus five days shelf life. Silicon postharvest dips had no significant effect on fruit weight loss compared with untreated fruit; however, fruit weight loss was accelerated post cold storage (Schirra and D'Hallewin, 1997).

Electrolyte leakage indicated the highest membrane damage at 7 and 21 days cold storage; at 7 days electrolyte leakage was significantly reduced by the 150ml/L K_2SiO_3 dip. High amounts of free phenolics seem to have been aligned to chilling resistance of lemon fruit stored at -0.5 or 2˚C.

Conclusion

Si dips seem to have a potential to mitigate chilling injury.

Acknowledgements

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Grapevine vegetative growth and reproductive development in response to silicon supplementation

Meunier M, Rogiers S, Gurr G, Siret R

Enseignant-Chercheur/Viticulture – Oenologie, GROUPE ESA, 55 rue Rabelais - BP 30748，49007 ANGERS Cedex 01

Abstract

Viticulture is an intensive user of agro-chemicals however grape-growers and winemakers have become increasingly aware of the need to develop environmentally sustainable systems to maintain a ‘clean and green’ image, especially for international markets. Silicon (Si) is a natural element to found in abundance in most soils and biological systems. The addition of this element to particular crop species benefits the plant through enhancement of nutrient uptake and mitigation of biotic and abiotic stresses. Some plant species, however, are more responsive than others. Si supplementation is currently used by a number of organic and biodynamic grape growers since it is believed to be a more sustainable means for increasing plant defence and crop quality. The potential benefits of Si supplementation to viticulture have not been rigorously tested. This project investigates the role of Si on grapevine, *Vitis vinifera* L, growth and reproductive development, including grape quality. The research is conducted for a three year period in a replicated trial in a commercial vineyard of France applying organic and biodynamic viticultural systems. The research compares foliar with soil applications of different form of Si within the organic viticultural system while it compares different rates and frequencies of foliar applications of silicon within the biodynamic viticultural system. Vine growth assessments will include measurement of shoot length, leaf chlorophyll content and leaf surface area. Reproductive development will be assessed through quantification of fruit set and berry composition. This conference will give the opportunity to present the results from the first year experiment. Better understanding of the effects of Si on vine growth will aid in the development of best management practises and provide potential alternatives for the development of sustainable vineyard systems.

Advances in the interpretation of foliar analysis of sugarcane with special reference to silicon

Meyer JH

Silicon in Agriculture Society of South Africa.

Email: jmeyer@netactive.co.za

Abstract

The mineral composition of plant tissue depends on all the dynamic factors of mineral uptake, distribution, redistribution and interactions. Nutrient ions in plant tissue do not change in concentration in a singular and isolated manner, a shift in the concentration of an ion is generally accompanied by secondary changes in the concentration of other ions. Heavy fertilizer applications are often responsible in this way for ion interactions which lead to imbalances and resulting problems in plant growth.

There has been increasing interest in recent years in the use of ratios between elements as an alternative approach to interpreting leaf analysis. Interpretation of plant tissue analysis based on the principle of minimum values has not always been satisfactory in interpreting the nutrient status of crops and silicon diagnosis has been no exception. For example in Hawaii and Mauritius the Mn: Si ratio has been successfully used for more accurately defining an induced Si deficiency in sugarcane due Mn toxicity.

The Diagnosis Recommendation Integrated System (DRIS) is one of the diagnostic systems based on the balance between nutrient ratios, has received the most attention since it was first developed for diagnosing the nutrient requirement of rubber trees in Vietnam (Beaufils 1958), then adapted to maize (Beaufils 1971) followed by sugarcane in South Africa (Beaufils and Sumner 1976).

Attention in this paper is focused on the authors experience in using nutrient ratios as part of the DRIS concept for diagnosing the nutrient requirement of sugarcane. Some of the main outcomes include:

- Predictions of a yield response to applied N,P,K using leaf analysis were more reliable when DRIS was used than when the nutrient threshold approach was used at an early rather than a late stage of crop development
- Based on an assessment of paired yield and leaf sample data from nearly 1000 cane fields, variance ratios between the high yielding (>7tc/ha/month) and low yielding population(7tc/ha/month),were the most highly significant for the N/Si and Si/K ratios. The highest yielding fields were associated with N/Si ratios that were below 1.7.
- Similarly, in a separate study, increasing risk from *E. saccharina stalk borer* damage was strongly correlated with N/Si values in excess of 2:1(Meyer and Keeping 2005)

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Movement of silicon through Saccharum officinarum (sugarcane) and its effect on *Puccinia melanocephala* (brown rust)

Naidoo PV [1], Caldwell PM [1], McFarlane S [2]

1.Discipline of Plant Pathology, University of KwaZulu-Natal, Private Bag X01, Scottsville 3209, South Africa,

2.South African Sugar Research Institute, Private Bag X02, Mount Edgecombe 4300, South Africa. E-mail: 202518477@ukzn.ac.za

Abstract

Sugarcane (*Saccharum officinarum* L.) is known to absorb more silicon (Si) than any other mineral nutrient. In addition, Si has been identified as a key element in the control of various diseases and pests. This study focused on the uptake and deposition of Si in sugarcane as well as its effect on the severity of brown rust of sugarcane, caused by *Puccinia melanocephala* H. & P. Sydow. Both trials consisted of 9 treatments i.e. 100, 200, 400, 800, 1200, 1600, 2000 mg ℓ^{-1} potassium silicate (K_2SiO_3), applied once a week for 8 weeks and Calmasil®, a commercially available form of calcium silicate, applied at the recommended dosage of 52 g 5 ℓ^{-1} incorporated in the potting soil at planting. The concentration of Si in the Calmasil® was calculated to be 1017 mg ℓ^{-1}. Each trial was replicated 4 times with 6 plants per replicate in a randomized complete block design. The trials were repeated twice. For the disease severity trial, plants were naturally infected with *P. melanocephala* by placing them in a tunnel with brown rust-infected spreader plants. From 3 weeks after planting, plants were rated weekly for 5 weeks for percentage disease severity using a rating scale. Significant differences were noted between treatments. Percentage disease severity was reduced from 85% in the control to 64% in plants treated with Si at 2000 mg ℓ^{-1}. For the Si uptake trial, total Si accumulation in leaves and stems was measured using ICP-AES. Si uptake increased with increased Si concentration but plateaued from 1600 to 2000 mg ℓ^{-1}. The area of highest deposition of Si within the stem and leaf tissue will be assessed using energy dispersion X-ray (EDX) analysis with environmental scanning electron microscopy. Current trials are focusing on the possible ability of Si to catalyze the plant's defense response to brown rust.

Keywords: Brown rust, Silicon, *Puccinia melanocephala*.

Isolation and functional analysis of Si transporters in two pumpkin cultivars contrasting in Si uptake

Mitani-Ueno N [1], Yamaji N [1], Ago Y [1], Iwasaki K [2], Ma JF [1]

1.Institute of Plant Science and Resources, Okayama University, Chuo 2-20-1, Kurashiki 710-0046, Japan,

2.Faculty of Agriculture, Kochi University, Otsu 200, Monobe, Nankoku-shi, Kochi 783-8502, Japan E-mail: namiki-m @rib.okayama– u.ac.jp

Abstract

Transporters for silicon (Si) have been identified in gramineous plants including rice, maize and barley, which accumulate high Si. However, it is unknown whether these transporters are also present in dicots. In this study, we isolated Si transporters in two pumpkin cultivars contrasting in Si uptake. These cultivars have been used as rootstocks for producing bloom and bloomless cucumber. Bloom is white powder on the surface of cucumber, which is primarily composed of silica.

Based on the sequence of rice silicon transporter *OsLsi1*, we first isolated a homologous gene from each pumpkin cultivar named *CmLsi1*. Comparison of the amino acid sequences of CmLsi1 between cultivars revealed that only two amino acids differ at the position of 75 and 242. Heterogeneous expression in both *Xenopus laevis* oocytes and rice mutant defective in Si uptake showed that the CmLsi1 from the bloom pumpkin rootstock had Si transport activity, whereas that from the bloomless rootstock did not. Furthermore, site-directed mutagenesis analysis showed that a mutation at the position of 75 (alanine instead of valine) did not affect the transport activity for silicic acid, whereas a mutation at 242 (leucine instead of proline) resulted in a loss of transport activity. Interestingly, all pumpkin cultivars for bloomless rootstocks tested have the same mutation at 242. Immunostaining showed that the transporter from two cultivars was similarly localized in all cells of the roots. However, investigation of the subcellular localization with different approaches revealed that CmLsi1 from the bloom pumpkin rootstock was localized at the plasma membrane, whereas the one from the bloomless rootstock was localized at the ER (endoplasmic reticulum).

We also isolated homologs of rice Si efflux transporter OsLsi2 in two pumpkin cultivars. Based on OsLsi2 information, we obtained two genes (designated CmLsi2-1

and CmLsi2-2) from each cultivar. However, there were no differences in the sequence of either between two cultivars. Heterogeneous expression in *X. laevis* oocyte indicated that both CmLsi2-1 and CmLsi2-2 showed efflux transport activity for Si.

Taken together, our results indicate that the difference in Si uptake between two pumpkin cultivars is attributed to one amino acid residue substitution of the Si influx transporter, which affects the subcellular localization and subsequent transport of Si from the external solution to the root cells.

The influence of silica on cell-culture growth parameters and cell-wall construction

Nissan H, Moshelion M, Elbaum R

Institute of Plant Sciences and Genetics in Agriculture, R. H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, Rehovot 76100, Israel

Email: elbaum@agri.huji.ac.il

Abstract

Silica increases the yield and mitigates biotic and a-biotic stresses in plants, but the mechanism of its action is only partially understood. Both active and passive processes appear to involve in silica absorption through the roots, transport with the transpiration stream, and deposition at the epidermis and epidermal features. The omnipresence of silica in soils, dust, and glassware interferes with our ability to isolate the effect of silica on plants. Another challenge in studying bio-silicification is following silicic acid and polymerized silica in vivo, as there is no molecular marker specific to silica, and no silicon radioactive isotope suitable for biological work. To cope with these obstacles we established a method to grow plant cells in suspension with varying amounts of silicic acid. This system allows us to produce identical growing conditions under known silica concentration. Thus we know the amount of silica available for individual cells, in contrast to the situation in a whole plant, where the silica concentration changes dramatically depending on the location within the tissue. In addition, the cells are easily accessible, allowing us to use a variety of methods to detect the silica both in soluble and in solid states. The main goal of our research is to unravel the interactions of the plant cells with silica. Specifically, we characterize the cell clusters in maize cell culture, when grown in growing medium solutions containing high versus low silicic acid concentrations. We found that the cells growth parameters were unaffected by the silicic acid. This agrees with the observations in whole plants that exclusion of silica from the growing medium does not interfere with the ability of plants to flourish under non-stress conditions. On the other hand, our preliminary thermal gravimetric results show that at high concentrations of silicic acid, the cell-walls incorporated more hemicelluloses per dry weight. The cellulosic matrix of these cell-walls decomposed at slightly larger

temperature range compared to the cells deprived of silicic acid. This may imply that the silica protected chemically the cell-wall. Using fluorescence microscopy and Raman micro-spectroscopy, we noted that in cells exposed to silicic acid, the content of cellulose and hemicelluloses per cell-wall unit area was larger. This may indicate that cell-walls deposited in the presence of silica are thicker. We will produce histological sections to test this hypothesis. To complete our observations we will evaluate the effect of silica on the expression profile of the known silicon transporters in the cells. Next, we will evaluate the reaction of the cells to various stresses such as high salt, high osmolarity, and pathogens. Revealing the interaction of silica with cell-walls will clarify how silica reduces the porosity of the cell-wall and increases its stiffness, factors that may be related to higher plant tolerance to changes in the water balance. The high accessibility of the cells may allow us a new insight into the positive effects of silicic acid on cells infected by pathogens. We predict that our system will enable a breakthrough in understanding plant bio-silicification, and open the possibility to future work on cellular mechanisms that involve silica.

Characterization of Si uptake and identification of Si transporter genes in wild rice

Oogai H [1], Yamaji N [1], Ma JF [1]

[1]*Institute of Plant Science and Resource, Okayama University, Chuo 2-20-1, Kurashiki 710-0046, Japan, Email: maj@rib.okayama-u.ac.jp*

Abstract

Rice (*Oryza sativa*) is able to accumulate high Si and this trait has been associated with high expression of Si transporters involved in Si uptake. However, most works on Si in rice have been done in cultivated species. In the present study, we investigated the Si uptake in wild rice species (*Oryza rufipogon*, *Oryza barthii*, *Oryza glumaepatula*, *Oryza meridionalis*, *Oryza punctata* and *Oryza australisnsis*). *Oryza punctata* and *Oryza australisnsis* contain BB- and EE-genome, respectively, while other species contain AA-genome. A short-term experiment showed that the Si uptake ability of BB- and EE-genome species was lower than that of cultivated species (cv. Nipponbare), whereas those of AA-genome species *Oryza glumaepatula* and *Oryza meridionalis* were higher than that of cultivated species. However, the Si content in the shoot was similar among all species when grown under field condition.

We then cloned Si transporter genes (*Lsi1*, *Lsi2* and *Lsi6*) from wild rice species. Sequence comparison showed that *Lsi1* from wild rice showed polymorphism at nucleotide level. However, at amino acid level, only BB- and EE-genome species showed 1-amino acid deletion in C-terminal region and 5 residue substitutions compared with *Lsi1* in cultivated species. *Lsi1* from all AA-genome species showed identical sequence as cultivated rice. However, all *Lsi1* possess the same NPA motif and aromatic/arginine selective filter. Furthermore, localization of *Lsi1* in AA-genome species roots was similar to that in cultivated species. There was a positive correlation between short-term Si uptake capacity and *Lsi1* expression level. Some changes in *Lsi6* sequence were also found between wild and cultivated rice, but there was no differences in the predicted transmembrane site, NPA motif and aromatic/arginine selective filter. The sequence of *Lsi2* in wild rice is being undertaken and will be presented and discussed at the meeting.

Silica Biominerallzations: their role in the evolution and degradation of soils in the southeast of pampean plant, Argentina

Osterrieth ML [1], Alvarez F [1, 2], Borrelli N [1, 2], Honaine MF [1, 2]

1.Instituto de Geología de Costas y del Cuaternario. Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Mar del Plata. CC 722 Correo Central 7600 Mar del Plata, Argentina,

2.CONICET. mosterri@mdp.edu.ar / mosterri @yahoo.com.ar

Abstract

The southeast of Buenos Aires province, Argentina, is an important socioeconomic sector of the Pampean region. The soils of this region are one of the most fertile of the world and they have been used for agricultural activities for more than 150 years. These human activities have modified the physical, chemical and biological properties of the soils and have a negative environmental impact. The rol of the silica in the matrix conformation which in turn modify the type, morphology and consistency of aggregates, their stability and response to different types of use, is little known. Also, the importance of the contribution of the plant silica biomineralizations of the most representative enviroments of the Pampean region is scarce studied. The aim of the study is to define and quantify the presence of silica biomineralizations in the natural plant communities, in the most common crops of the area and in the horizons of the typical Argiudolls affected by agricultural practices. Lastly, the matrix of the aggregates is analyzed at microscopic and submicroscopic levels. The silica biomineralizations of plants and the aggregates of the horizonts of typical Argiudolls in natural and agricultural plots were analyzed by loupe, optical and petrographic microscopes, SEM and EDAXs analyses. In the study area the plant communities that have been developed through all the Cenozoic are represented by grasslands. Mean values of silica content of the plant communities range between 2 and 7% dry weight. The presence of silicophytoliths in the soils ranges between 3% (parental material) and more than 50% (superficial horizons). In these last horizons the contribution of amorphous silica is relevant. The content of silicophytoliths ranges between 60 to 105 tn/ha and Si ranges between 25 and 45 tn/ha. These values are higher in the cultivated plots due to burning activities and the presence of crop residues. The matrix of the aggregates of strong pedal, is made up in turn by microaggregates with a recurring

elemental composition, mainly consisting of carbon and silicon. As the use of these soils is higher, the proportions of these elements and the substructures of the organominerals complexes are modified. A higher land use leads to lower carbon content and to an increment of amorphous silica, along with calcium, iron, aluminum subordinates. The weathering of silicophytoliths is an ongoing process in these soils and contribute to the formation of amorphous silica-rich matrix of the aggregates and thus to maintain stability. Despite the intensity of tillage in cultivated soils, the negative effect would be mitigated by the high contribution of the same silicophytoliths.

Silicon ameliorates iron deficiency chlorosis in strategy I plants: first evidence and possible mechanism (s)

Pavlovic J [1], Samardzic J [2], Ilic P [1], Maksimovic V [1], Kostic L [1], Stevic N [1], Nikolic N [1], Liang YC [3], Nikolic M [1]*

1.IMSI, University of Belgrade, 11030 Belgrade, Serbia,

2.IMGGE, University of Belgrade, 11000 Belgrade, Serbia;

3.Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China.

**Corresponding authour. Email: mnikolic@imsi.rs*

Abstract

Silicon (Si) and iron (Fe) are respectively the second and the forth most abundant minerals in the earth's crust. While the essentiality of Fe is discovered at the middle of the 19th century, Si is still not fully accepted as an essential element for higher plants. However, Si is the only known element that alleviates multiple stresses in plants (e.g. metal excess, drought, salt, lodging, diseases and pests). Fe deficiency chlorosis is a wide-spread nutritional disorder of many crops grown in calcareous and alkaline soils. The various adaptation mechanisms are involved in Fe acquisition from rhizosphere by roots of the so-called strategy 1 plants (all dicots and monocot species, with exception of grasses which belong to strategy 2), i.e. morphological changes (e.g. lateral roots and enhanced root hair formation in the apical zones) and physiological changes such as enhanced proton excretion, Fe^{III} reduction by a plasma membrane reductase and Fe uptake via an inducible Fe^{II} transporter (IRT1). These root responses have been studied and characterized mainly in the nutrient solutions without Si supply. Therefore, unambiguous information on an interaction between these two mineral elements is still lacking. We demonstrated for the first time that the application of Si in nutrient solution experiments also ameliorates Fe deficiency chlorosis in cucumber, a Si accumulating dicot, which is also commonly used as a model plant of strategy 1. I will present recent work from our lab in the context of the effect of Si on both physiological (e.g. Fe^{III} reducing capacity, release of phenolics and organic acids) and molecular (e.g. expression of *FRO2*, *HA1* and *IRT1*, the genes coding Fe^{III} chelate reductase, H^+-ATPase and IRT1, respectively) aspects of root responses to Fe deficiency. In particular, I will focus on the storage and utilization of

root apoplastic Fe, root-to-shoot Fe transport and utilization of Fe from the leaf apoplast. Based on these investigations we propose the possible role of Si in Fe deficiency stress as 1) increasing apoplastic Fe pool in roots and 2) improving internal Fe status and thus delaying Fe chlorosis, rather than a direct regulatory/signaling effect of Si on the key Fe deficiency inducible root responses.

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Silicon extractors in fertilizer induced by autoclave

Pereira HS [1], Assis MHS [2], Barbosa NC [2], Korndörfer GH [1]

1.Federal University of Uberlândia - Instituto de Ciências Agrárias, C.P. 593 - 38400-902 - Uberlândia, MG – Brasil. E-mail: hseron@uol.com.br, ghk@uber.com.br,

2.Federal University of Goias – Campus Jataí, Agronomia. Rod BR 364, km 192, Zona Rural - 75800-000 - Jataí, GO – Brasil. E-mail: assis.bio@hotmail.com, cabralagro@gmail.com.

Abstract

An extraction method of silicon in slag and fertilizers was developed to quantify the potentially available Si for the plants. The method is based on the solubilization of the Si content materials in an alkaline extractor of Na_2CO_3 + NH_4NO_3. This study aimed at evaluating variations in the use of Na_2CO_3 + NH_4NO_3 as extractors of Si fertilizers. An experiment completely randomized with the rice culture in a Quartzipsamment soil and in a greenhouse was installed with 18 Si sources applied at a rate of 250 kg ha^{-1} and a control with four replications. Another experiment was installed in factorial scheme (18 x 5) with 18 Si sources and five extractions of Si fertilizers and three replications in the laboratory. For this study, it was used four extractant solutions: Solution 1: Na_2CO_3 (0.1 $mol.dm^{-3}$) + NH_4NO_3 (0.2 $mol.dm^{-3}$); Solution 2 - Na_2CO_3 (0.1 $mol.dm^{-3}$) + disodium EDTA (0.03 $mol.dm^{-3}$) + NH_4NO_3 (0.2 $mol.dm^{-3}$); Solution 3 - Na_2CO_3 (0.1 $mol.dm^{-3}$) + disodium EDTA (0.03 $mol.dm^{-3}$) + NH_4NO_3 (0.2 $mol.dm^{-3}$) + $C_2Na_2O_4$ (0.06 $mol.dm^{-3}$) and; Solution 4 - Na_2CO_3 (0.1 $mol.dm^{-3}$) + disodium EDTA (0.03 $mol.dm^{-3}$) + NH_4NO_3 (0.2 $mol.dm^{-3}$) + CH_3COONH_4 (0.1 $mol.dm^{-3}$). The extractions with 4 solutions were induced by autoclave for 1 h at 120 °C. The solution 1 was also used in an extraction without application of autoclave but with rest of 5 days, thus totaling 5 extractions. The most efficient source for Si release to rice was Wollastonite [$Ca_3(Si_3O_3)$] followed by phosphorous slag and stainless steel slag, while the schist, blast furnace slag and silicate clay were the lowest on Si release. The autoclave was efficient in increasing the Si extraction, replacing the 5 days rest in the sample in solution. The highest extraction and better correlation between soluble Si and Si uptake by the rice crop was

obtained in solutions with EDTA, but solution 2 showed greater extraction capacity of the Si sources.

Keywords: Silicon analysis, Slags, Silicon application

Introduction

The slags have been suggested for use in agriculture as soil liming materials and to supply the plant with silicon (Si), mainly for rice (dry and flooded), sugar cane and pasture. There are some products being traded as a source of Si in Brazil, but the content provided can hardly be proven and the consumer must believe in the companies. The silicate market depends for good methodology on Si fertilizers analysis so that consumers can know in advance, and with certainty, the reactivity of those products in the soil, thus providing silicate producing companies implement systems for quality control products.

The chemical extraction with hydrochloric acid (HCl) 0.5 $mol.dm^{-3}$ has been traditionally used in Japan to evaluate the Si "available" in the slag (NIAES, 1987). However, this extraction method often fails to estimate the amount of Si "available" in the slag (Takahashi, 1981, Kato and Owa, 1997). Other extraction methods were suggested such as cation exchange resin (Kato and Owa, 1997), soluble Si through column leaching (Snyder, 2001) and Na_2CO_3 + NH_4NO_3 (Pereira et al. 2003) but these methods are hard to work with and do not adequately quantify the Si "available".

The Si in solution behaves like a very weak acid (H_4SiO_4), so that even at pH 7.0 only 2 $mg.kg^{-1}$ is ionized as anion, $H_3SiO_4^-$, and the degree of ionization increases with high pH (McKeague and Cline, 1963). Due to its alkaline pH, The Na_2CO_3 has been used to determine some forms of soluble Si (Conley et al., 1993). This carbonate is also used to solubilize the silica clay resulting from the sulfuric acid (Vettori, 1964), but does not show good results of correlation between Si “available” in soil and Si absorbed by plants. According to Voguel (1981), when hydrolysates, silicates of alkali metals have alkaline reaction raising the pH. Therefore, in alkaline medium, these materials have lower solubility, unless you provide for the means a source of protons (NH_4^+).

This method developed by Pereira et al. (2003) also presents problems in its adoption, because the balance of the reaction in air temperature can take many days, and even when in balance it takes long for Si to be soluble. The increase in temperature is an option to accelerate this reaction. Many analytical procedures were used to solubilize Si in different compounds using high temperatures (Voguel, 1981). Another option is to use substances to the complexation of calcium and magnesium of silicate, shifting the reaction to the formation of silicate in a more soluble form.

Because of the need to increase the method reliability to evaluate the fertilizer potential to provide Si for plants, we studied the dissolution of Si present in slag, using the extractor sodium carbonate + ammonium nitrate in different solutions associated with EDTA, sodium oxalate and ammonium acetate induced in autoclave. The extraction of Si fertilizers (slags) was evaluated by the correlation between the extracted Si with accumulation of Si by rice plants.

Materials and methods

An experiment was carried out in a greenhouse in a potted rice crop (Oryza sativa L.) (5 kg dry soil per pot), with subsurface samples of a Quartzipsamment with low soluble Si content in $CaCl_2$ 0.01 mol.dm^{-3}. The chemical attributes of the soil used in the experiment were: pH (water) 5.6; P 26.5 mg.dm^{-3} (extracted by H_2SO_4 0.025 mol$_c$.dm^{-3} + HCl 0.05 mol$_c$.dm^{-3}); Si 0.8 mg.dm^{-3}; Al 2 mmol$_c$.dm^{-3}; Ca 7 mmol$_c$.dm^{-3}; Mg 4 mmol$_c$.dm^{-3}; potassium 0.4 mmol$_c$.dm^{-3}; H+Al 9 mmol$_c$.dm^{-3}; organic matter 9 g.kg^{-1}; sand 905.7 g.kg^{-1}; silte 40.6 g.kg^{-1}; and clay 53.7 g.kg^{-1}.

The treatments were a complete randomized design with 18 Si sources and a control, 4 replications. The Si sources were characterized with regard to their origin, total Si, Ca, and Mg contents, and Neutralizing Power (NP) (Table 1). Wollastonite - a product with high degree of purity used worldwide in the Si studies - was used as standard source for comparisons. The slag materials were dried and sifted through a 50-mesh screen.

The treatments were applied in the dose 250 kg.ha^{-1} of Si as shown in Table 1. Amounts of $CaCO_3$ and $MgCO_3$ were added to each treatment in order to balance the same pH, Ca and Mg. The soil was moistened up to 70% of field capacity, being incubated for about 40 days. After, it was seeded the rice, variety Biguá, indicated for the floodplain ecosystem, provided by Embrapa. For the nutritional needs of plants, were applied weekly 100 cm^3 of nutrient solution containing N 0.67 g.dm^{-3}, P 0.5 g.dm^{-3}, S 0.24 g.dm^{-3}, K 0.45 g.dm^{-3}, B 0.50 g.dm^{-3}; Mn 0.54 g.dm^{-3}, Zn 0.09 g.dm^{-3}, Cu 0.02 g.dm^{-3}, Mo 0.02 g.dm^{-3} and Fe 4.0 g.dm^{-3}.

Table 1 – Characteristics of Si sources studied and amounts applied in each treatment.

	Treatments	Provided silicate			Dose per pot [2]		
		Si	Ca	Mg	Silicate	$CaCO_3$	$MgCO_3$
		------$g.kg^{-1}$------			------- $g.pot^{-1}$ ---------		
1.	Control	-	-	-	-	13.4	2.5
2.	Wollastonite	235	303	1	2.7	11.4	2.5
3.	Blast Furnace S Si-AF[4, 5]	179	215	45	3.5	11.5	1.9
4.	Blast Furnace S CSN-AF	156	304	31	4.0	10.3	2.1
5.	Blast Furnace Slag Aco-AF	134	200	38	4.7	11.0	1.9
6.	Blast Furnace Slag Us-AF	160	159	27	3.9	11.8	2.1
7.	Blast Furnace Slag Pi-AF	165	166	8	3.8	11.8	2.4
8.	Blast Furnace Slag Ac-AF I	191	304	31	3.3	10.9	2.1
9.	Blast Furnace S Ac-AF II	200	156	6	3.1	12.2	2.4
10.	LD furnace steel s Si-LD	57	293	44	10.9	5.4	0.8
11.	LD furnace steel s CSN-LD	51	201	46	12.3	7.2	0.5
12.	LD furnace steel s Aco-LD	52	197	17	12.0	7.5	1.8
13.	LD furnace steel s Ac-LD I	50	186	46	12.5	7.6	0.5
14.	LD furnace steel s	64	238	73	9.8	7.6	0.0

	Ac-LD II						
15.	AOD furnace steel s AOD	47	403	35	13.3	0.0	0.9
16.	Phosphorus solub. slag	215	311	4	2.9	11.1	2.5
17.	Stainless steel slag Ac	108	262	57	5.8	9.6	1.4
18.	Silicate clay	263	6	11	2.4	13.3	2.4
19.	Schist	247	15	10	2.5	13.3	2.4

(1)NP = neutralization power, calculated and determined respectively of Si sources; (2)$CaCO_3$ and $MgCO_3$ dose to balance the Ca and Mg contents applied with treatments; (3)%E $CaCO_3$ = equivalent percentage in $CaCO_3$ of 100g of product; (4) material of the companies: Si=Silifertil, CSN=National Siderurgica company, Aco=Açominas, Us=Usiminas, Pi=Pitangui, Ac=Acesita; (5)Designation given to the type of furnace used to convert iron into steel.

When the plants had the third leaf, it was made the thinning, leaving 5 plants per pot, and the pots were flooded with water depth of about 1 cm up the soil. The plants were grown up for 90 days and after this time they were harvested from the air part. The vegetal matter was conditioned in paper bags and taken to drying in the oven of air circulation until constant weight and then weighted to determine the dry matter of shoot (DMS). After weighing, the DMS were ground in Willey mill type and analyzed for silicon content using methods described by Elliott and Snyder (1991).

Another experiment was conducted in the laboratory in a factorial (18x5), 18 sources of silicon and five extractions. Were used four extracting solution, where all were induced in an autoclave to accelerate the extraction process, the solution 1 was also evaluated without autoclave but keeping it at rest for 5 days.

SOLUTION 1- A) sodium carbonate (Na_2CO_3) 0.1mol.dm^{-3} and B) ammonium nitrate (NH_4NO_3) 0.2 mol.dm^{-3};

SOLUTION 2- A) sodium carbonate (Na_2CO_3) 0.1 mol.dm^{-3} + disodium EDTA 0.03 mol.dm^{-3} and B) ammonium nitrate (NH_4NO_3) 0.2 mol.dm^{-3};

SOLUTION 3- A) sodium carbonate (Na_2CO_3) 0.1 mol.dm^{-3} + disodium EDTA 0.03 mol.dm^{-3} and B) ammonium nitrate (NH_4NO_3) 0.2 mol.dm^{-3} + sodium oxalate ($C_2Na_2O_4$) 0.06 mol.dm^{-3};
SOLUTION 4- A) sodium carbonate (Na_2CO_3) 0.1 mol.dm^{-3} + disodium EDTA 0.03 mol.dm^{-3} and B) ammonium nitrate (NH_4NO_3) 0.2 mol.dm^{-3} + ammonium acetate (CH_3COONH_4) 0.1 mol.dm^{-3}.

The procedures used for Si analysis include weighing 0.1 g of each source and transfer into in 250 cm^3 bottle autoclavable polypropylene. Then there were added 50 cm^3 of "A" solution (Na_2CO_3 or Na_2CO_3 + EDTA), it was shaken the bottle to homogenize the samples and then added to 50 cm^3 of "B" solution with new manual shaking. The bottles were taken to an autoclave for 1 hour at 121 °C. After autoclaving, the bottles were rest to cool and decant. The Si sources were also analyzed using Solution 1, using the methods described by Pereira et al. (2003), without autoclave and 5 days resting.

The samples were diluted 100x in a rate of 2 cm^3 of the extracts in polypropylene volumetric flask of 200 cm^3. An aliquot of 20 cm^3 was withdrawn for the Si determination through the formation of the beta-molibdosilicon, with add of 2 cm^3 sulfo-molybdenum solution (75 g of ammonium molybdate + 100 cm^3 of sulfuric acid per dm^3). After 10 minutes there were added 2 cm^3 of tartaric acid 200 g.dm^{-3} and after 5 minutes the complex was reduced with 10 cm^3 of ascorbic acid 3 g.dm^{-3} to produce the blue color. After one hour of rest the blue color intensity was measured in the spectrophotometer at 660 nm wavelength (Kilmer, 1965).

The analysis of variance was run using the software SAS, and the means were compared using the Tukey 5%. The Si uptake by the rice crop and the percentage of extracted Si in the Si sources (extracted Si / total Si * 100) for each extractant solutions were correlated.

Results and discussion

There was no significant difference in dry matter production of rice due to the Si sources used (Table 2), but the Si content showed differences reflecting the Si accumulation in the rice plants. The 11 treatments (LD furnace steel slag CSN-LD), 15 (AOD furnace steel slag Ac) and 16 (Phosphorus solub. Slag) had the highest Si contents in the dry matter while the treatment 4 (Blast Furnace Slag CSN-AF) was the source with the lowest level, being lower than the control. Vidal (2005) evaluated the

Si adsorption in the soil and found that certain Si forms in the soil or applied on soil can promote the adsorption or polymerization of Si in compounds of lower solubility. Although not very much known, these silicates may explain the reasons why some Si sources reduce the Si content in the soil as occurs with the blast furnace slags. These slags are generally of higher Si concentrations, in which a good part of Si is in the silica amorphous form and not in the silicate form. The Si content in dry matter also reflected in the Si extraction. The treatment 15 (AOD furnace steel slag Ac) was the one which presented the highest Si extraction, differing from the treatments 1, 3 and 4 with the lowest extractions. Similar results were obtained by Pereira et al. (2004).

Degradation of PCP in the planted rhizobox was most rapid at 2 or 3 mm from the root surfaces, followed by 1, 4, 5 mm (Fig. 1). Microbial biomass measured as total C_{mic} or PLFAs also varied as a function of distance from RC in planted soil. The highest microbial biomass at either PCP amended soil was found in the near-rhizosphere soils, especially in the 1, 2 and 3 mm soil layers, while the lowest microbial biomass occurred invariably in the far-rhizosphere layer (Fig. 1). The PCA figures of soil 1 suggest that the effect of the rhizosphere gradient resulted in changes not only quantitatively but also qualitatively in the microbial community, which was similar to those induced in the behavior of PCP. In Fig. 2, there appeared to be little separation between the layers of unplanted soil and the community in the > 5mm far-rhizosphere layer in the planted soil was more similar to the community in the unplanted soil. While as for the layers of planted soil, the dominant microbial community developed with the gradient influence of root exudates and PCP concentration, showing a clear shift from hydroxyl to saturated taxa, then to fungi, then to gram-negative bacteria and gram-positive bacteria, then to actinomycetes, and then to arbuscular mycorrhizal fungi (AMF). This kind of development in the microbial community resulted finally in the selective gathering of AMF, actinomycetes and partly bacteria in the 2 or 3 mm near rhizosphere, where the spiked PCP exhibited coincidently the highest degradation.

Table 3 shows the Si content obtained from sources by the extractors. There is, for the results, a significant variation of Si content in the sources, depending on the different extractors. The solution 01 was less efficient to evaluate the Si availability at the sources, differing from the other solutions, and this difference was greater in the solution 01 without the use of the autoclave. On the other hand, the solution 2 was the most efficient solution, also differing from the other ones.

Table 2 Effect of Si sources on dry mass yield, Si content in the dry mass of rice and total of Si extracted by rice.

Treat.	Dry mass yield		Si content in the dry mass		Si accumulated in the dry mass	
	- g.pot^{-1} -		- g.kg^{-1} -		- g.pot^{-1} -	
1.	24.1	a[(1)]	17.7	ad	425.1	bc
2.	27.7	a	20.9	ac	607.8	ab
3.	28.7	a	15.7	cd	450.3	bc
4.	26.9	a	14.4	d	386.7	c
5.	29.7	a	15.9	bd	470.1	ac
6.	27.5	a	17.9	ad	492.9	ac
7.	27.2	a	17.0	ad	462.7	ac
8.	25.2	a	18.8	ad	473.3	ac
9.	27.2	a	16.8	ad	457.0	ac
10.	27.9	a	19.4	ad	541.0	ac
11.	28.2	a	22.4	a	629.3	ab
12.	32.1	a	17.7	ad	569.7	abc
13.	29.2	a	21.7	ab	633.3	ab
14.	26.8	a	20.3	ad	543.4	abc
15.	31.9	a	22.2	a	676.2	a
16.	24.4	a	22.5	a	550.7	ac

17.	25.9	a	21.5	ac	556.8	ac
18.	26.4	a	17.5	ad	462.7	ac
19.	28.6	a	16.0	bd	487.8	ac
C.V.	15.4		12.1		16.5	
D.M.S. 5%	11.1		5.9		221.3	

(1) Means followed by the same letter in the column do not differ by Tukey ($P < 0.05$).

Table 3 Levels of silicon extracted from the sources applied in the treatments by solutions extractants.

Treat.	Without autoclave			autoclaved												Average	
	S1			S1			S2			S3			S4				
							------------------------ g.kg^{-1} ------------------------------										
2.	46.8	a(1)	C(2)	88.7	a	B	108.0	a	A	93.1	a	B	87.7	a	B	84.9	a
3.	0.9	d	C	3.1	ef	BC	20.5	de	A	18.4	eg	A	14.3	de	AB	11.5	gh
4.	0.7	d	A	3.0	ef	A	5.7	f	A	8.5	gh	A	7.2	ef	A	5.0	jk
5.	0.3	d	A	1.0	f	A	5.0	f	A	5.2	h	A	3.9	ef	A	3.1	jk
6.	1.8	d	B	4.8	df	AB	14.7	ef	A	15.2	fg	A	12.7	df	AB	9.8	hi
7.	0.0	d	A	1.1	f	A	2.3	f	A	2.7	h	A	2.5	f	A	1.7	jk
8.	0.1	d	A	1.3	f	A	3.1	f	A	2.2	h	A	1.1	f	A	1.5	k
9.	0.6	d	A	1.9	f	A	4.5	f	A	5.0	h	A	3.6	ef	A	3.1	jk
10.	6.3	b	B	7.4	df	B	27.3	cd	A	22.3	ef	A	23.1	d	A	17.3	f
11.	5.6	b	C	10.8	df	BC	23.5	ce	A	19.1	eg	AB	18.8	de	AB	15.6	fg
12.	2.3	cd	B	3.7	df	B	19.3	de	A	17.0	eg	A	18.0	de	A	12.1	gh
13.	16.1	b	BC	14.6	de	C	33.0	c	A	26.9	de	AB	29.2	cd	A	24.0	e
14.	13.8	bc	B	15.1	d	B	45.4	b	A	33.7	cd	A	35.3	c	A	28.6	d

15.	3.3	cd	B	4.2	df	B	27.5	cd	A	20.3	ef	A	20.9	d	A	15.2	fg
16.	47.2	a	C	58.9	b	BC	99.3	a	A	65.0	b	B	58.5	b	BC	65.8	b
17.	17.5	b	C	29.7	c	BC	49.5	b	A	40.3	c	AB	37.4	c	B	34.9	c
18.	0.3	d	A	1.1	f	A	10.6	ef	A	9.0	gh	A	8.8	ef	A	6.0	ij
19.	0.1	d	A	1.1	f	A	2.6	f	A	2.6	h	A	2.1	f	A	1.7	jk
Average	9.1		D	14.0		C	27.9		A	22.6		B	21.4		B		

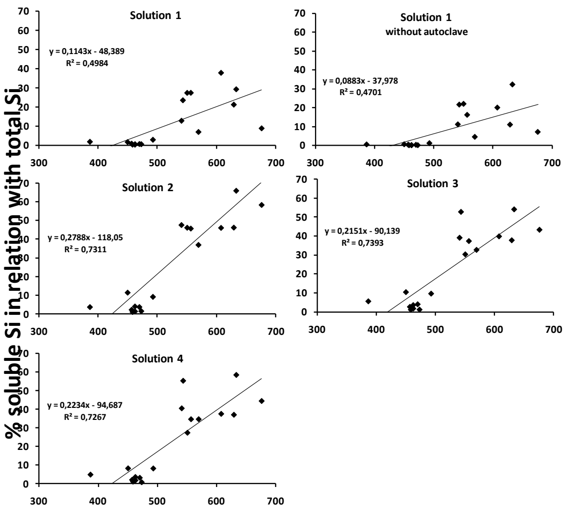
(1) Means followed by the same lowercase letter in the column do not differ by Tukey ($P < 0.05$).

(2) Means followed by the same uppercase letter in the row do not differ by Tukey ($P < 0.05$).

According to Pereira et al (2003), the choice of extractant to evaluate the Si availability in the sources should take into account the behavior of these sources. There are sources that have high total Si and this Si is not available to plants, and sources with low total Si, but available to plants; so the best way to evaluate their efficiency is through the Si percentage extracted by the solution, since the dose was based on the total content of Si for each source.

Wollastonite was the source that got the highest Si contents on average and in all the extraction solutions where it used the autoclave. However, with the solution 1 without autoclave, the phosphorous slag showed a higher Si content, but did not differ from Wollastonite. The phosphorous slag was the second source with higher Si content obtained by extractors on average, and it differed from other sources. It was following the steel slag that also differed from other sources. The sources with the lowest Si content were schist, blast furnace slags and silicate clay, showing that although they have higher total levels of Si, the forms of Si in these sources are less readily available.

In Figure 1, it was observed correlations between Si uptake by rice plants with the percentage of extracted sources in relation to the total Si by different extractants. The correlations obtained using solution 1 with and without autoclaving proved very close indicating that 1 h of autoclaving successfully replaced the resting time of 5 days to extraction solution, and the autoclaving accelerated the Si solubilization and increased the extraction (Table 3), but the Si extraction from solution 1 either with autoclaving or without autoclaving was smaller than the correlations of the solutions which were added EDTA.



Si extract of dry mass, mg.pot^{-1}

Fig .1 Correlation between Si extract of dry mass and percentage of soluble Si in relation with total Si of the sources.

All the solutions where EDTA was included showed satisfactory correlations between Si uptake by rice with the percentage of Si obtained by the extracting solutions, but the more solubilization happened with solution 2, which proved to be the easiest and the best application.

An obstacle in the evaluation of fertilizers as well as the ability to provide Si for plants is the determination of a reliable method. Testing the method of extraction using resin in 20 different slag samples, Kato and Owa (1997) obtained a significant correlation at 1% (R = 0.68) between Si uptake by rice plants and Si of the slag, and they considered the method as very satisfactory. In another study, using only six Si sources, Barbosa Filho et al. (1996) obtained the highest correlation (R = 0.94) with the column leaching followed by the resin method, with R = 0.89. The column leaching identifies mainly the materials with Si available, but it does not quantify Si in the sources. The sodium carbonate + ammonium nitrate has been used as an alternative, but the methodology proposed by Pereira et al (2003) presents a low Si extraction and in addition there is a high waiting time for obtaining results (5 days). The autoclave adoption and the EDTA addition in the extraction solution presented a promise to increase the extraction and reduce the time for analysis.

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Response of rice to soil and foliar applied silicon sources

Prakash NB, Chandrashekhar N

Department of Soil Science and Agricultural Chemistry,

University of Agricultural Science, Bangalore, GKVK, Bangalore, India

Email: nagabovanaliprakash@rediffmail.com

Abstract

Silicon is the second most abundant element in the Earth's crust and in agricultural soils, it exists primarily as silicate minerals. Most of these minerals are largely insoluble, though low levels of mono and polysilicic acid invariably found dissolved in the soil solution. Plants assimilate Si solely as monosilicic acid. The ability of soils to meet plant requirements for Si depends upon the Si solubility and the dissolution kinetics of various silicate minerals under typical soil conditions is not well understood. Similarly, the response of crops to foliar Si (silicic acid) application at different growth stages of the rice crop is not well established.

A series of experiments conducted using Rice Hull Ash (RHA), Calcium silicates, silicagel and foliar silicic acid as different sources of silicon indicated a promising results in increasing growth and yield of rice. All these sources have wide variation in their nature of solubility, form and amount of silicon. The efficacy varied with silicon concentration and/or availability in the amendments/sources, amount of amendment/sources supplied. The effect of RHA as source of Si in rice cultivation indicated that continuous application of 2 to 4 t ha^{-1} increased the rice yields. Studies conducted with 3 and 4 t calcium silicate ha^{-1} also revealed a significant increase in grain and straw yield of rice. Repeated number of studies conducted with foliar silicic acid revealed that grain and straw yields were significantly increased due to the application of 2 and 4 ml L^{-1} along with need based pesticides. Regular application of different sources of Si in different agro-climatic situations also increased the tissue content of Si and provided the best protection from both biotic and abiotic stresses in rice suggesting the need for continuous supply of Si source.

The benefits of silicon fertiliser for sustainably increasing crop productivity

Prentice P., Crooks R.

Agripower Australia Limited, Suite 11, Level 3, 50 Stanley Street Darlinghurst , NSW 2010, Australia. Email: peterp@agripower.com.au

Introduction

Silicon (Si) exists in all plants grown in soil and its content in plant tissue ranges from 0.1 to 10% (Epstein, 1999). While its essentiality in plant growth has not yet been clearly established, Si is considered a nutrient of agronomic essentiality for high Si-accumulating crops such as rice and sugarcane, in that its absence causes imbalances of other nutrients resulting in poor growth, if not death of the plant (Savant et al, 1999).

Numerous laboratory, greenhouse and field experiments have shown the benefits of silicon fertilisers for agricultural crops and the importance of silicon fertilisers as a component in sustainable agriculture (Belanger et al, 1995; Laing et al, 2006; Ma and Takahashi, 2002, Matichenkov and Calvert, 2002). The beneficial effects of Si are mainly associated with its high deposition in plant tissues, enhancing their strength and rigidity. This increased mechanical strength reduces lodging and pest attack and increases the light-receiving posture of the plant, increasing photosynthesis and hence growth (Epstein, 1999). The deposition of Si in the culms, leaves and hulls is also purported to decrease transpiration from the cuticle thereby increasing resistance to low and high temperature, radiation, UV and drought stress (Ma et al, 2006). Indeed, the beneficial effect of Si is more evident under stress conditions. More recent studies suggest that Si also plays an active role in the biochemical processes of a plant and may play a role in the intracellular synthesis of organic compounds (Fawe et al, 1998; Ma et al, 2006).

Plants differ in their ability to accumulate Si (Ma et al, 2006) but in order for any plant to benefit from Si it must be able to acquire this element in high concentrations. Plants can only absorb Si in the form of soluble monosilicic acid, a non-charged molecule. Monosilicic acid, or plant available silicon (PAS), is a product of Si-rich mineral dissolution (Lindsay, 1979). Different Si sources have different dissolution rates (and therefore PAS); where the solubility of quartz is very low compared to soluble amorphous silica (Savant et al, 1999).

The presence of Si in nutrient solutions has also been reported to affect the absorption and translocation of several macro- and micro-nutrients (Epstein, 1999). More recently, Si-amendments were shown to reduce the leaching of phosphate, nitrate and potassium (NPK) (Matichenkov and Bocharnikova, 2010). This is of particular importance in Australia where leached phosphates and nitrates promote eutrophication in the Great Barrier Reef and Western Australian waterways. Nutrient leaching also results in soil nutrient deficiencies that require additional fertilisation. Given that the leaching of NPK fertilisers poses a significant environmental and economic concern, Si-amendments that are able to mitigate these risks are worthy of further investigation.

To date, a large amount of the reported research, field trials and commercial applications have been with calcium silicate slags, an easily obtained by-product of furnaces. Silicate slag has been used extensively in the USA; however, slags can be variable in composition and although they have high concentrations of total Si, often only a small proportion is easily solubilised (Gascho, 2001). An important consideration with silicate sources derived from industrial by-products is the possible high level of heavy metals associated with their origin or processing (Berthelsen et al, 2003). These are not only toxic to plants but leach into waterways causing environmental damage. Likewise, cement and cement building board waste can contain heavy metals (Muir et al, 2001).

Amorphous diatomaceous earth (DE) is known to be a good source of plant available silicon as amorphous silica is more easily solubilised than crystalline silica. Amorphous DE is also expected to exhibit soil-conditioning properties given its high water holding capacity, without the heavy metal contaminants of slags. The purpose of the analyses and trials presented here is to understand the efficacy of AgriPower Silica (which is rich in DE) in soil fertility and as a sustainable soil conditioner, while reducing the negative impacts of chemical fertilisers on the environment.

Gascho (2001) postulated that before a Si amendment can be considered useful for agricultural applications it should meet a number of criteria, such as solubility, availability, suitable physical properties and be free of, or have acceptably low levels of contaminants. AgriPower Silica meets these four criteria.

Furthermore, we set out to create a product with an enhanced level of plant available silicon and achieved this by creating an Enhanced Agripower Silica. This green Si amendment delivers a high level of plant available silicon while maintaining suitable physical characteristics (granular or powder and easy to apply) with none of the contaminants of heavy metals and cristobalite which are often present in silicate slags.

AgriPower Silica

AgriPower Silica is mined and processed in Australia and largely comprises the silica-rich Diatomaceous Earth (DE). Diatomaceous Earth is a naturally occurring substance, the fossilized remains of salt or freshwater organisms called diatoms. Diatoms are predominantly composed of amorphous Silica (SiO_2). The fossilised skeletal remains (a pair of symmetrical shells – frustules) vary in size but are typically 10 to 200 microns across and have a broad variety of shapes, from needles to discs or balls. The frustules present in AgriPower Silica has the ideal barrel shape (see Figure 1 below). The morphology and porosity of the DE present in AgriPower Silica are attributed with enabling large amounts of moisture to be absorbed from its surroundings.

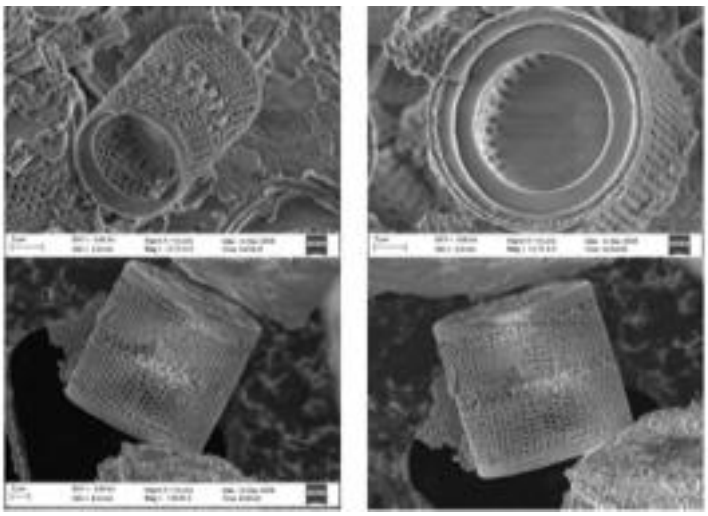

Figure 1: Scanning electron microscopy images of samples of Agripower Silica showing the morphology of individual diatoms

Being free of crystalline silica (cristobalite) is an important consideration when sourcing DE products. It is often a specification required by occupational, health and safety (OH&S) regulations as the inhalation of crystalline silica is a health hazard for the lungs causing the deadly disease; silicosis.

Soon to be the largest producer of freshwater diatomaceous earth, Agripower sources their diatomaceous earth from its deposits that are free of cristobalite. Quantitative X-Ray Diffraction Analysis performed independently by AGR Science and Technology Pty Ltd confirmed that cristobalite was not present.

Soil Conditioning Properties

The soil conditioning properties of AgriPower Silica were evaluated in four different soils (in triplicate): clay, sand, potting mix and turf substrate. Containers were charged with these soils and AgriPower Silica was added at increasing concentrations: 0 (control), 3, 5 and 10% (Sadgrove, 2006):

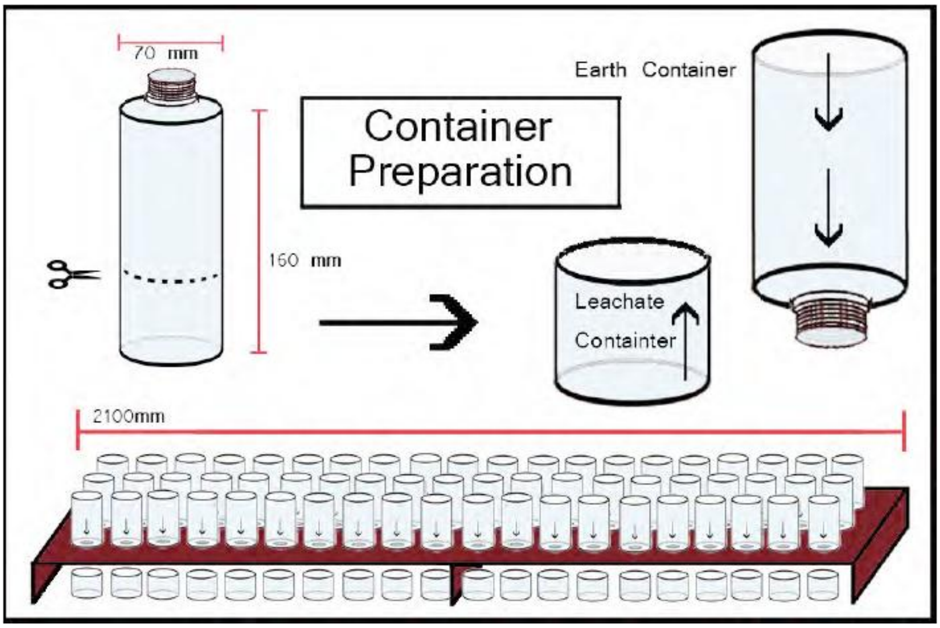

Figure 2: Structural configuration that was used to carry out the pot trials

Soil nutrient properties

The containers were pre-charged with a standard nitrogen, potassium and phosphorous fertiliser product followed by a standard application of water that was passed through each container at specific sampling intervals. The leachate volumes were analysed and subtracted from the total nutrient load in order to determine nutrient losses. It was found that AgriPower Silica facilitated a significant improvement in nutrient retention compared to the control in all soil types. Results for all four soils are shown in Figure 3:

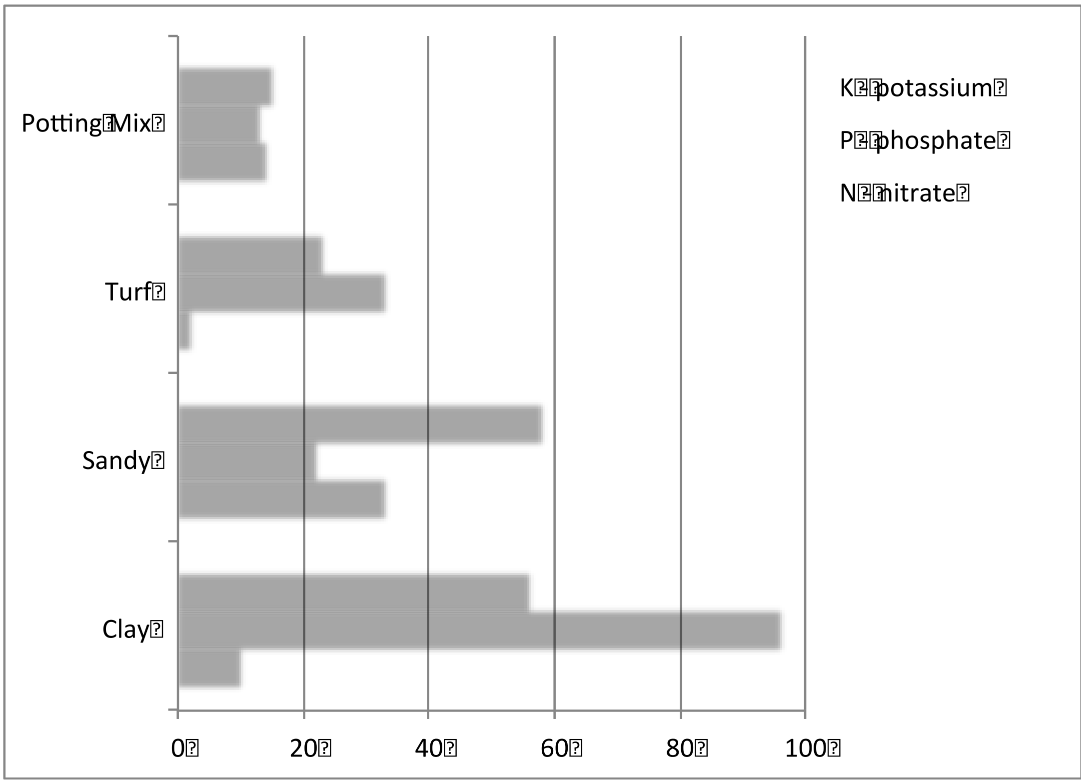

Figure 3: Percentage increase in nutrient retention *above the control* (at day 7) for soils amended with 5% Agripower Silica [measurements taken of the leachate using the Modified Morgan Technique]

Figure 3 shows that there is an increase in the retention of all three nutrients (potassium, nitrate and phosphate) in all four soils amended with 5% AgriPower Silica. Sandy and deeply weathered soils usually have a low nutrient retention (Sims et al., 1998) therefore the increased retention of nutrients in the sandy soil due to the inclusion of AgriPower Silica is impressive.

It is well known that diatomaceous earth, a large constituent of AgriPower Silica, has a good cationic exchange capacity, and its this capacity which is attributed with retaining the cations; potassium and ammonium.

The improved retention (reduced leaching) of phosphate could potentially be attributed to the action of several mechanisms; including the formation of a complex between the phosphate ion and surface hydroxyls of the amorphous silica (Leung and Kamara, 1998).

The improvement in nutrient retention in various soils by AgriPower Silica demonstrated in Figure 3 has significant implications for reducing the environmental and economic impact of leached nutrients.

Soil moisture properties

Various cycles of watering and drying were executed using the same configuration as in Figure 2. Table 1 shows the moisture content of each soil type, as a percentage of the control.

Table 1: Percent moisture content compared to the control as a function of percent AgriPower Silica after 11 days drying phase

	Potting Mix	Clayey Soil	Turf Substrate	Sandy Soil
Control	100	100	100	100
3	105	103	158	101
5	104	84	203	116
10	114	91	274	141

In the potting mix, the turf substrate and sandy soil; moisture retention significantly increased with AgriPower Silica. In contrast, the clayey soil showed a decrease in retained moisture. The sandy soil and turf substrates improved the moisture retention by up to 41% and 174%, respectively.

During the 11 days of drying, the moisture content of each soil decreased at a similar rate and AgriPower Silica had the lowest percent moisture loss throughout the 11 days of drying, even though it held the greatest quantity of water.

In summary, AgriPower Silica improved water retention in two ways:

1) During watering events soils with AgriPower Silica held a greater bulk quantity of water, and

2) Soils with AgriPower Silica dried at a slower rate.

These relationships were proportional to the amount of AgriPower Silica that was added to the soil.

Plant available Silicon properties

With the recognition that Si is an important element for the growth of plants, many methodologies have been used to determine the plant available Si of Si amendments, although there has been no systematic survey of these methodologies (Sauer et al, 2006). The chemical extractant methods used to estimate the PAS of the Si source often do not correlate well with the plant uptake of Si once applied to the soil therefore it is important to carefully select the extraction method.

Three commonly used extractants were used to measure the extractable Si of AgriPower Silica and other Si amendments:

- Alkaline extractant: NH_4NO_3 and Na_2CO_3 (Pereira et al, 2003)
- Acid extractant: 0.005M H_2SO_4 (described in Berthelsen et al, 2001)
- Neutral extractant: 0.01M $CaCl_2$ (described in Berthelsen et al, 2001)

The extractions were carried out at different extraction ratios as the availability of monosilicic acid (PAS) varies with dilution, a soil phenomenon attracting much attention in the literature.

The various Si amendments that are discussed later in this article are compared in Figures 4, 5 and 6 below via these three different extraction techniques. The description of the Si amendments is given below:

Table 2: Description of products analysed in Figures 4-7

	DESCRIPTION
Lab grade calcium silicate	Riedel-de Haën product 13703
Slag 2	Phosphorous furnace byproduct
Enhanced AgriPower Silica	Described in following section
Slag 1	Sourced from Asia
AgriPower Silica	Described in preceding section
Wollastonite	A natural calcium silicate

An acid extraction was carried out on all the Si amendments listed in Table 2, given its historic popularity as a chemical extractant:

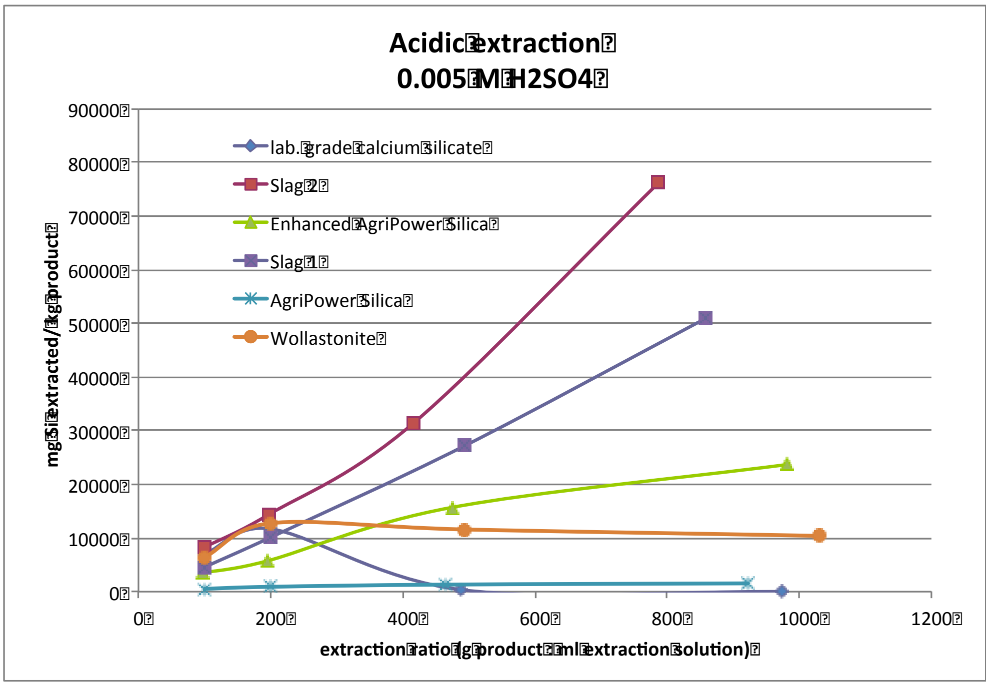

Figure 4: mg Si extracted per kg product by acidic extraction as a function of extraction ratio for various Si amendments

The sulphuric acid (H_2SO_4) attacks silicates, dissolving calcium silicates and any clay minerals present in the sample or soil. Sauer et al (2006) also suggests that this extractant acts both mechanically and chemically so that levels of plant available Si are highly overestimated. Therefore it is not surprising that the slags show such high extractable silicon via this method compared to the AgriPower Silica given that calcium silicates are soluble in acid, however, this level of extractable silica is unlikely to be indicative of the plant available silicon.

An alkaline extraction was also performed on these same Si amendments, following the method of Pereira et al (2003):

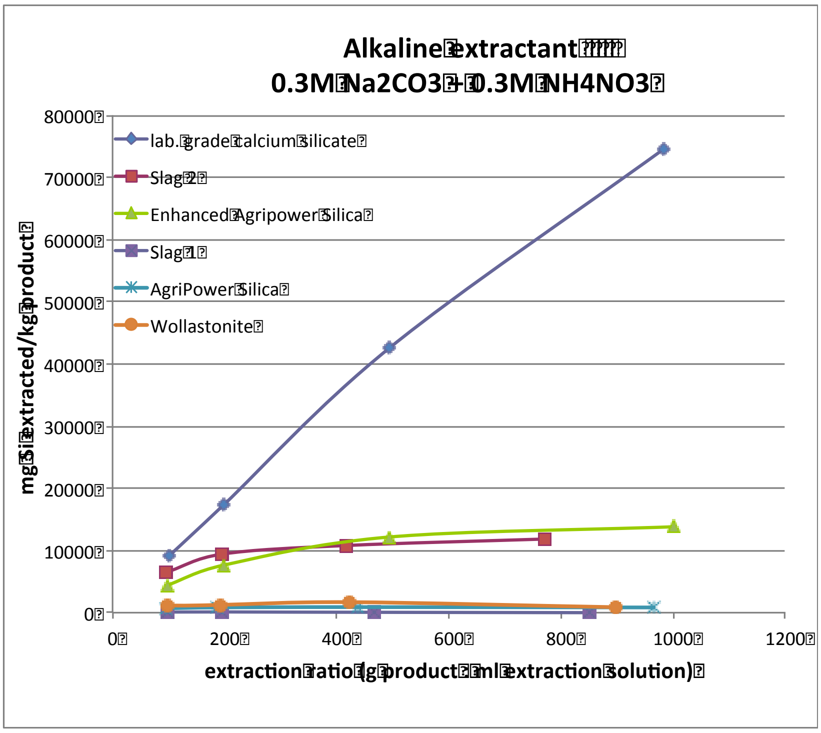

Figure 5: mg Si extracted per kg product by alkaline extraction as a function of extraction ratio for various Si amendments

The method of Pereira et al (2003) was developed for measuring extractable silica from calcium silicate, where slag was one of the test products. Therefore not surprisingly the pure, lab grade calcium silicate shows the highest level of extractable silicon, followed by the Enhanced AgriPower Silica product and the other Si amendments.

And finally, extractions were performed using a neutral extraction of 0.01M $CaCl_2$:

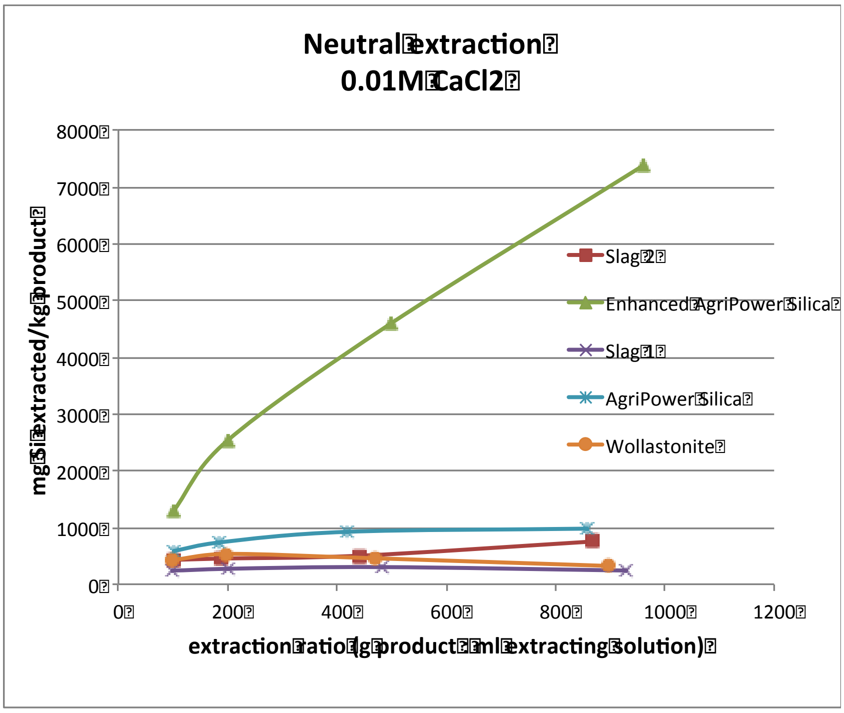

Figure 6: mg Si extracted per kg product by neutral extraction as a function of extraction ratio for commonly used extractants

In order to focus on the Si amendments of practical relevance, the scale of Figure 6 was adjusted, which excludes the data points for the lab grade calcium silicate (the extractable Si of the lab grade went from 7,400mg Si/kg product at an extraction ratio of 100 to 59,300 mg Si/kg product at an extraction ratio of 980).

The Enhanced AgriPower Silica yields the highest extractable silica of the Si amendments, followed by AgriPower Silica. The two slags and the wollastonite have significantly lower levels than these two products across all the extraction ratios.

The neutral extraction method measures the easily soluble silica and is therefore cited as being a closer approximation to plant available silicon compared to the other methods (Sauer et al, 2006 and Berthelsen et al, 2001).

Figures 4 to 6 clearly demonstrate that is important to carefully choose the extraction method as the extraction process itself may solubilise more Si compounds in the Si amendment and/or soil than usually available to plants in the natural environment (Muir et al, 2001). Also, Figures 4 to 6 demonstrate the variability in extractable Si that is possible between slags of different sources.

The neutral extraction result in Figure 6 confirms that AgriPower Silica has a significant level of extractable silicon. The high availability of plant available silicon measured in AgriPower Silica is attributed to the diatomaceous earth, which is composed of amorphous silica.

The true test of plant available Si is through plant tests, described in the next section.

The efficacy of AgriPower Silica in Field Trials

AgriPower Silica was included in a strawberry demonstration trial in Queensland, Australia at 250, 500 and 1000kg/ha. The AgriPower Silica was applied in addition to the normal fertiliser application (control) and was found to yield significant improvements in growth and yield compared to the control, with the following observations:

- ✓ Significantly increased root development/root mass by 100-200%
- ✓ Increase in flowers, foliage, crown size and fruit
- ✓ Brix was increased and maintained later in the season
- ✓ Increase in survival rates of runners
- ✓ Significantly increased soil moisture while not being water logged.
- ✓ Ability to increase uptake of key nutrients (N, P, K) during wet period when nutrients are typically leached away from the root zone
- ✓ Increased yields by an average of 35%

Recommended application rates would be from 200 - 500kg / ha pre plant depending on the soil condition.

Treated – 500kg / ha top and 1000kg / ha bottom

Control – Untreated top and bottom

Figure 7: Comparison between the control and AgriPower Silica (Treated) grown strawberries

An analysis of the soil showed significant improvements in the level of nutrients retained in the soil treated with AgriPower Silica compared to the control:

Table 3: Soil analysis comparison [ASPAC[1] Accredited lab]

	Treated 500kg/ha	Untreated control	Effect
Nitrate – N (mg/kg)	84	59	42% increase
Colwell P (mg/kg)	145	90	61% increase
K (mg/kg)	295	209	41% increase
Si[2] (mg/kg)	168	145	16% increase
ECEC* (cmol/kg)	6.4	5.9	Increased

[1] ASPAC: Australasian Soil and Plant Analysis Council
[2] BSES method: H_2SO_4 extraction

** soil cationic exchange capacity*

The improved retention of nutrients in the AgriPower Silica treated soil resulted into an increased uptake of these key nutrients by the strawberry plants compared to the control:

Table 4: Sap analysis (initial flower/fruit) comparison [ASPAC Accredited lab]

	Treated 500kg/ha	Untreated control	Effect
Nitrate (ppm)	4,291	3,812	13% increase
Phosphate (ppm)	441	308	43% increase
Potassium (ppm)	4,983	4,430	12% increase
Silicon (mg/l)	27	15	80% increase

A demonstration study was carried out in Queensland, Australia on sweet potato. AgriPower Silica showed significant improvements over the control[3]:

- ✓ The inclusion of DE into the nutrition program as a base soil conditioner pre plant delivered a 47% improvement in yield and gross margin
- ✓ This is a significant result given this crop received approx 60 inches of rain (most unusual) resulting in a highly leached growing environment.
- ✓ The increased retention and uptake of nutrients by the plant is evident in the yield increase.

The recommended rate would depend on the silicon content of the soil. The above results were obtained at 200kg/ha of AgriPower Silica.

And finally observations from Table Grape field trials in Victoria and Queensland, Australia reported:

[3] Normal fertiliser applications, broadcast basal dressing pre-planting

- ✓ A revised nutrition program that now replaces 300kg/ha of superphosphate (SSP) with 200kg/ha AgriPower Silica and 75kg/ha SSP, yielding an economic and environmental benefit
- ✓ Increased root zone and no fruit split

Summary

The improved crop growth and yield observed in these field trials can be attributed to diatomaceous earth's ability to:

- Increase nutrient retention and plant uptake (Figure 3, Tables 3 & 4),
- Improve moisture retention (Table 1), and
- Deliver plant available silicon (Figure 6, Tables 3 & 4)

The improved soil retention and plant uptake of key nutrients indicate the potential for AgriPower Silica to displace a significant portion of NPK fertilisers. In particular, AgriPower Silica can help reduce urea and phosphate inputs thereby reducing costs and significantly reducing the environmental impact of these fertilisers.

An enhanced silicon amendment

Calcium Silicate ($CaSiO_3$) from slag has been used by the Hawaii sugar industry for years (Medina-Gonzales, 1988) and to increase sustainable rice production in Japan (Ma, 2009). Kato and Owa (1997) proposed several possible reactions occur in the soil after the addition of calcium silicate. Calcium silicate (readily released fraction) is dissolved in the soil, which generally has a low/neutral pH, producing monosilicic acid (or plant available silicon - PAS) for plant uptake. The Ca^{2+} resulting from this dissolution will be continuously absorbed onto the soil colloids, releasing protons from the hydroxylated surfaces, gradually making the system more acidic, which in turn enhances the dissolution of Si (slowly released fraction) from the calcium silicate. These dissolution kinetics potentially favour the delivery of an enhanced level of PAS. Calcium silicate is also hypothesized to assist in improving soil acidity, a more effective method than liming, which reduces the uptake of Si from the soil.

Calcium silicate occurs naturally as wollastonite although the availability and solubility of wollastonite is variable and can be low compared to slag silicates (Muir et al, 2001). However, slag has its downfalls. It can also be quite variable in composition in terms of its plant available silicon and most importantly silicate sources derived from industrial by-products such as slag can contain high level of heavy metals associated with their origin or processing (Berthelsen et al, 2003).

We set out to synthesize an Enhanced AgriPower Silica product that mirrored the performance of calcium silicate, without the contaminants of slag.

Synthesis of the Enhanced AgriPower Silica

The Enhanced AgriPower Silica was characterized via several techniques to identify its morphology and composition. Thermogravimetric Analysis (TGA) is a technique used to characterise materials as a function of temperature and measures when phase changes occur. As interpreted from the TGA spectra below, the Enhanced AgriPower Silica maintains its amorphous form up to 761°C, above which the product transforms to a crystalline product. This result coupled with an X Ray Diffraction Analysis confirmed that the Enhanced AgriPower Silica is not crystalline.

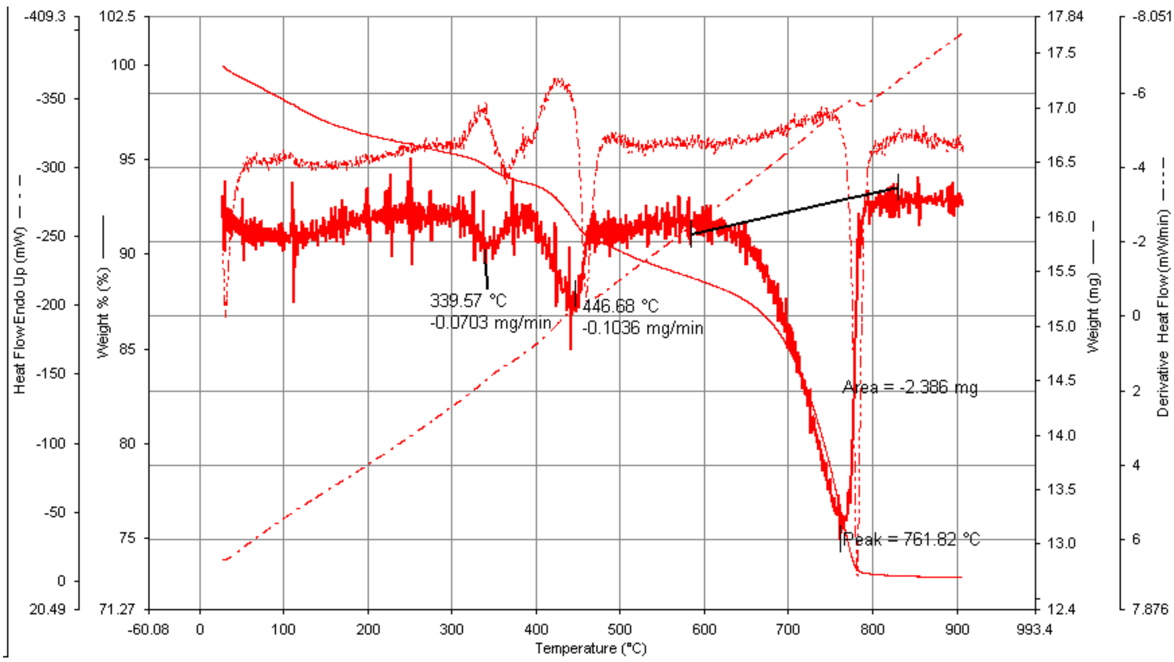

Figure 8: TGA spectrum of the Enhanced AgriPower Silica

A lack of crystallinity is important for two reasons:

- Avoids the formation of cristobalite, and
- Amorphous products are expected to be more plant available

A Scanning Electron Microscope (SEM) image of a sample of the Enhanced AgriPower Silica in Figure 9 below reveals a product consisting predominantly of flocs with a porous structure and large specific surface. The average particle diameter of the reaction product is about 10 microns. Residual frustules of diatomaceous earth are evident in the micrograph as well and would lend soil-conditioning properties to the product.

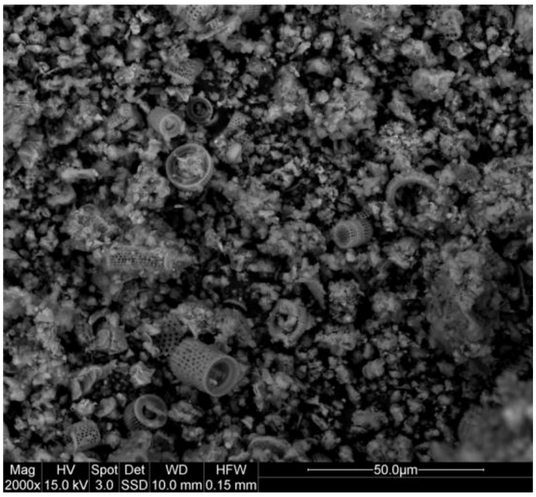

Figure 9: SEM images of a sample of Enhanced AgriPower Silica

Plant Available Silicon

Figure 10 reports results using the direct chemical extraction via the neutral extraction method (0.01M $CaCl_2$) described previously in regards to Figure 6. This extraction method provides a measure of the readily available silicon that is present at the pH and conditions of the soil and is therefore unlikely to overestimate the plant available silicon.

The extractable Si of the Enhanced AgriPower Silica was measured in an iterative process to develop an optimised product. Figure 10 compares the optimised

Enhanced AgriPower Silica to several other Si amendments.

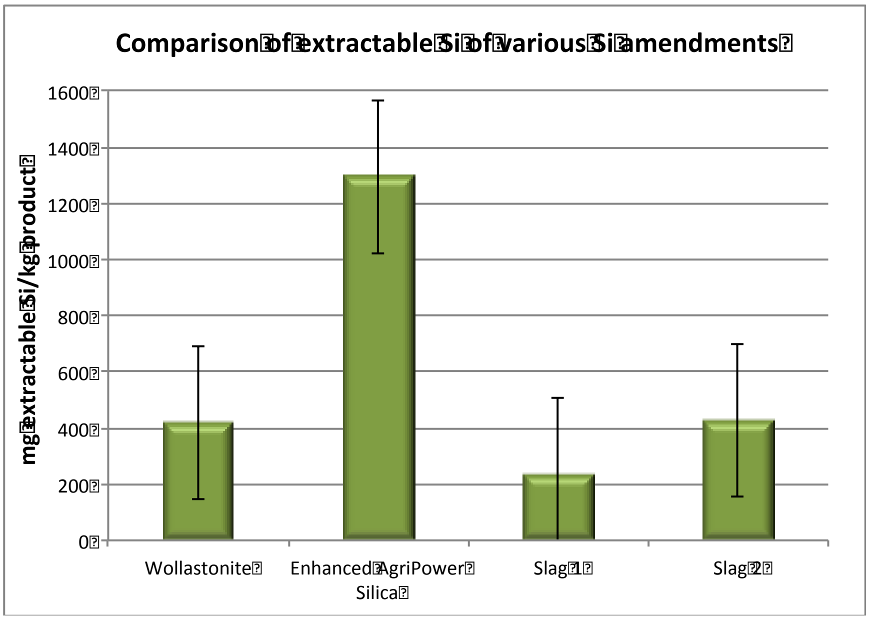

Figure 10: Comparison of the extractable Si in various Si amendments using the neutral extraction method (0.01M $CaCl_2$) [data selected from Figure 6 at an extraction ratio of 100]

The extractable Si of The Enhanced AgriPower Silica as shown in Figure 10 is significantly higher compared to wollastonite, slag 1 and slag 2. This compelling result warranted further investigation into the soils themselves in order to quantify the improvement in soils amended with The Enhanced AgriPower Silica.

While many chemical extractants may provide the first estimate of the potential value of a Si source, the more reliable method of determining the PAS of a Si source is through indirect chemical extraction after soil incubation (Savant et al, 1999). Soil incubation trials were carried out in 4 different soils typical of Queensland, the properties of which are reported in Table 5 below.

Queensland sugarcane soils are considered deficient in Si if the concentration is less than 10-15mg Si/kg dry soil following extraction with 0.01M $CaCl_2$ (Muir et al, 2001). Therefore the Galmare and Hawkins soils are classified as being deficient in Si and are expected to be responsive to Si amendment.

Table 5: Description of the four Queensland soils used in soil incubation trials

Soil	Description**	Si* ($CaCl_2$)	Si* (H_2SO_4)
PinGin (Innisfail)	Acidic Dystrophic Red Ferrosol	14.4	284
Galmare (Mena Creek)	Acidic Dystrophic Red Kandosol	3.7	4
Hawkins (Ingham)	Fluvic Stratic Rudosol	4.4	93
Bundaberg		23.7	214

**measured in mg extractable Si per kg product*

***Isbell (1996), Murtha (1986), Wilson and Baker (1990)*

Soil incubation trials were carried out on the Enhanced AgriPower Silica using a $CaCl_2$ extraction given that this extractant has a similar ionic strength to the soil solution and only extracts the easily soluble Si fraction. The Enhanced AgriPower Silica was run at rates from 100 to 750 kg/ha[4] in all four soils and the soils were incubated for at least one week before the extractions were carried out.

There is a significant increase in the extractable Si (or plant available silicon) in all four soils amended with the Enhanced AgriPower Silica. The extractable Si generally increases with the application rate, and a similar trend was found for acid extractable Si[5]. There is a significant increase of up to 120% extractable Si from the Galmara and Hawkins soils. These soils are the most deficient in Si (Table 5) and therefore stand to benefit significantly from the Enhanced AgriPower Silica.

[4] The rate experienced in a field trial could be different depending on how deep the product is incorporated into the top layer

[5] The $CaCl_2$ extraction method is preferred by the authors of this paper given its close approximation to soil solution conditions. The acid extraction method (H_2SO_4) tends to exaggerate the extractable Si as it dissolves other minerals, clays, in the soil

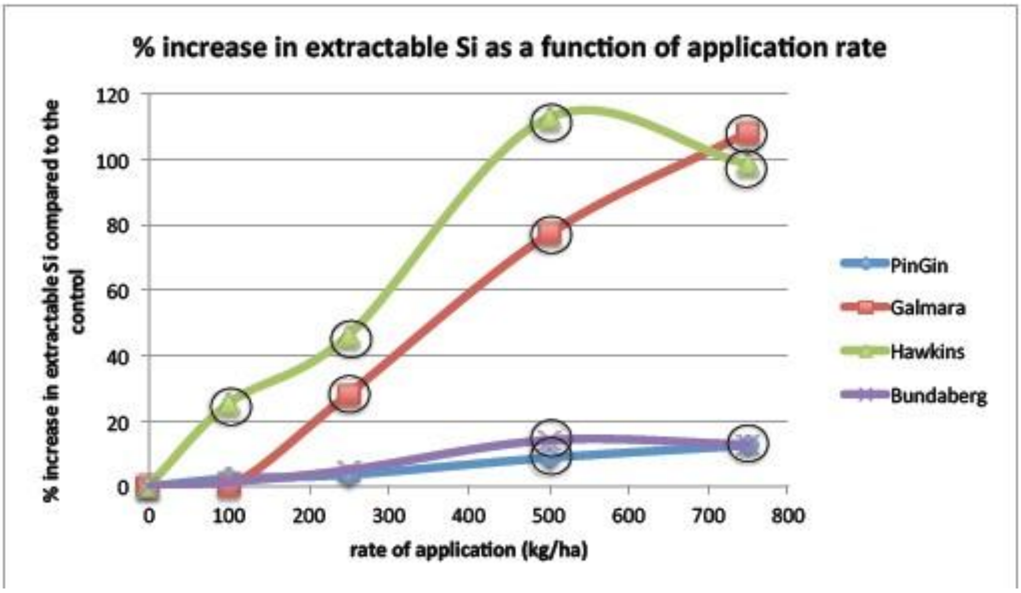

Figure 11: Percentage increase in extractable Si ($CaCl_2$ method) compared to the control – soil alone – at different application rates of the Enhanced AgriPower Silica in four different Queensland, Australia soils (data points in circles are significantly different from the control based on three replicates).

Conclusion

The inclusion of AgriPower Silica into the nutrition program of several crops as a base soil conditioner ahead of planting delivered significant improvements in crop productivity and the gross margin per hectare grown. This was attributed to diatomaceous earth's ability to increase nutrient retention and plant uptake, improve moisture retention and deliver plant available silicon.

NPK (Nitrogen, Phosphorous, Potassium) based fertilisers are often considered a necessary part of intensive crop cultivation to improve crop production. Problematically, these fertilisers are a major source of water pollution due to Australian soils' susceptibility to leaching. The initial results presented in this paper support the argument that AgriPower Silica could improve the soil retention and plant uptake of these key nutrients, indicating the potential for AgriPower Silica to displace a significant portion of NPK fertilisers. A reduced requirement of urea and phosphate inputs would provide an economic benefit and reduce the environmental impact of these fertilisers. AN improved crop yield due to the application of AgriPower Silica similarly provides an economic benefit.

Calcium Silicate slag as an industrial by-product is a proven Si-rich amendment, however, it carries the risk of polluting soils and natural waters. An Enhanced AgriPower Silica was developed based on the natural AgriPower Silica. This product is free of the contaminants typically found in slags and delivers a significant amount of plant available silicon in all the four soils tested. The level of Si in the most Si-deficient soils was increased by 120% and therefore stands to benefit significantly from the Enhanced AgriPower Silica.

Acknowledgements

We are immensely grateful to Suzanne Berthelsen for her analysis and insight into plant available silicon and to John Provis for his assistance and interpretation of mineral analyses.

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Practical application of silicon-rich minerals

Quero E [1, 2]

1.Laboratory of analysis for the diagnosis of patrimony. El Colegio de Michoacán A.C., extensión La Piedad, Cerro de Nahuatzen 85, Fracc. Jardines del Cerro Grande, C.P. 59370, La Piedad, Michoacán, México

2.Dolomita Agrícola de México S.A. de C.V. Ejército Nacional 1112-503, Polanco C.P. 11560 México D.F.

Email: quero@colmich.edu.mx, quero@loquequero.com, queroed@hotmail.com

Abstract

In systems of intensive production, agricultural and aquaculture, in different agro-ecological zones of Mexico, it is used as scenario to study the biogeochemical cycle of silicon, and develop a productive and sustainable management in crops of corn, wheat, beans, barley, oats, sorghum, rice, strawberry, pepper, avocado and shrimp.

The silicon flow is studied using a low vacuum scanning electron microscope, coupled with energy dispersive X-ray spectrometer (EDS) and X-ray fluorescence spectrometry (XRF).

Soil analyses showed a large gradient of demand for silicon-rich primary minerals. The re-mineralization was conducted with a natural mineral with an average concentration of SiO_2 (34 %), C (36 %), Fe_2O_5 (1.5 %), CaO (13 %), MgO (3 %), K_2O (3 %), P_2O_5 (9 %), ZnO (2 %), available biogeoquímicamente. This mineral is applied annually to the soil, preferably at the beginning of the plantation, in a dose of 500 to 1000 kg ha^{-1}, according to the demand soil-plant.

To improve the dissolution and mobilization of silicon and other minerals are required increase in soil organic matter content and improve the density and diversity of microorganisms.

The results show an improvement in primary productivity, resistance to biotic and abiotic factors, minimization of the use of chemical inputs. Correlate with the accumulation of Silicon in the epidermis of leaves through the biosilicification process, which is accompanied by the mineralization of the phosphorus.

Silicon induced molecular and structural responses during the interaction between miniature roses and the biotrophic pathogen *Podosphaera pannosa*

Radhakrishna S [1,3]*, Birgit J [1], Christensen LP [3], Fretté X [3], Shetty NP [1], Hansen M, Hansen CW [2], Starkey KR [2], Jørgensen HJL [1]

1.Department of Plant Biology and Biotechnology, Faculty of Life Sciences, University of Copenhagen, Thorvaldsensvej 40, DK-1871 Frederiksberg C, Copenhagen, Denmark,

2.Department of Horticulture, Research Centre Aarslev, Faculty of Agricultural Sciences, Aarhus University, Kristinebjergvej 10, DK-5792 Aarslev, Denmar,

3.Institute of Chemical Engineering, Biotechnology and Environmental Technology, Faculty of Engineering, University of Southern Denmark, Niels Bohrs Allé 1, DK-5230 Odense M, Denmark,

Email: rsh@life.ku.dk

Abstract

Miniature potted roses are a very important ornamental crop and rose powdery mildew caused by *Podosphaera pannosa* is a huge and economically significant problem all over the world, particularly in greenhouse potted roses. The disease results in poor quality and low marketing value and environmental considerations necessitate increasing restrictions on the use of pesticides. Therefore, eco-friendly methods for plant disease control in a sustainable way need to be developed.

This study investigated the possibility of controlling powdery mildew in miniature potted roses using Si as inducer. A bioassay was established with four rose genotypes, i.e., ‘99/9496-19’, ‘95/5166-1’, ‘98/8285-1’ and ‘Smart’, representing different genetic backgrounds and different levels of susceptibility. Plants were watered with a nutrient solution containing either 3.6 mM Si (100 ppm) supplied as K_2SiO_3 (Si+) or no Si (Si-) before inoculation and were inoculated with a defined density of a virulent powdery mildew isolate.

Si application increased leaf Si-content two to four fold compared to control plants. Confocal microscopy showed that Si-accumulation was larger in Si+ than in Si- plants and that deposition mainly occurred in the apoplast, particularly in epidermal cell walls. Si-application delayed the onset of disease symptoms by one to two days and disease severity was reduced by up to 49%. The largest reduction was

found in the two most resistant genotypes, which also had the highest increase in Si-uptake. The Si-induced disease protection was accompanied by increased formation of papillae and fluorescent epidermal cells (FEC) as well as accumulation of callose and H_2O_2, especially at the sites of penetration and in FEC, which are believed to represent the hypersensitive response. Furthermore, deposition of callose and accumulation of H_2O_2 were involved in the defence of rose against *P. pannosa*, as evidenced by use of inhibitors and scavengers. Total peroxidase activity was generally increased by Si-application and upon infection. Catalase activity showed an early increase, especially in Si- plants, after which time the activity decreased. Two genes were differentially up-regulated and here Si application enhanced the transcript levels, especially in inoculated plants. Elevated transcript levels of *hsr203J* indicate that FEC represent the hypersensitive response.

Si treatment of ‘Smart’ also increased the concentration of phenolic acids and flavonoids in response to *P. pannosa* infection and transcript levels of key enzymes in the phenyl-propanoid pathway, i.e., PAL, CAD and CHS were simultaneously up-regulated in inoculated Si+ plants. Si application alone (without pathogen inoculation) altered transcript levels as well as the concentration of several phenolics compared to the Si- plants. Chlorogenic acid was the phenolic acid detected in the highest concentration with an increase of more than 80% in Si+ inoculated compared to the Si- uninoculated plants. Among 11 identified flavonoids, rutin and quercetrin were detected in the highest concentrations and the rutin concentration increased >20 fold in Si+ inoculated compared to Si- uninoculated plants. Both rutin and chlorogenic acid had an anti-microbial effect on *P. pannosa* since leaf treatment with the two compounds reduced the powdery mildew severity with 40-50% *in planta*. A similar efficacy of the phenolics was demonstrated after spray application and leaf infiltration, indicating that the two phenolics can be transported to the epidermal cell surface since they, in both cases, reduced conidial germination and appressorium formation of *P. pannosa*. Since treatment with 3.6mM Si significantly reduced powdery mildew development by inducing host defence responses, Si can be used as an alternative eco-friendly disease control measure.

Effects of Silicon under NaCl stress and salicylic acid on growth, antioxidant activity and powdery mildew infection of cut roses (*Rosa xhybrida* L.) 'Red Power'

Reezi S [1,2]*, Babalar M [3], Kalantari S [3], Okhovvat SM [4], Jeong BR [5]

1.Department of Horticulture, Faculty of Agriculture, University of Shahrekord, Shahrekord, Iran,

2.Department of Horticulture, Faculty of Agriculture and Natural resources, University of Hormozgan, Hormozgan, Iran,

3.Department of Horticulture, Faculty of Agriculture, University of Tehran, Karaj, Iran,

4.Department of Plant Pathology, Faculty of Agriculture, University of Tehran, Karaj, Iran,

5.Department of Horticulture, Division of Applied Life Science (BK21 Program), Graduate School, Gyeongsang National University, Jinju, Korea 660-701.

Abstract

Silicon (Si) is a beneficial element that has important role in resistance to abiotic and biotic stresses such as salinity, drought, nutrient imbalance, freezing, and powdery mildew. To essay the effects of silicon and salicylic acid (SA) as nonchemical methods on quality of two cultivars of cut flower roses ('Red Power') under salt stress treatment and powdery mildew infection, experiments were conducted. The effects of different concentrations of Si (0, 50 and 100 ppm) were studied with combined of NaCl (28 mM) and SA (4 mM) on qualitative and quantitative traits. The results showed that different Si concentrations alone or with combination of SA, could affect on quality of flowers but NaCl alone had some adverse effects. In this experiment, Si in 50 and 100 ppm alone or with SA alleviated the effects of salt stress on cut rose and also could increase storage life of flowers. Na absorption, peroxidases (POD) and superoxide dismutases (SOD) activity was lower in plants that treated with Si. The lowest disease extension recorded for 100 and 50 ppm of Si, respectively. Si alone or with SA decreased adverse effects of salinity and powdery mildew disease in hydroponically grown roses. This finding indicates that the stimulation of the vegetative growth of roses by Si under conditions of salt stress and infection was due to mitigation of toxic Na or Si effects on treated roses.

Silicon on the control of foliar diseases on rice, sorghum, and wheat

Rodrigues FA

Viçosa Federal University, Department of Plant Pathology, Laboratory of Host-Parasite Interaction. Zip Code 36570-000, Viçosa, Minas Gerais State, Brazil

Abstract

The beneficial effects of silicon (Si) on plants have been reported in various situations, especially under biotic and abiotic stress conditions. In the pathosystem sorghum-*Colletotrichum sublineolum*, high content of Si on leaf tissue of a pathogen-susceptible line dramatically decreased the area under anthracnose index progress curve and the final disease severity. In the pathosystem rice-*Bipolaris oryzae*, it was demonstrated that Si content was higher on leaf tissue of plants from the cultivar Oochikara than in the *lsi1* mutant, which is deficient in active Si uptake. Area under brown spot progress curve was significantly reduced by 76% and 50%, respectively, on plants from the cultivar Oochikara and *lsi1* mutant for the +Si treatment in comparison to the control. There was no difference between the cultivar Oochikara and *lsi1* mutant in the -Si treatment. However, in the +Si treatment, this component of resistance was significantly reduced by 50% for the cultivar Oochikara in comparison to *lsi1* mutant. Data from the present study clearly shows that by using a mutant deficient in active Si uptake, the low content of this element on plant tissue can dramatically impact rice resistance to brown spot. For spot blotch on wheat, the concentration of Si in leaf tissue was significantly increased by 91% for the +Si treatment. The incubation period was significantly increased by 40% for the +Si treatment. The area under spot blotch progress curve, number of lesions per cm^2 of leaf area, and real disease severity significantly decreased by 62, 36, and 43.5% in +Si treatment. For *Xanthomonas translucens* pv. *undulosa*-wheat interaction, Si concentration in leaf tissue increased by 97% for the +Si as compared to -Si treatment. There was no difference between Si treatments for incubation period, latent period, necrotic leaf area, and severity estimated by the software QUANT. However, chlorotic leaf area was reduced by 50.2% for the +Si as compared to –Si treatment. There was no difference between Si treatments for bacteria population on leaf tissue. Chitinases activity was high at the most advanced stages of bacterial infection on leaves from +Si treatment and probably affected bacterial growth on leaf tissue. In the

pathosystem rice-*Rhizoctonia solani*, Si also showed great potential to complement host resistance to sheath blight. Si significantly reduced disease severity and the total area under the vertical lesion extension progress curve on moderately susceptible and susceptible cultivars compared to those cultivars high in partial resistance without Si. Altogether the results from these studies indicate that Si application is an effective strategy for managing foliar diseases in rice and sorghum, especially when the soil is low or limiting in plant-available Si.

Silicon-manganese interactions in plants: mitigation of manganese toxicity and defence of fungal hyphal leaf penetration

Römheld V [1], Kirkby E. A[2].

[1]*Plant Nutrition, Institute of Crop Science (340i), University Hohenheim, 70593 Stuttgart, Germanyd;* [2]*Institute of Integrative and Comparative Biology, Faculty of Biological Sciences, University Leeds, UK. E-mail:* v.roemheld@uni-hohenheim.de

Abstract

In the past few years silicon (Si) has become recognized as a beneficial mineral nutrient in higher plants with a particular role in alleviation of various abiotic and biotic stress events such as aluminium, salt or drought stress and fungal diseases. In the present review two aspects of the silicon-manganese (Mn) interaction in plants are discussed, namely, alleviation of Mn toxicity by Si and defence of leaf penetration by fungal hyphae. Although the underlying physiological mechanisms of Si in these stress alleviations is still under discussion, the positive effects of Si are well described in the literature and recognized in farming practice.

In relation to the beneficial effect of Si in alleviating Mn toxicity in plants, it is now known that in contrast to earlier findings, Si does not affect Mn uptake by plants. Alleviating mechanisms are present within plants in which genotypic differences occur between plant species. In cowpea (*Vigna unguiculata* (L.) Walp for example Si results in an obvious change of the leaf apoplastic metabolomic profile, including peroxidases (PODs) and phenolics. In cucumber (*Cucumis sativus* L.), however, the main mechanism of Si-mediated alleviation of Mn toxicity seems to be an induced increase in cell wall binding capacity for Mn which lowers free apoplastic Mn and H_2O_2 concentrations and thus decreases production of hydroxyl radicals and Mn toxicity symptoms.

The mitigating role of Si in fungal hyphal leaf penetration is also well established. It has been shown that a short-term redistribution of non-deposited Si can successfully obviate hyphal leaf penetration. However, the simultaneous redistribution of Mn and Si in epidermis cells over short periods following attempted penetration by fungal hyphae has not as yet been studied seriously. Although it is well known that Mn plays a key role in disease suppression by stimulating the formation of phytoalexins the possible physiological role of these compounds in relation to Si-Mn interaction in this disease suppression needs to be investigated. Such studies should consider the possibility of a basic role for Si as a signal for Mn redistribution in suppressing disease.

Experimental study of the impact of silicon fertilizers on the growth, quality and output of big cherries

Rong JF

Municipal Agricultural and Rural Committee of Zhengzhou, Henan Province, Zhengzhou, P.R. China

Abstract

Although silicon fertilizers have been extensively used in Japan since 1970s, they have not yet been widely used in agriculture in China. The study of silicon fertilizers focuses on hobby silicon crops. More recently, more and more reports have been documented on the application of silicon fertilizers especially their impact on fruit trees. However, reporting has been very limited in the use of silicon fertilizers on big cherries. Hence, this paper probes deeply into the development of silicon fertilizers and their impact on the growth, quality and output of big cherries. The applications are mainly on the big cherries and the amount of fertilizers that should be used for their healthy growth. We believe that this experimental study will provide the basis for applying silicon fertilizers to the agricultural sector in China.

This paper studies the development of silicon fertilizers including their impact on the growth, quality and output of big cherries. The result of our research shows that silicon fertilizers can have great impacts on the amount of chlorophyll, SOD (superoxide dismutase) activity and MDA content in the big cherry leaves and also on soluble solid matters, total sugar, total acid and total output in the fruits. Taking Experiment 3 as an instance, the proportion of each nutritional element is proved to increase by 6.52%, 17.65%, -38.43%, 12.03%, 11.39%, 1.87% and 16.01% respectively.

Keywords: Big cherries, Growth, Output, Physical quality, Silicon fertilizers.

Genotypic variation for silicon accumulation and effect of foliar silicic acid on growth and yield of finger millet (*Eleusine coracana* (L.) Gaertn.)

Sandhya TS [1], Prakash NB [2], Nagaraja A [3], Nanja Reddy YA [3]

1.Department of Soil Science and Agricultural Chemistry, Kerala Agricultural University, Thrissur Kerala, India,

2.Department of Soil Science and Agricultural chemistry, University of Agricultural Sciences, GKVK Campus, Bangalore, Karnataka, India,

3.AICRIP on millets, ZARS, GKVK Campus, Bangalore, Karnataka, India.

Email: santsagri@gmail.com

Abstract

Field experiments were conducted in the experimental field of ZARS, GKVK campus, Bangalore to investigate the genotypic variation for Si accumulation in finger millet and the effect of foliar applied Si on growth, yield, nutrient uptake and blast disease of finger millet. In one experiment ten popular finger millet cultivars *viz.*, GPU 28, GPU 67, GPU 48, GPU 66, Indaf- 9, Indaf- 5, RAU 8, VL 149, K 7, MR- 2 were used to study the genotypic variation for Si accumulation. Another field trial was conducted using three genotype, GPU 28 (resistant to blast disease), GPU 67 (moderately resistant to blast disease) and K 7 (highly susceptible to blast disease) with three levels of foliar silicon as 0, 2 and 4 ml L^{-1} of concentrated soluble silicic acid (SiLife, Leusden, The Netherlands) to know the effect of foliar silicon on growth, yield, nutrient uptake and blast disease resistance in finger millet genotypes. Foliar silicon spray was given on 21 DAS and 36 DAS. The experiments were laid out in RCBD, with three replications by following all the recommended management practices.

The study showed a significant variation for Si accumulation between the finger millet genotypes and the trend followed was, K7 < GPU 67 ≤ Indaf 9 = MR 2 ≤ GPU 28 = Indaf 5 ≤ GPU 66 ≤ GPU 48 ≤ VL 149 < RAU 8. Si content in the finger millet genotypes varied from 1.1- 2.5 % with an average Si content of 1.67 %. K 7, a blast susceptible variety recorded the lowest (1.03%) and in RAU 8 (2.46 %) the highest accumulation of silicon. Irrespective of all the genotypes, the highest accumulation

was found in glumes (1.5- 3.9 %) followed by straw (1.6 - 3.1%) and grains (0.18-0.38%).

Yield parameters like test weight, grain and straw yield increased significantly with the application of foliar Si. Irrespective of genotypes, grain weight at 2 and 4 mlL^{-1} of foliar spray of Si were on par (3.29 g and 3.30 g respectively), but were significantly high over the control weight of 3.12 g. GPU 28 responded to both the levels of foliar applied Si and recorded significant increase in grain yield, $2.23tha^{-1}$ and $2.32tha^{-1}$ at 2 and $4mlL^{-1}$ over the control. Increase in grain yield in GPU 67 ($2.3tha^{-1}$) and K7 ($2.29tha^{-1}$) was significant only at 4 ml L^{-1} when compared to that of control. There was also a greater variation in the straw yield of different genotypes (5.27 tha^{-1} by GPU 28, 4.82 tha^{-1} by K7 and 3.66 tha^{-1} by GPU 67). There was also a significant increase in straw yield with the foliar applied Si

Si content of glumes increased in all the genotypes with the application of foliar Si. The highest Si content (2.45%) was obtained with 4ml L^{-1}. Though the Si accumulation in glumes was highest for GPU 28 in all the treatments, K- 7 was also able to accumulate appreciable amount of Si in glumes (the increase was about 80% at 4ml L^{-1} over control).

Application of 4 ml L^{-1} foliar Si as silicic acid increased Si uptake to an extent of 54.6 % over control. There was a significant increase in Ca and P content in straw and glumes with the application of foliar Si. In grains the concentration of all these mineral nutrients remained unaffected but the grain weight showed significant increase with the Si treatment. Foliar application of Si significantly reduced the incidence of finger blast and the effect was on par with the application of 2 and 4 ml L^{-1}. Two sprays of foliar Si @ 4 ml L^{-1} at an interval of 21 days reduced the blast symptoms to an extent of 69.8 % in GPU 28, 53.75 % in GPU 67 and by 50.4 % in K 7.

It was summarized that average Si content of finger millet is 1.67% and there was a greater variation for Si accumulation among the genotypes. Foliar application of Si as silicic acid had a significant effect on improving the yield, nutrient uptake and blast disease resistance in finger millet.

Influence of exogenous silicon on germination indices of wheat (*Triticum aestivum* L.) under drought stress

Sara TA [1], Raheem H [2]

1.MSc on Agricultural Biotechnology, Department of Agricultural Biotechnology, Imam Khomeini International University.

2.Corresponding author, Assistant professor, Department of Agricultural Biotechnology, Imam Khomeini International University, Qazvin, IR of Iran, POBox 34149-288. Tel: (0098) 281 8371165, Fax: 3780073. (raheemhaddad@yahoo.co.uk)

Abstract

The effect of exogenous silicon (Si) was investigated on seedling parameters of wheat (*Triticum aestivum* L.) under drought stress. Experiment was performed in a completely randomized design for three treatments including control, drought and Si-drought (1mM silicate sodium) in three replications in the Lab growth room. Drought stress was imposed through PEG 6000 of osmotic potential 0, -6 and -9 bar. Germination rate (GR), germination rate index (GRI), germination stress index, percentage germination, early seedling growth and mean germination time (MGT) were investigated in the present research project. The results indicated significant decrease in all parameter with increase in stress level, while addition of Si could partially improve the seedling growth and increase the percentage and rate germination of stressed seeds. Inclusion of Si in culture solution also maintained of mean germination time at the same level as that of the control plants. These results suggested that silicon may be involved directly or indirectly in both morphological changes and physiological processes in plants. Thus, our findings seemed plausible that Si shows a protective role in germination of wheat seeds to prevent them from being severely affected by drought stress.

Key words: Drought stress, Seed germination, Silicon, Wheat.

Growth of chrysanthemum cultivars as affected by silicon source and application method

Sivanesan I [1], Son MS [2], Jeong BR [1, 2, 3]

1.Institute of Agriculture and Life Science, Gyeongsang National University, Jinju, Korea 660-701,

2.Department of Horticulture, Division of Applied Life Science (BK21 Program), Graduate School, Gyeongsang National University, Jinju, Korea 660-701,

3.Research Institute of Life Science, Gyeongsang National University, Jinju, Korea 660-701.

Abstract

Silicon (Si) has been demonstrated for its beneficial effects in many crop plants, though it has not been considered as an essential element for the plant. The role of Si in the nutrition of horticultural plant species has not been well documented in comparison to agricultural crops such as barley, rice, sugarcane and wheat. Although Si is the second abundant element in mineral soils, in greenhouse production most plant species are grown in containers using soilless substrates as the growth medium, which have limited plant-available Si. Therefore, specific information regarding plant responses to the supply of this element via the growing medium or a nutrient solution is needed. Addition of potassium silicate to the fertilizer mix increases the ability of the chrysanthemum to withstand attack by leafminers. The objective of this study was to evaluate the effect of Si on the growth of a few chrysanthemum cultivars. Rooted terminal cuttings of *Dendranthema grandiflorum* 'Gaya Pink', 'Lemon Tree' and 'White Angel' were transplanted into a 10 cm (370 mL) pots containing a commercial medium and a nutrient solution containing 0, 50 or 100 mg L^{-1} Si as potassium silicate (K_2SiO_3) was supplied once a day through a subirrigation system. Application of Si significantly increased plant height, stem diameter and chlorophyll content, as compared with the control. Number of flowers and flower diameter were significantly affected by cultivars. Molybdenum blue method confirmed the presence of silicon in leaves of the three cultivars, where leaf contents of Si increased linearly with increasing Si concentration in the nutrient solution. Concentrations of phosphorus (P), sulfur (S), calcium (Ca), magnesium (Mg), and zinc (Zn) in the leaves increased, while the concentrations of potassium (K), boron (B), copper (Cu), iron (Fe) and manganese (Mn) decreased with increasing Si concentration in the nutrient solution. When the plants were supplied with Si a marginal chlorosis appeared in the older leaves. Therefore, we investigated the effect of different Si sources and application methods on the growth of two cultivars. Rooted terminal cuttings of *Dendranthema grandiflorum* ‘Lemon Eye’ and ‘Pink Eye’ were transplanted into a 10 cm (370 mL) pots containing a commercial medium and were laid out in a randomized complete block design on beds in a greenhouse. 0 or 50 mg L^{-1} Si was applied either by foliar spraying twice in a week or a nutrient solution containing 0 or 50 mg L^{-1} Si as calcium, potassium or sodium silicate was supplied once a day through a subirrigation system. In both cultivars, plant height was significantly increased by application of potassium or sodium silicate, while it decreased by application of calcium silicate. Application of Si also increased the mean number of flowers, and diameter, fresh and dry weights of flower as compared with the control. Plants fed with subirrigational supply of Si developed marginal chlorosis on the older leaves, whereas those fed with foliar applications did not. The data demonstrate a beneficial and detrimental effect of Si on the growth of these chrysanthemum cultivars.

Key words: Chlorosis, *Dendranthema grandiflorum*, Ebb and flow, Foliar spray, Silicate.

Effect of silicon on tolerance to high temperatures and drought stress in *Euphorbia pulcherrima* willd. 'Ichiban'

Son MS [1], Song JY [1], Lim MY [1, 2], Sivanesan I [2], Jeong BR [1, 2, 3]*

1.Department of Horticulture, Division of Applied Life Science (BK21 Program), Graduate School, Gyeongsang National University, Jinju, Korea 660-701,

2.Institute of Agriculture and Life Science, Gyeongsang National University, Jinju, Korea 660-701,

3.Research Institute of Life Sciences, Gyeongsang National University, Jinju, Korea 660-701

Tel. 055-772-1913; Fax. 82-55-757-7542; brjeong@gnu.ac.kr.

Silicon (Si) is a non-essential element with beneficial effects reported for several crops. The beneficial effects of Si are particularly distinct in plants exposed to abiotic and biotic stresses, such as drought, frost, metal toxicity, nutrient imbalance, salinity, and diseases. In this study, we investigated the effect of Si on tolerance to high temperatures and drought in *Euphorbia pulcherrima* Willd. 'Ichiban'. Terminal cuttings of were taken from stock plants and then rooted under a mist bed with a mean temperature of 25˚C and 80% relative humidity. After a month, rooted cuttings were transplanted into 10 cm (370 mL) pots and a nutrient solution containing 0 or 50 mg L^{-1} Si, either as potassium (K_2SiO_3), sodium (Na_2SiO_3), or calcium ($CaSiO_3$) form was supplied through a subirrigation or foliar applications. Plants were grown in a greenhouse at Gyeongsang National University from 14 October, 2010 to 7 January, 2011 under a normal day light condition with night/day set temperatures of 18/27°C and RH of 60–70%. After 3 months, plants were placed in an environment controlled chamber under a 12 h photoperiod with 410 µmol m^{-2} s^{-1} irradiance and maintained at 35±1°C (high temperature) and drought condition simultaneously. The application of Si (K_2SiO_3, Na_2SiO_3, or $CaSiO_3$) did not affect plant growth as compared to the control. However, Si-treated plant had more tolerance to high temperatures and drought stress than the control plant. Of the silicate sources tested, $CaSiO_3$ supplied through a subirrigation was found to be the most effective.

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The alleviation of zinc toxicity by silicon is related to zinc transport and antioxidative reactions in rice

Song AL [1], Li P [1], Li ZJ [1], Fan FL [1], Nikolic M [2], Liang YC [1]*

1.Ministry of Agriculture Key Laboratory of Crop Nutrition and Fertilization, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, P.R. China,

2.Institute for Multidisciplinary Research, University of Belgrade, Kneza Višeslava 1, 11030 Belgrade, Republic of Serbia,

** Corresponding author: Prof. Yongchao Liang, Email: ycliang@caas.ac.cn*

Abstract

The objective of this study is to elucidate the roles of silicon (Si) in enhancing tolerance to excess zinc (Zn) in two contrasting rice (*Oryza sativa* L.) cultivars: i.e. cv. TY-167 (Zn-resistant) and cv. FYY-326 (Zn-sensitive). Root morphology, antioxidant defense reactions and lipid peroxidation, and histochemical staining were examined in rice plants grown in the nutrient solutions with normal (0.15 μM) and high (2 mM) Zn supply, without or with 1.5 mM Si. Significant inhibitory effects of high Zn treatment on plant growth were observed. Total root length (TRL), total root surface area (TRSA) and total root tip amount (TRTA) of both cultivars were decreased significantly in plants treated with high Zn, whereas these root parameters were significantly increased when Zn-stressed plants were supplied with 1.5 mM Si. Supply of Si also significantly decreased Zn concentration in shoots of both cultivars, indicating lower root-to-shoot translocation of Zn. Moreover, superoxide dismutase (SOD), catalase (CAT), and asorbate peroxidase (APX) activities were increased, whereas malondialdehyde (MDA) and hydrogen peroxide (H_2O_2) concentrations were decreased in Si-supplied plants of both Zn-sensitive and Zn-resistant rice cultivars exposed to Zn stress. These alleviative effects of Si, further confirmed by the histochemical staining methods, were more prominent in the Zn-resistant cultivar than in the Zn-sensitive one. Taken together, all these results suggest that Si-mediated alleviation of Zn toxicity is mainly attributed to Si-mediated antioxidant defense capacity and membrane integrity. The possible role of Si in reduction of root-to-shoot translocation of Zn can also be considered.

Keywords: Lipid peroxidation, Oxidative stress, Rice, Zn stress.

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Comparison of silicon uptake by rice and horticultural plants in response to different silicate sources in a hydroponic culture

Song JY [1], Son MS [1], Jeong BR [1, 2, 3]*

1.Department of Horticulture, Division of Applied Life Science (BK21 Program), Graduate School, Gyeongsang National University, Jinju, 660-701, Korea,

2.Institute of Agriculture and Life Science, Gyeongsang National University, Jinju, 660-701, Korea,

3.Research Institute of Life Science, Gyeongsang National University, Jinju, 660-701, Korea.

Tel. 055-772-1913; Fax. 82-55-757-7542; brjeong@gnu.ac.kr.

The beneficial effects of silicon (Si) are mainly associated with its deposition in plant tissues and Si accumulation differs greatly between plant species. Although, Si is the most abundant mineral in soil and plays important roles in the plant, greenhouse production of horticultural crops have limited amounts of plant-available Si and that can inhibit Si accumulation in plants. The objective of this experiment was to investigate Si uptake by rice and some valuable horticultural plants in response to different (potassium, sodium, calcium, and fumed) silicate sources supplemented to a hydroponic solution at varying concentrations (0.0, 50.0, or 100.0 $mg \cdot L^{-1}$ Si). These plants were rooted in a soilless substrate and then transferred to and grown in a nutrient solution contained in the magenta box for 2 weeks. The growth of rice and some horticultural plants were differed from species to species. A combination of ethanol-benzene displacement and staining with crystal violet lactone, scanning electron microscope, and electron probe X-ray microanalyzer were used to visualize different forms of silica body in the plant. Concentrations of silicon, macro-, and micro-nutrient elements in the plant and a nutrient solution measured by an ICP spectrometer and a colorimetric method showed that addition of different sources of Si to the nutrient solution influenced each plant species differently. The beneficial effects of Si supplementation to rice and some horticultural plants depended upon the form and concentration of Si supplied.

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Gene expression profiles in rice as affected by silicon treatment and blast stress using cDNA microarray

Sun WC [1, 2], Ge GF [1], Zhang J [1], Xue GF [1], Li ZJ [1], Liang YC [1]

1.Ministry of Agriculture Key Laboratory of Crop Nutrition and Fertilization, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, P.R. China,

2. Institute of Environment, Resource, Soil and Fertilizer, Zhejiang Academy of Agricultural Sciences, Hangzhou 310021, P.R China.

Abstract

Rice (*Oryza sativa* L.) is a typical silicon-accumulating plant species. Silicon (Si) plays an important role in protecting rice from blast caused by *Magnaporthe grisea* (*M. grisea*). However, the role of silicon in plant biology and the mechanism of silicon-enhanced plant resistance are still debated. Several studies have suggested that Si activates plant defense mechanisms, yet the exact nature of relation between Si and plant defense response remains unclear. To obtain new insights into the effect of Si on the model crop, we performed a complete transcriptome analysis of both control and blast-stressed *Oryza sativa* plants, with or without Si application. Using a rice gene chip containing 60727 rice cDNAs representing 36926 unique genes, we identified 1210 genes differentially expressed in the Si-amended plants without inoculation (Si/CK), with 126 genes up-regulated and 1084 genes down-regulated. Among 670 differentially-expressed genes in rice plants infected by *M.grisea* (M/ CK), 346 genes were up-regulated and 324 genes were down-regulated. After inoculation with *M. grisea,* 483 genes in Si+ plants were differentially expressed, compared with the Si-plants (Si+M/M), with up-regulation of 27 genes and down-regulation of 456 genes. These genes included stress-related transcriptional factors, and genes involved in signal transduction, the biosynthesis of stress hormones (SA, JA, and ethylene), the metabolism of reactive oxygen species, the biosynthesis of antimicrobial compound, primary and/or secondary metabolism, defense response, photosynthesis, and energy pathways, etc. On the basis of analyzing expression profile of rice genes, it can be concluded that silicon can exhibit obvious impacts on growth and development of plants, especially in rice plants. Moreover, it can regulate natural resistance mechanisms of plant to produce more efficient and timely defense response, and consequently alleviate damage caused by pathogens in plants subjected to pathogens stress.

Key words: cDNA microarray, Expression profiling, *Magnaporthe grisea*, *Oryza sativa*, Silicon.

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Growth of seedlings and drought tolerance in tobacco as influenced by Si nutrition

Vageesh TS [1], Nataraju SP [1], Prakash NB [2], Shilpashree YP [1], Ravindra H [1]

1.Department of Soil Science, Zonal Agricultural Research Station, Shivamogga-577 204, Karnataka, India,

2.Department of Soil Science, College of Agriculture, UAS, GKVK, Bangalore-560 065, Karnataka, India. E-mail: vageeshts@rediffmail.com

Abstract

It has been well established that Si has many beneficial functions in crop growth and development. Si is known to play an important role in protecting plants from abiotic and biotic stresses besides increasing the photosynthetic activity, lodging resistance and drought tolerance in crops. Large area under tobacco in southern transitional zone of Karnataka, South India has red sandy soils subjected to heavy leaching of Si. So far, possible benefits of Si in tobacco crop have not been studied systematically. Hence, a study was conducted to know the effect of Si on growth of tobacco seedlings in the nursery and also to assess its impact on biotic and abiotic stresses viz., frog eye spot and drought.

A nursery experiment was conducted for two years during 2009 and 2010 at Zonal Agricultural Research Station, Navile, Shimoga to evaluate different Si sources for their influence on growth of tobacco seedlings in the nursery. Rice Hull Ash (RHA), Calcium silicate and foliar silicic acid (Silife, The Netherlands) were the three sources of Si compared by adopting Randomized Block Design. A separate study was also conducted in HDPE bags to assess the impact of foliar spray of silicic acid on drought tolerance in tobacco. Thirty different promising tobacco genotypes were grown during rain free season. Silicon was sprayed @ 5 ml L^{-1} from 20 days after planting at an interval of 20 days for three times. Moisture stress was imposed for one set of genotypes by withholding water and bringing the soil moisture to 50% of field capacity. Chlorophyll content and EC (solute leakage) was estimated both in well watered and also in stressed plants.

Results of two years of the study indicated that there was a significant improvement in the plant height, leaf area per plant and number of healthy transplantable seedlings per m^2 of tobacco nursery due to application of different

sources of Silicon. Highest number of transplantable seedlings (208 per m^2) was recorded with application of RHA @ 1.5 kg per m^2 followed by foliar silicic acid spray @ 6 ml L^{-1} (203 per m^2) while control recorded only 146 seedlings per m^2. Spray of foliar silicic acid @ 6 ml L^{-1} recorded highest leaf area (3.07 dm^2/plant) followed by calcium silicate @ 1.5 kg/m^2 (2.86 dm^2/plant) which were significantly superior to control (2.04 dm^2/plant). There was a significant decrease in the incidence of frog eye spot from 5.6 at control to 1.52 at RHA application @ 1.5 kg per m^2 (on 0-9 scale). Use of foliar silicic acid and Ca silicate also resulted in significant decrease in incidence of frog eye spot. Results of the other study in HDPE bags indicated that there was an increase in chlorophyll content in all the genotypes of tobacco when silicon was sprayed. Chlorophyll content varied from 0.548 mg g^{-1} fresh weight (FW) of leaf at control where silicon was not sprayed to 0.670 mg g^{-1} FW in silicon sprayed plants. Foliar spray of soluble Si significantly increased the chlorophyll content under moisture stress conditions. It was 0.414 mg g^{-1} FW at control and 0.514 mg g^{-1} FW when silicon was sprayed at 50% field capacity. The EC values of fresh leaves varied from 0.195 dSm^{-1} at control to 0.185 dSm^{-1} when Si was sprayed under moisture stress (50% field capacity) conditions. It was noted that the electrolyte leakage in terms of EC was less when silicic acid was sprayed both under field capacity and at 50% field capacity. The leaves were subjected to heat treatment at 70^0C and EC was recorded. EC values were 1.218 dS m^{-1} at control and 1.008 dSm^{-1} when silicon was sprayed at 50% field capacity showing integrity of the membrane.

Over all it can be concluded that Si application in the nursery helps in producing significantly higher number of healthy transplantable seedlings of tobacco besides reducing the incidence of frog eye spot disease. The results also indicated that Si can stabilize the structure and integrity of plasma membrane there by imparting drought tolerance to tobacco.

Silicon-induced brown spot resistance in rice (*Oryza sativa* L.)

van Bockhaven J, De Vleesschauwer D, Höfte M

Ghent University, Phytopathology lab, Coupure-Links 653, 9000 Ghent, Belgium, E-mail: jonas.vanbockhaven@ugent.be

Abstract:

In a world where half of the population depends on rice as their main staple food the need of a consistent manner to protect rice plants against a wide range of pathogens is of high importance. Silicon (Si) enables rice plants to fend off these pathogens. The resulting silicon–induced broad spectrum disease resistance in rice is the result of a combination of passive and active defense. The passive defense originates from the silicon deposition in the epidermal rice cells which renders a certain rigour to these cells. However, relatively little is known about the role of silicon in active defense. In our research several intruiging results in the field of Si-induced defense against *Cochliobolus miyabeanus*, the causal agent of brown spot, have been found.

Extensive microscopic analysis on brown spot–infected rice plants, revealed that fungal growth is hampered in the mesophyll of Si-amended plants. Different stainings also suggested that the Si-induced defense responses against brown spot mainly consist of an enhanced production of phenolic compounds, whereas active oxygen species and cell wall reinforcements do not seem to be part of Si-induced brown spot resistance.

The mechanisms underlying the Si-induced defense responses against brown spot appear to be regulated by the abscisic acid (ABA), cytokinin (CK) and especially ethylene (ET) pathway and also seem to be SA independent which is confirmed by previously conducted experiments with mutant and transgenic lines. Moreover, pharmacological experiments and hormone measurements suggest that a decrease of the ET pathway is a major regulator of Si-induced brown spot resistance.

These results along with several microarray studies strongly suggest that the mode of action of silicon can be found in the priming of the defense mechanisms. Dependent on the type of pathogen Si-treated plants can activate specific defense responses much quicker and stronger upon pathogen infection granting the plant with a strategy to fend off a broad spectrum of pathogens. To validate this hypothesis the

role of various signaling components thought to play a key function in the Si-mediated priming for enhanced defense will be studied thoroughly. These future studies not only will shed new light on how plants cope with pathogen assault, but may also guide novel strategies for biologically based, environmentally friendly and durable disease control in various agricultural settings.

The effect of potassium silicate on the control of *Phakopsora pachyrhizi* on soybean

Visser D, Caldwell P, Laing M

School of Agricultural Sciences and Agribusiness, Discipline of Plant Pathology, University of KwaZulu-Natal, Private Bag X01, Scottsville 3209, South Africa

Abstract

Phakopsora pachyrhizi (Sydow), the causal organism of soybean rust (SBR), is a fungal pathogen causing significant soybean yield losses throughout the world. In South Africa, fungicides provide optimum control. However, with the recent emergence of silicon (Si) for managing many other plant diseases, field trials in the 2009/2010 growing season were undertaken. To determine the effect of various concentrations of Si (potassium silicate), two trials were conducted where Si was applied as a foliar spray and as a root drench. For the foliar trial, treatments were as follows: 0, 1000, 2000 and 4000 mg/L Si, root drench (1000 mg/L Si) and Punch C (800 ml/ha), applied at the V6, R1 and R4 growth stages. For the drench trial, treatments were as follows: 0, 5000, 10 000 mg/L Si, Punch C (800 ml/ha), Punch C (800 ml/ha) + 10 000 mg/L Si, Punch C (400ml/ha), Punch C (400ml/ha) + 10 000 mg/L Si, Fly Ash (95, 189, 378 kg/ha), K Si slow release fertilizer (59, 118, 236 kg/ha) and Na Si based slow release fertilizer (62, 124, 248 kg/ha), applied twice during the season. Plants were rated on a scale of 0-9 for disease, the Area under the Disease Progress Curve (AUDPC), and yield were determined. The effect of combining Si and Punch C for the drench trial was determined, using $X^2 = (O-E)^2/E$. For the foliar trial, Punch C had a significantly lower AUDPC and higher yield than all other treatments. All foliar Si applications had a significantly lower AUDPC compared to the untreated control. Yields of Si treatments were not significantly different from that of the untreated control. AUDPC decreases of 20, 12 and 14% for 1000, 2000 and 4000 mg/L Si and yield increases of 12, 6 and 10% for 1000, 2000 and 4000 mg/L Si were observed. Regression analysis of AUDPC versus yield gave a positive correlation coefficient of $R^2 = 0.98$. The late onset of the rust could account for the lack of differences in yield. For the drench trial, all Punch C treated plants had a significantly lower AUDPC and higher yield than all other treatments. AUDPC of Si treatments were not significantly different from that of the untreated control. Si

treatments of 10 000 mg/L Si, K Si (236 kg/ha) and Na Si (62 kg/ha) had a significantly higher yield than the untreated control. AUDPC decreases of 5 and 14% for K Si (236 kg/ha) and 10 000 mg/L Si, respectively, and yield increases of 28 and 32% for K Si (236 kg/ha) and 10 000 mg/L Si, respectively, were obtained. Regression analysis of AUDPC versus yield gave a positive correlation coefficient of $R^2 = 0.90$. No evidence of antagonism between Si and Punch C was observed. Both interactions were additive, i.e., Si and Punch C act independently on the control of SBR. Although no significant differences for yield were found for the foliar trial, yield increases were observed. This, together with significantly lower AUDPC's, indicates that the foliar application of Si could be used to manage SBR. The K Si based slow release fertilizer (236 kg/ha) could also be considered for the management of SBR, as this treatment had a significantly similar yield to the 10 000 mg/L Si as well as AUDPC decreases and yield increases. The 10 000 mg/L Si could also be used, however, the slow release fertilizer, which is applied at planting would be less labor intensive and more economically viable.

Effect of silicon fertilizer on resistance to wheat take-all

Wang DJ [1], Zhou CF [2], Wang XX [3]

1.Zoucheng City Old Association for Science and Technology, Shandong Province, P. R. China,

2.Zoucheng Experimental High School, Zoucheng, Shandong Province, P. R. China,

3.Zoucheng Plant Protection Station, Zoucheng, Shandong Province, P. R. China,

Email: wangdengjia@126.com

Abstract

It is well documented that silicon (Si) is very effective in enhancing resistance to plant diseases, especially fungal attacks. However, mechanisms underlying still remain poorly understood. We made a two-year survey on effect of silicon fertilizers on the incidences of wheat take-all caused by *Gaeumannomyces graminisvartritici* in six field plots in three villages of Zoucheng city in Shandong Province. The results showed that application of silicon fertilizer at a rate of 560-750 kg/ha could effectively put wheat take-all disease under control. The efficiency percentages of silicon fertilizer for controlling wheat take-all ranged from 75-95% with an average of 86%. The incidences (white head) in control plants (with no silicon treated) ranged from 6-12% compared to 0.5-1.6% in plants amended with silicon fertilizer. These control efficiency percentages are equal to those obtained by chemical pesticides. We have also observed that peanut blight and watermelon blight were also effectively prevented by silicon fertilizers with the control efficiency of 60-70%

Key words: Control effect, Gaeumannomyces diseases, Silicon fertilizer.

Agronomic effects of silicon-potash fertilizer in wheat/maize and wheat/soybean rotation system during 2008~2010

Wang DJ, Du FB

Association of the Elderly, Bureau of Science and Technology of Zoucheng County, Shandong Province, P.R. China

Email: wangdengjia@126.com

Abstract

We performed 5 field experiments including 4 wheat/maize rotation systems and 1 wheat/soybean rotation system during 2008-1010. Treatments were control (no fertilizer applied), conventional fertilization, conventional fertilization plus silicon-potash fertilization. The yield of the treatment with conventional fertilization and silicon-potash, on the average, was 34.2% higher than that of the control, and was 15.8% higher than that of the treatment with conventional fertilization. Moreover, the treatment with conventional fertilization plus silicon- potash fertilization had significant residual effect with an average yield increase of 41.9% compared with the control, and of 17.7% compared with the conventional fertilization. The effects of silicon-potash fertilizer lasted for 2 seasons after use. The net-increased value of the treatment with conventional fertilization and silicon-potash fertilization was 534 USD/ha compared to 9.5 USD/ha for the treatment with conventional fertilization. The economic benefit generated by application of silicon-potash fertilizer was 519.2 USD/ha. In the silicon-potash fertilization plot，the average nitrogen fertilizer use efficiency was 31.4% compared to 17.04% in the conventional fertilization plot; the average P_2O_5 use efficiency was 24.9% compared to 14.5% in the conventional fertilization plot; the average K_2O use efficiency was 34.26%, compared to 27% in the conventional fertilization plot. It can be concluded that conventional fertilization plus silicon-potash fertilization, namely NPK plus silicon fertilizer, show its significant agronomic implications and the extensive application of NPK plus silicon fertilizer is imperative.

Key words: Fertilizer use efficiency, Maize, Silicon-potash fertilizer, Soybean, Wheat.

Control effect of silicon fertilizer on gaeumannomyces

Wang DJ [1], Zhou CF [2], Wang XX [3]

1.Zoucheng City Old Association for Science and Technology of Shandong Province,

2. Zoucheng Experimental High School,

3.Zoucheng Plant Protection Station

Abstract

Through the investigation and study in the six land parcel of four household in three village of two town for two years, increasing silicon fertilizer by 560-750kg/hm^2 is very ideal to the Gaeumannomyces control action on the base of conventional application of N, P, K fertilizers. The disease control effect is 75-95%, with an average of 86%, incidence (white head) rate of 6-12% before the onset of silicon fertilizer, incidence rate of 0.5-1.6% after the onset of silicon fertilizer. This is the reach of chemical pesticides. The author has observed the field for silicon fertilizer to prevent peanut blight and watermelon blight, the disease control effect is 60-70%.

Key words: Control effect, Gaeumannomyces diseases, Silicon fertilizer.

Isolation and characterization of a silica-binding protein from silicified endodermis of sorghum roots

Wang H, Zhang FS

Department of Plant Nutrition, China Agricultural University, Beijing, P. R. China, 100193

Abstract

A 103KD protein tightly binding with silica aggregates was extracted from the silicified endodermis of sorghum roots，and it was named as SBP103 (Silica-Binding Protein 103 KD). The N-terminal amino acid sequence of SBP103 is AELPQPEPQP. Using this N-terminal sequence, we searched the corresponding EST sequences in NCBI and have cloned the full length cDNA of SBP 103. In vitro experiments showed that SBP103 could induce silicon acid polymerization in aqueous solution; the amount of polymerized silica was proportional to the adding amount of SBP103 and sodium silicate. The optical pH for silica polymerization is 6.5. Observation using scanning microscope and X-ray microanalysis showed that silicon aggregates were mainly located on the inner tangential walls of endodermis of sorghum roots. Accordingly immuno-cytochemical localization demonstrated that the distribution SBP103 coincided with the deposition sites of silica aggregates in endodermis of + Si roots. In the –Si roots the intensity of immuno-cytochemical reaction is very low. So these results suggested that SBP103 may be involved in the control of silica deposition in roots. It was showed that the expression of SBP103 was strongly induced by + Si treatment. SDS-PAGE and western blot analysis revealed that the amount of SBP103 synthesis was increased considerably under + Si treatment. In contrast, its level under –Si treatment became much lower. Furthermore, RT-PCR and fluorescence real-time-PCR showed that the relative expression level of SBP103 mRNA increased by 44 and 160 times after +Si 3d and 6d respectively.

In conclusion，above research results suggests that silicon can induced the expression of SBP103 in sorghum roots, inversely, the accumulation of SBP103 in endodermal cell walls promotes the deposition and formation of silica aggregates.

cDNA Isolation and function study of Si transporter gene of cucumber

Wang HS [1], Yu C, Zhu ZJ

Department of Horticulture, School of Agriculture and Food Science, Zhejiang A & F University, Lin'an, Zhejiang 311300, PR China

Email: whsych88@126.com

Abstract

Silicon is beneficial to plant growth and helps plants to overcome abiotic and biotic stresses by preventing lodging (falling over) and increasing resistance to pests and diseases, as well as other stresses. Silicon is important for high and sustainable production of cucumber, but the molecular mechanism responsible for the uptake of silicon is unknown. Herein, two Si transporter genes (Accession ID FJ595947 and FJ595948DQ449030) were identified and cloned from cucumber. The full-length cDNA sequences of these genes contain 753 bp and 861 bp nucleotides. We then overexpressed these two genes in cucumber plants to test the content of Si in different tissues and the function of Si transporter genes of cucumber.

Keywords: Si transporter gene, Si, cucumber, stresses

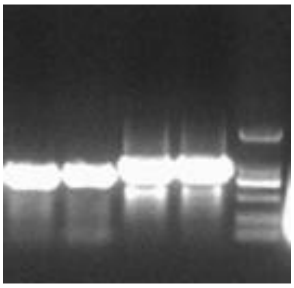

Fig.1 Isolation of *CSiT-1*(FJ595947) and *CSiT-2*(FJ595948) cDNA by

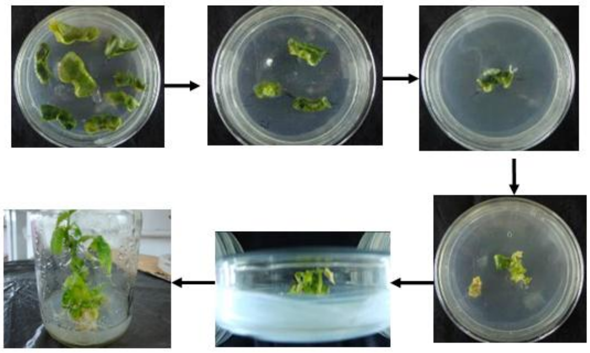

Fig.2 construction of regeneration and genetic transformation system for Cucumber

Extracellular silica nanocoat confers thermotolerance to individual cells

Wang LJ

College of Resources and Environment, Huazhong Agricultural University, Wuhan, Hubei 430070, China

Abstract

To ensure survival, unicellular plants such as diatoms and multicellular plants such as rice had to develop means to defend against a wide variety of environmental stresses. A defence mechanism common to each of the aforementioned plant types is intra- or extra-cellular deposition of silica, which, in addition to imparting mechanical strength, confers significant resistance to disease as well as abiotic stresses such as high temperature. Most investigations to determine the protective role played by silica have been carried out at the level of the whole plant, tissue or organ. Physical chemical mechanisms operating at the single-cell level, however, have not been extensively studied. We have coated live *Saccharomyces cerevisiae* cells, a non-Si-accumulating eukaryote, with a uniformly thin (about 100 nm) and continuous layer of biocompatible silica through a layer-by-layer chemical modification approach. Remarkably, we find that the resulting silica nanoshell endows cells with enhanced protection against high temperature induced deformation. The measurements of cell weight loss and heat flow were performed by thermogravimetric analysis and differential scanning calorimetry. Prolonged cell viability at elevated ambient temperatures is achieved by suppressing overall water loss, thus maintaining cell integrity, and is concomitant with decreased cell surface temperature which helps to retain the dynamic structures of the cell wall and membrane. Theoretically and experimentally, silica coating increases the water-absorption/retention capability of cells through hydrogen-bonding between water and the silica surface hydroxyl groups, thereby maintaining the cells in a fluid, water-rich microenvironment. The lower surface temperature of silica shells may be attributed to increased emission of infrared radiation that is responsible in part for reducing the heat load of silica-coated cells. These results broaden our understanding of how cell wall silicification helps defend organisms against adverse environmental conditions. Moreover, they offer a versatile and simple approach to preserving cells for a variety of applications.

Silicon improves the tolerance of rice plants to cadmium and zinc complex stress

Wen XH, Cai KZ *

Key Laboratory of Ecological Agriculture of Ministry of Agriculture, South China Agricultural University, Guangzhou 510642, China

E-mail: kzcai@scau.edu.cn

As China's important crop, rice（*Oryza sativa* L.）plays an important role in the entire national economy and social stability. Cd is harmful to crops, and it is one of the widely distributed heavy metals. As one of the same group elements of Cd, Zn has also came our attention. The objective of this study was to explore the possible mechanism of Si-alleviating Cd and Zn complex toxicity of rice.

Single and combined treatment of Cd and Zn significantly reduced biomass and rice yield. Cd or Zn content of rice plants in combined Cd and Zn stress were higher than those single Cd or Zn treatment. However, silicon supply alleviated these effects, biomass and yield of rice plants were significantly increased, Cd and Zn content in different rice organs were reduced by addition of silicon, rice grain and root system had relatively higher reduction ratio of heavy metal than stem, leaf and chaff.

The hydroponic experiment showed that, Cd and Zn stress significantly restrained root growth. Total root length, root surface area, root volume and root vigor were markedly reduced, While silicon application significantly increased these root traits. Under single and combined stress of Cd and Zn, oxalic acid, acetic, tartaric acid, maleic acid and fumaric acid content of root exudates for Feng-hua-zhan were all reduced, but silicon application increased them. For Hua-hang-si-miao, the oxalic acid and fumaric acid content were reduced in the Cd and Zn single and combined treatments, but the acetic, tartaric acid and maleic acid content were increased, and Si application countertrend their changes. By using transmission electron microscope (TEM), we found that cell wall, cell membrane and vacuoles of rice root cortex cells were serious damaged under cadmium and zinc stress, while silicon treatment resulted better cell structure integrity.

Key word: Cell structure, Cd, Combined stress, Rice (*Oryza sativa* L.), Root system, Silicon, Zn.

Stable Silicon Isotope Composition and Fractionation in Rice

Wu LH [1], Sun L [1], Li XY [1], Ding TP [2], Tian SH [2]

1.College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310029, China

2.Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China

Abstract

Si isotope is fractionated during weathering and biological activity, which could provide unique information about numerous physical and biological processes. An understanding of the variations of silicon (Si) isotopes in plants has potentially important applications in elucidating the biogeochemical Si cycle and Si accumulation in plants. We studied Si isotope fractionation in rice plant organs over an entire life cycle. Rice plants were grown hydroponically under a closed Si system. Two types of kinetic Si isotope fractionations occurred during the plant development: one when Si is taken up by plant roots and the other when silica precipitates in plant tissues and organs.

The ^{30}Si-depletion of whole rice plant relative to external nutrient solution displayed that light Si isotope entered plants more readily than heavy Si isotope. This phenomenon indicated that biologically mediated Si isotope fractionation occurred during uptake by the root. The Si isotope fractionation factor ($\alpha_{Pl\text{-}Sol}$) was estimated to be 0.9986~0.9996 in rice.

The silicon isotope compositions of rice exhibit significant variations. The δ^{30}Si values varied from-2.3‰ to 2.6‰ among different organs, by the order stem < root < leaf < husk < grain. There is a significantly gradient with a progressive increase from lower to upper organ except root. The silicon isotope compositions of rice leaf also exhibit significant variations. The δ^{30}Si values varied from -2.6‰ to 1.7‰ among different parts. It is a same increasing trend of δ^{30}Si values from lower to upper tissues (leaf sheath < leaf blade base <leaf blade middle < leaf blade top). The result reflected a preferential incorporation of the lighter Si isotopes from transpired water to biogenic opal, suggesting that Si isotope fractionation in rice plants appears to be a "Rayleigh-like" process.

The Si isotope fractionation among different organs and between whole plant and source solution indicated that Si uptake and transport might be dominated by mass-flow, ion channels or via electrogenic pumps rather than by carrier-mediated transport. The contribution of passive component (mass-flow driven) played an important role in Si accumulating plants in this experiment.

Effects of Si fertilizer on lodging, yield and yield components of different rice varieties in Iran condition

Yadi R [1], Mobasser HR [2], Dastan S [3], Ghanbari Malidarreh A [4]

1.Department of Agriculture, PNU, Boshehr, Iran. Reza_yadi2007@yahoo.com

2.Department of Agronomy, Islamic Azad University, Ghaemshar Branch, Ghaemshar, Iran

3.Department of Agronomy, Science and Research Branch, Islamic Azad University, Tehran, Iran. Sdastan@srbiau.ac.ir

4.Department of Agriculture, Jouybar Branch, Islamic Azad University, Jouybar, Iran.

Abstract

In order to investigate the effects of Si fertilizer on agronomical and morphological characteristics of various Iranian rice varieties, an experiment was carried out as split plot in a randomized completely block design with four replications in Mazandaran province in 2009. The main plot was comprised five rice varieties (Mahalli Tarom, Hashemi Tarom, Deylamani Tarom, Langrodi Tarom and Sang Tarom) and three Si fertilizer including (0, 300, 600 kg Si ha^{-1}) were design as sub-plot. Results showed that, the least total spikeletes and strile spikeletes were obtained in Langrodi Tarom and the least tiller number per hill and panicle number per m^2 were produced in Mahalli Tarom and Sang Tarom, respectively. Shortest length of first, second and third internode and biggest third internode diameter and also the least plant height were obtained in Langrodi Tarom. As a result the most lodging resistance and the least lodging index for third and fourth internode were produced in Langrodi Tarom. Total tiller numbers were decreased with increasing of plant density but in this case the panicles numbers were increased significantly. Node number, the length first, second internodes, the fourth internode diameter and also the third, fourth internode bending of the moment were increased with Si fertilizer application. Minimum lodging index in the third and fourth intrnodes were produced in 0 kg Si ha^{-1} application. Interaction effect of variety and Si fertilizer had significant effect an all agronomical traits and morphological characteristics that related to lodging traits.

Key words: Bending momemt, Lodging index, Rice, Si fertilizer.

Transporters involved in preferential distribution of Si to the panicles at the node in rice

Yamaji N, Mitani-Ueno N, Ma JF

Institute of Plant Science and Resources, Okayama University, Chuo 2-20-1, Kurashiki 710-0046, Japan. Email:n-yamaji@rib.okayama-u.ac.jp

Abstract

Silicon is an important nutrient for the growth of rice, a typical Si accumulating crop. High Si accumulation especially in the husk is required for high productivity of rice. Preferential distribution of Si at the node is a key step for Si accumulation to the husk. Node is a place where connects the root, leaf, inflorescence and highly developed vascular systems are located. At uppermost node I beneath the panicles, there are two different vascular bundles; enlarged and diffuse vascular bundles. Enlarged vascular bundles originate from the two lower nodes and connect to the flag leaf, while diffuse vascular bundles connect toward the panicle tissues. Therefore, inter-vascular transfer of Si between two different vascular bundles is required to deliver Si taken up by the roots to the panicle.

Expression profiles revealed that three Si transporters, *Lsi6*, *Lsi2* and *Lsi3* are highly expressed in the node I. *Lsi6* is a close homolog of *Lsi1* and belongs to NIP III subfamily of plant aquaporin, which is permeable to silicic acid. Lsi6 is strongly expressed at the xylem transfer cells at the node I with polarity facing toward the xylem vessel. These cells are located at the outer boundary region of the enlarged vascular bundles and characterized by increased surface area due to cell wall ingrowth. On the other hand, *Lsi2* and *Lsi3* are Si efflux transporters. *Lsi2* is expressed at the bundle sheath cell layer next to the xylem transfer cells and polarly localized opposite to *Lsi6*, whereas *Lsi3* is expressed at several parenchyma cell layers located between the enlarged vascular bundles and the diffuse vascular bundles. Knockout of *Lsi6* resulted in decreased Si accumulation in the panicles, but increased accumulation in the flag leaf. These results indicate that all three transporters are required for the inter-vascular transfer of Si; *Lsi6* is responsible for unloading Si from transpirational flow in the enlarged vascular bundles, while *Lsi2* and *Lsi3* are responsible for reloading Si to diffuse vascular bundles.

Evaluation of silicon supplying capacity in paddy field soil by Isothermal Adsorption

Yang D, Liu MD, Zhang YL *

College of land and Environment, Shenyang Agricultural University, Key Laboratory of Soil and environment in Northeast China, Ministry of Agriculture, Shenyang, Liaoning, 110866, *China.*

*Corresponding author：Zhang Yu-long. Email: yangdan_dfcy@163.com

Abstract

Silicon is an important mineral nutrient for the growth of rice. So it is very important to know the silicon supplying capacity in paddy field soil. At present, content of the available Silicon in paddy field soil is used to evaluate silicon supplying capacity, and that can be determined by a variety of methods with different extractants. 1M HAc-NaAc (pH =4.0) buffer solution was one of widely-used extractants for evaluating silicon supplying capacity in paddy field soil, however some studies have shown that this method was not suitable for paddy field soil which had been applied with slag, or for calcareous paddy field soil and alkaline paddy field soil. Therefore, it has been an urgent problem demanding a suitable method to evaluate silicon supplying capacity in paddy field soil in terms of theory and practice. On the other hand, adsorption-desorption, a basic physical and chemical process in soil, plays a fundamental role in constraining the available concentration of nutrients in soil. Commonly, the concentration of some elements in solution is so high that their adsorption and desorption doesn't express the true situation in soil. Such as silica, when its concentration in solution exceeds 120 mg • L^{-1}, it would be in polymerization. So it is necessary to conduct adsorption and desorption experiment with low concentration silicon solution. In this paper, 18 soils of major rice producing areas in Liaoning were screened to discuss the relationship between silicon adsorption and desorption in soil and silicon supplying capacity in paddy soil with isothermal adsorption in low silicon equilibrium solutions combined with pot experiments of rice. Main results were as follows.

Silicon adsorption capacity of different soils increased with silicon equilibrium concentration at 0-100 mg·L^{-1}. The equation $y=bx-a$, silicon equilibrium concentration as abscissa and silicon adsorption capacity as ordinate, could express the

silicon-adsorbed characteristics. The differences of parameters *a*, *b* and *a*/*b* of different soils were statistically significant and *a*, the exchangeable silicon in soil, can be as the index to represent the silicon supplying capacity of soil. Further analysis showed that *a* had a extremely significant negative power function correlation with organic materials (a=423.29$OM^{-0.395}$, r=0.631, $r_{0.01}$=0.590, n=18), a significant positive linear correlation with free iron oxide (*Fed*) （a=15.409Fe_d+54.657，r=0.506，$r_{0.05}$=0.468，n=18), a significant negative logarithmic correlation with activation grade of iron oxide (Fe_o/Fe_d) (a=-62.807ln（Fe_o/Fe_d）+48.062, r=0.502, $r_{0.05}$=0.468, n=18) and a significant positive linear correlation with crystal/gel ratio ((Fe_d-Fe_o)/Fe_o) (a=15.931 (Fe_d-Fe_o)/Fe_o+82.153, r=0.563, $r_{0.05}$=0.468, n=18), but *a* had no significant correlation with pH, *b, a*/*b* and soil physicochemical property. So main factors affecting the parameter *a* included organic materials, free iron oxide, activation grade and crystal/gel ratio of iron oxide.

The results indicated that Si_{RE}, relative silicon content in rice, and Y_{RE}, rice relative yield increased with *a* and they had significant and extremely significant positive linear correlation with *a* respectively (Si_{Re}=0.092a+80.838, r=0.549; Y_{Re}=0.120a+79.897, r=0.611; $r_{0.05}$=0.468, $r_{0.01}$=0.590, n=18). There were bigger *a* values in those soils with higher silicon supplying capacity and there were no effects of applying silicon fertilizers. When a≤126 mg·kg $^{-1}$ (SiO_2) (rice yield =95%), the yield of rice will be improved by applying silicon fertilizers.

In general, the equation *y*=*bx*-*a* could be used to reflect the silicon supplying capacity of soil. *a* had significant or extremely significant correlations with organic materials, free iron oxide, activation grade and crystal/gel ratio of iron oxide and applying silicon fertilizers could improve rice yield at a≤126mg·kg $^{-1}$ (SiO_2). So *a* could be used as the index to evaluate silicon supplying capacity of soil.

Key words： Isothermal absorption, Paddy Field soil, Supplying silicon capacity, Yield.

Acknowledgement:

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Silicon and nitrogen use efficiency in Aerobic rice

Yogendra ND [1], Kumara BH [2], Chandrashekhar N [1], Shashidhar HE [3], Prakash NB [1]

1.Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, Bangalore, India 560065,

2.Department of Soil Science and Agricultural Chemistry, CCS Haryana Agricultural University*, Hissar, Haryana, India,*

3.Professor, Department of Biotechnology, University of Agricultural Sciences, Bangalore, India 560065. Email: nagabovanalliprakash@rediffmail.com

The field experiments were conducted during *kharif* - 2008 and 2009 at eastern dry zone soils of Bengaluru, Karnataka, South India, to evaluate the effect of silicon, nitrogen and their interaction effect on nutrient use efficiency in aerobic rice. The soil was sandy loam in texture slightly acidic (6.6), with medium organic carbon and available N content (331.6 kg ha^{-1}). Similarly, available soil K_2O and P_2O_5 values were low (115 kg ha^{-1}) and medium (35.8 kg ha^{-1}), respectively. Plant available Si content was low according to the categorization made by Narayanaswamy and Prakash (2009) during both seasons. Two seeds per hill of aerobic rice (BI-34) were sown in 30 x 15 cm spacing. The design was split plot with three replications with the treatments consisted of four main plots viz., control (No N), 60 kg N ha^{-1} (No basal + LCC-3), 90 kg N ha^{-1} (Urea at 30 kg N ha^{-1} as basal + LCC-3) and 100 kg N ha^{-1} as urea (RDF) and two sub plots viz., with (calcium silicate at 2 t ha^{-1}) and without silicon treated plots. In 2009, experiment was laid out in randomized block design comprising of five treatments (viz. T_1: Recommended P&K (Control); T_2: Recommended NPK (RDF); T_3: T_2 + calcium silicate @ 2 t ha^{-1}; T_4: T_1 + Basal 30 kg N ha^{-1}+LCC-3; T_5: T_4 + $CaSiO_3$ @ 2 t ha^{-1}). The recommended N of 100 kg N ha^{-1} was applied in three splits with 50 % at the time of sowing 25 % each at maximum tillering stage and before flowering stages in both seasons. For those treatments with N application based on LCC (leaf colour chart), periodical LCC readings were taken in ten top most fully expanded leaves randomly and based on critical values, N was supplied as urea. Grain and straw samples were analyzed for total N content. Nitrogen and Silicon use efficiency (NUE & SiUE) in rice was calculated by using different efficiency formulae.

There was a significant increase in the grain yield of aerobic rice with the application of different amount of N over control. During 2008, the grain yield was significantly higher (5274.9 kg ha^{-1}) in the treatment with 90 kg N ha^{-1} (Urea at 30 kg N ha^{-1} as basal + LCC-3) and on par with 60 kg N ha^{-1} (No basal + LCC-3) over package of practices at 100 kg N ha^{-1}. In 2009, the highest grain yield was recorded in LCC based N application at 75 kg N ha^{-1} along with calcium silicate 2t ha^{-1} and on par with package of practices at 100 kg N ha^{-1} (RDF). Application of 60 kg N ha^{-1} during 2008 and 75 kg N ha^{-1}during 2009 was on par with 100 kg of N (RDF) in achieving the grain and straw yield. Application of 50 kg N ha^{-1} as basal along with two splits of 25 kg N ha^{-1} each during maximum tillering stage and before flowering stage registered higher straw yield (6183.5 kg ha^{-1}) in 2008 but LCC based N application of 75 kg N ha^{-1} (basal at 30 kg N ha^{-1} + LCC-3 at 15 kg N ha^{-1} with three splits) and RDF of 100 kg N ha^{-1} were on par with each other with respect to straw yield during 2009.

The AE_N (Agronomic efficiency of nitrogen) is a function of both physiological efficiency and RE_N (Recovery efficiency of nitrogen) of applied N. The higher agronomic efficiency was achieved when less N fertilizer was used, along with the application of calcium silicate @ 2 t ha^{-1} without sacrificing the yield. The AE_N, RE_N and PFP_N (Partial factor productivity of nitrogen) values were higher for LCC-3 based application of N than RDF in both seasons. During 2009, the highest AE_N (19.2), RE_N (66.3) and PFP_N (63.4) were due to the effect of LCC based N application and higher values were recorded with calcium silicate at 2 t ha^{-1}.

Data pertaining to the AE_{Si} (Agronomic efficiency of silicon) was significant in the treatments with Si as calcium silicate at 2 t ha^{-1}. The application of calcium silicate at 2 t ha^{-1} with 60 kg N ha^{-1} and 100 kg N ha^{-1} recorded the highest AE_{Si} (3.6 & 3.4) values than RDF (0.5) and 75 kg N ha^{-1} (2.0). Present study confirms that use of optimum levels of Si and N is essential than using only optimum Si or N levels. The application of Si as calcium silicate at 2 t $ha^{-1}$and treatments receiving 60 kg N ha^{-1} (urea at 30 kg N ha^{-1} + LCC-3) recorded highest RE_{Si} (3.6) (Recovery efficiency of silicon) than RDF (0.5).

Application of calcium silicate at 2 t ha^{-1} with 90 kg N ha^{-1} (Urea at 30 kg N ha^{-1} + LCC-3) recorded higher PFP_{Si} (23.0) (Partial factor productivity of silicon) over control (14.8) in 2008 and application of calcium silicate at 2 t ha^{-1} with 100 kg N ha^{-1} noticed higher PFP_{si} (19.33) over 75 kg N ha^{-1} (18.93) in 2009.

It was concluded that basal application of low dosage of N fertilizer (30 kg ha^{-1}) along with calcium silicate as a source of silicon was effective for aerobic rice. Application of calcium silicate along with LCC based N application has achieved high N and Si use efficiency in aerobic rice.

Effect of Si deposition on the responses of turfgrass to abiotic stresses

Yu M *, Xiao HD, Wang HZ, He LL

Department of Horticulture, Foshan University, Foshan, 528000, Guangdong, China

Corresponding author: Tel: 0757-85501986 Fax: 0757-82272233 Email: yumin@fosu.edu.cn

Abstract

Si application is strongly recommended in turfgrass management as it is widely thought to be beneficial for improving the resistance of turfgrasss to abiotic stresses besides biotic stresses. We present improvement effects of silicon deposition on the resistance of chilling and light shortage which are major problems in the management of warm season turfgrasses.

Different shape and size of Silica cells are observed in Seashore paspulum（*Paspulum vaginatum Swarfz*）and Tifgreen 419（*Cynodon dacytlon* × *C. transvaanesis*）. Silica cells in Tifgreen 419 is tooth shape and much larger than that in Seashore paspulum which is dumbbell shape in leaf. The development of Silica cells in leaf tip are quite delayed than that in leaf base. Si application promotes the development of Silica cells predominately in leaf base to the extent that cork cell is hardly found in the interval array of silica cells and cork cells in Seashore paspulum. The well development of silica cells in leaf is reflected by the straight status of leaf as well as its resistance to light shortage and chilling.

Two different light shortages are set up, one is lower light intensity (6% natural light using plastic adumbral web) and the other is 1 h light duration versus 12h duration. Under both light shortages, content of sucrose (majority of soluble sugars) drops significantly if Si is not applied. However, the drop of sucrose is hardly found after Si application. It indicates that Si application can compensate for the possible light shortages during turfgrass management.

Silicon supplementation can enhance chilling resistance of Seashore paspalum (*Paspalum vaginatum* Swartz). For turfgrass treated by chilling temperature, it is found that chilling induces significant adaptive increases of free proline and soluble sugar ($p<0.01$) and the activities of peroxidase (POD) ($p<0.05$). Chilling also significantly decreases the activities of superoxide dismutase (SOD) and catalase

(CAT) ($p<0.05$), and leads to notably higher measurements of malondialdehyde (MDA) ($p<0.05$). Silicon addition promotes significant increase of proline and sucrose ($p<0.01$), while maintaining significantly higher activities of SOD, POD, CAT, and notably leveling off of MDA ($p<0.05$) under chilling stress. These results indicate that silicon can enhance the chilling resistance of turfgrass via maintaining a stable membrane and a beneficial cell status readily coping with the chilling induced oxidative stress.

In conclusion, Si deposition in turfgrasses can promote the resistance to light shortage and chilling, thus the foliar fertilizer containing Si helps maintain green in warmseason turfgrass in winter.

Key words: Chilling, Light shortage, Oxidative stress, Si, Sucrose Turfgrass.

The silicification in silica cell's walls precedes silica deposition in leaf epidermis of rice (*Oryza sativa* L.)

Zhang CC, Wang LJ, Zhang WX, Zhang FS*

Department of Plant Nutrition, China Agricultural University, Beijing, 100193, China

**Corresponding author: Fusuo Zhang. E-mail: zhangfs@cau.edu.cn*

Abstract

The mechanisms involving in silica deposition are well studied for lower plants, such as diatom, but unclear for higher plants, such as rice. Rice is a silicon-rich plant which accumulates silicon in leaf epidermis and forms a dumbbell-like silica cell, called phytolith or 'plant opal'. This study is to present the process of silicon depositing in silica cells in the epidermis of leaves.

A hydroponic experiment was conducted in greenhouse to highlight the importance of silicon for rice growth. The leaf samples were collected at different growth stages; the ultrastructure observation and Si microanalysis for silica cells were performed with the Scanning Electron Microscopy (SEM) coupled with Electron Dispersive X-ray (EDX-ray) and the Transmission Electron Microscopy (TEM).

The hydroponic experiment approved that silicon was important for rice growth. The rice plant under exogenous silicon addition increased shoots biomass by 101% and roots biomass by 87.6% compared with the plants under no silicon addition. The shape of the silica cells was changing with growing stages. The silica cell presented as a cross-like structure at very beginning but the cross-like structure was gradually swelling up with leaf developing and finally turned to dumbbell-like shape. However, Si deposition in the silica cells was not occurred until the dumbbell-like silica cells were formed morphologically. The further studies by using the TEM coupled with Si microanalysis indicated that the silica cell's walls were silicified prior to the intensive silica deposition in the lumen of the silica cells and that the silicified needles were stacked regularly and filled the lumens when leaves became mature. Overall, there were two processes involved in the formation of the silica cells: (1) the silica cell was formed morphologically and the wall silicified; (2) silica deposited in the lumen of silica cells and the dumbbell-like silica cells were finally presented when leaves were fully expanded.

Key words: *Oryza sativa* L., Phytolith, Silicon deposition, Silica cells, Silicification.

Rhizosphere pH was important in silicon availability and plant uptake at various types of soil

Zhang CC [1], Zhang FS [1], Roemheld V [2]

1.Department of Plant Nutrition, China Agricultural University, Beijing, P. R. China, 100193

2.Institute of Plant Nutrition, Hohenheim University, Fruwirthstraße 20, D-70599 Stuttgart, Germany

Abstract

Our previous report showed that Si extractability by water or $MgSO_4$, as well as Si uptake by both rice (*Oryza sativa*. L.) and cucumber (*Cucumis sativus*. L.) was increased at lower pH when two soils which were collected at Yunnan Province were stabilized with NH_4-N form. It is however unknown whether the soil type will affect this statement. Thus, a soil incubation experiment that included eight soils with different original pH values (5.22 to 7.81) and a pot growth experiment with a manipulated rhizosphere pH by different supply of N forms to rice and cucumber were conducted.

Overall, Si extractability by water or $MgSO_4$ was increased at lower pH when soil original pH was more than pH 6.0, but $MgSO_4$– extractable Si was decreased at lower pH when the acid soil (pH 5.22) was manipulated to pH 4.0 by adding acid solution. Silicon uptake by cucumber or rice, as well as Mn or Zn, was increased at lower pH when five different soils ranging pH from 6.13 to 7.81 were stabilized with NH_4-N form, respectively. The results confirmed the pH effect on Si solubility and plant uptake that Si availability for plants will be increased at lower pH if the soil pH is not lower than 6.0.

Key Words: Nutrient uptake, Nitrogen form, Rhizosphere management, Silicon availability.

Nature of "Anomalous Silicon" in Plant Biology

Zhang FS [1], Wang LJ [2]

1.College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China. E-mail: zhangfs@cau.edu.cn

2.College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, China

Abstract

Many experiments have corroborated the phenomenon involving the formation of intracellular or extracellular silica that is important for plant growth, mechanical strength, and alleviating biotic (including fungal diseases) and abiotic conditions, such as drought and high temperature.[1] Despite such benefits, 'Si' is not counted among the elements defined as "essential" or nutrients, for most terrestrial higher plants with the exception of the primitive Equisetaceae,[2] and the nature of this phenomenon remained unclear and widely differing viewpoints and hypotheses were put forward to clarify it. It is evident that the anomalous properties of extracellular silica may be explained, not by a more active involvement of Si in plant physiological processes, as was previously proposed, but by the peculiar features of a chemical modification of the cell walls through silica deposition in the apoplast. Extended cell wall networks are predominant in the extracellular spaces and serve as templates for inorganic nucleation and the interfacial molecular recognition which facilitates the formation of silica. It is possible that Si deposition modifies the cell wall polysaccharides thereby providing a modest improvement in stability and rigidity of the cell wall against biotic and abiotic stresses. The underlying chemical mechanisms suggest that the cell wall modified by silica increases the water-absorption/retention capability of cells through hydrogen-bonding between water and the silica surface hydroxyl groups, thereby suppressing overall water loss, and maintaining cell integrity in a fluid, water-rich microenvironment. This can explain why the modified cell walls with Si reduce transpiration rate of water (conserve water) during moisture stress or drought.[3,4] In addition, the silica-cell wall networks possibly exhibit more net negative charges that prevent heavy metal ions to cross the cell wall/membrane, thus improving plant tolerance to metal toxicity.[5,6] In summary, silica helps a plant to survive many abiotic stresses through the reinforcement of the cell wall and the stability of its underlaid cell

membrane, which may reflect evolutionarily conserved mechanisms for silica-accumulating organisms especially higher plants occupying stressed habitats.

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Silicon mediated resistance to rice sheath blight by enhancing phenolic metabolism

Zhang GL

College of Life Science and Chemistry Engineering, Huaiyin Institute of Technology, Huaian 223003, China, e-mail: hgzgl@126.com

Abstract

Sheath blight caused by *Rhizoctonia solani* (*R.solani*) is one of the major diseases worldwide in rice. Silicon (Si) has been reported to improve the resistance to rice sheath blight. The two rice cultivars with different levels of resistance to *R.solani* (resistant cultivar Teqing, susceptible cultivar Ningjing 1) were selected to determine the effects of Si on the severity and incidence of rice sheath blight and if phenolics are involved in disease resistance. The variation in the amount of phenolics (including total soluble phenolic level, flavonoid level, ferulic acid level, chlorogenic acid level, lignin level) and the activities of defense-related enzymes (polyphenoloxidase, PPO; phenylalanine ammonia-lyase, PAL) in rice leaf sheaths were investigated. The results showed that Si application reduced the disease rating of sheath blight by 2.96 and 0.65 for Ningjing 1 and Teqing, and disease index by 18.29% and 4.35%, respectively. For uninoculated plants, Si application alone did not change the phenolics amount and PPO and PAL activities significantly. For inoculated plants, Si application increased the phenolics amount and PPO and PAL activities of Ningjing 1 significantly, whereas increased those of Teqing, but not significantly. It was concluded that the important way of Si mediated resistance in rice against sheath blight was probably through the phenolic metabolism.

Key words: Defense-related enzyme, Mediated resistance, Phenolic metabolism, Rice (*Oryza sativa* L.), *Rhizoctonia solani*, Silicon.

The role of silicon in mitigating arsenic accumulation in rice plant

Zhu YG [1, 2], Li G [1]

1.Key Laboratory of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen, 361021, China

2.Research Center for Eco-Environmental Sciences, the Chinese Academy of Sciences, Beijing, 100085, China

Abstract

Arsenic (As), a nonthreshold class I carcinogen, is ubiquitous in the environment. Rice is much more efficient in accumulating As into its grain than other cereals. Therefore, rice is the major pathway for human exposure to As for populations taking rice as the stable food. Silicon (Si) is the second most abundant element in soils, the mineral substrate for most of the world's plant life. Furthermore, rice can accumulate Si up to 10% in the shoots on a dry matter basis. In this talk, effects of Si on As uptake by rice plants will be reviewed. By using hydroponic experiments, we are among the first demonstrating that the addition of Si can significantly decrease As uptake by rice plants. This finding was supported by soil-based experiments conducted in the Germany and England. The mechanism of Si-mediated decrease in As uptake was not clear until the outstanding molecular work by Ma and his colleagues. Ma et al. have identified OsNIP2;1 (*Lsi1*) and *Lsi2*, which localize at the distal and proximal side in the exodermis and endodermis, respectively, can transport efficiently both Si and arsenite into rice roots. To be specific, the processes of Si and As transport from the external medium to the stele involve the influx of silicic acid and arsenite by *Lsi1* and then the efflux of them towards the stele regulated by *Lsi2*. Moreover, *Lsi*2 can play a more important role in controlling As accumulation in rice shoots and grain than *Lsi1*. Therefore, the mechanisms of Si-mediated decrease in As uptake can be explained by the competitive inhibition between Si and arsenite and the reduced expression of *Lsi1* and *Lsi2* when supplying Si. In addition, Si can also affect the uptake of other heavy metals like cadmium and zinc in rice plant, the mechanisms of which are still unknown.

Roles of silicon-mediated alleviation of salt stress in higher plants: A review

Zhu ZJ, Fan HF, He Y

School of Agricultural and Food Science, Zhejiang A & F University, Lin'an, Hangzhou, Zhejiang, China
E-mail: zhuzj@zafu.edu.cn Tel: 0571-63743001

Abstract

Silicon is the second most abundant element both on the surface of the earth's crust and in soils, yet it has not been listed among the essential elements for higher plants due to the fact that direct evidence is still lacking that Si is part of the molecule of an essential plant constituent or metabolite. However, the beneficial role of Si in stimulating the growth and development of many plant species has been generally recognized, especially when plants are submitted to biotic or abiotic stresses. The experiments suggested that Si may be involved in metabolic or physiological and/or structural activity in higher plants exposed to biotic and abiotic stresses. Salt stress has been a major obstacle to the successful use of salt-affected soils for crop production. It is estimated that about a third of the world's cultivated land is affected by salinity and that there are approximately 27 million ha of salinised soils in China's coastal and inland areas. How to exploit saline soils has received worldwide attention. The ability of Si to ameliorate the negative effect of NaCl on plant growth is well documented. The main roles of Si-mediated alleviation of salt stresses in higher plants include: (1) Improvement of plant growth. Si significantly increases the cell wall extensibility and results in an increase in root and shoot growth under salt stress, in turn, it contributes to salt dilution into the plant and mitigates salt toxicity effects; (2) Improvement of the water storage within plant tissues; (3) Inhibition of transpiration. Si induces the reduction in transpiration rate and the partial blockage of the transpirational bypass flow, which decreases Na concentration in the shoots of plant; (4) Stimulation of antioxidant systems in plants; (5) Maintenance of the structure, integrity and functions of plasma membranes; (6) Improvement of photosynthesis. Si induces enhancement of photosynthesis and/or chlorophyll fluorescence parameters under salt stress; (7) Improvement of ion balance under salt stress; and (8) Increase of root activity. This review describes the progress in roles of silicon-mediated alleviation of salt stress in higher plants and its important role in enhancing plant salt stress resistance. Future research for the mechanisms of Si-mediated alleviation of salt stress is also discussed.