7th International Conference on Silicon in Agriculture

24-28 October 2017, UAS, Bengaluru, India

PROCEEDINGS OF

ABSTRACTS

University of Agricultural Sciences, Bengaluru

Indian Society of Soil Science, Bangalore Chapter

The International Society for Silicon in Agriculture & Related Disciplines (ISSAG)

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Foreword

The essentiality of silicon on growth of higher plants remains debatable till now even though research has demonstrated many beneficial and functional roles of Si, especially under stressful conditions, in agriculture and horticulture crops. To unravel the secrecies of silicon, the first International Conference on Silicon in Agriculture was held at Florida, the United States of America during 1999, followed by meetings at Tsuruoka, Japan (2002), Uberlandia, Brazil (2005), KwaZulu-Natal, South Africa (2008), Beijing, China (2011) and Stockholm, Sweden (2014). Since the first conference, the silicon family has grown substantially, leading to the knowledge and understanding of silicon in agriculture.

India holds the second largest agricultural land in the world and 50% of India's geographical area used for agricultural activity. Therefore, in this endeavour, the 7th International Conference on silicon in Agriculture to be held at Bengaluru, the silicon valley of India will provide a platform for scientists, policy makers, industries and students to exchange scientific knowledge, share practical experiences, motivate youngsters and prepare road map for furthering the knowledge of silicon for the benefit of mankind.

The proceedings of abstracts brought out on the occasion of the 7th International Conference on Silicon in Agriculture reflect knowledge, information and ideas of researchers studying all aspects of silicon research in the world. The major theme of the Conference is "Silicon Solution to Sustainable Agriculture". The proceedings includes seven sections: 1) Biogeochemistry of Silicon cycle in agriculture; 2) Chemistry and analysis of Silicon in soils, plants and fertilizers; 3) Mechanism of Silicon uptake and accumulation in plants; 4) Role of Silicon in abiotic stress management; 5) Role of Silicon in biotic stress management; 6) Silicon fertilizers on performance of plants; and 7) Influence of Silicon on plant growth and development.

We thank Dr. Jean Dominique Meunier and Dr. Ravin Jugdaohsingh for their plenary lectures. We also convey our wholehearted thanks to Dr. Brenda Servez Tubana, Dr. Kazuyuki Inubushi, Dr. Miroslav Nikolic, Dr. Naoki Yamaji, Dr. Richard Bélanger, Dr. Rivka Elbaum and Dr. Yongchao Liang for their keynote lectures. Special thanks to Dr. Lawrence E. Datnoff for chairing the panel discussion on "Future Scenario of Silicon in Agriculture" and his constant support and encouragement for the silicon community is highly acknowledged.

We thank the University of Agricultural Sciences, Bengaluru, and all individuals who made this conference and publication of the proceedings of abstracts possible.

We highly acknowledge all the sponsors for their financial support. We are also grateful to the members of the International and National Steering Committee for their valuable support, suggestions and guidance. We thank the delegates for their outstanding contributions to this great scientific event.

We thank all the office bearers and board members of The International Society for Silicon in Agriculture and Related Disciplines (ISSAG), Bangalore Chapter of Indian Society of Soil Science for their support and suggestion for publication of proceedings of the abstracts.

We would like to appreciate all the hard work and diligent effort that has given us fruitful result eventually provided by Meetings and More, Gurugram, Haryana, India. The efficient and hard work of Mr. Ravikumar B. A., Resolution Print Media, is gratefully acknowledged.

-The Editors

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PROGRAMME SCHEDULE

TUESDAY 24th OCTOBER 2017

14.00 - 16.00	**Departure from Radisson Blu Atria to University of Agricultural Sciences, GKVK** **Visit to Dry Land Agriculture Farm, Visit to Pedonarium** **Visit to Field Demonstration Plots**
17.00 - 18.00	**Registration at Radisson Blu Atria**
18.00 - 18.30	**WELCOME RECEPTION**

WEDNESDAY 25th OCTOBER 2017

09.00 - 09.45	**REGISTRATION**
09.45 - 11.00	**INAUGURAL FUNCTION**
11.00 - 11.30	**INAUGURAL TEA**
11.30 - 12.00	*Plenary Speaker I* : **Jean Dominique MeunierBiogeochemistry of silicon in agriculture: a review**
12.00 - 12.30	*Plenary Speaker II* : **Ravin Jugdaohsingh Establishing the biological role of dietary silicon**
12.30 - 13.30	**LUNCH BREAK**

SESSION I

Sub Theme I : **Biogeochemistry of silicon cycle in agriculture &**
Sub Theme II : **Chemistry and analysis of silicon in soils, plants and fertilizers**

Chair : **Jean Dominique Meunier**, *Co-Chair* : **Brenda S. Tubana**

13.30 - 14.00	Key Note : **Tubana S. Brenda**	Understanding the dynamics of silicon in plant and soil are essential for establishing silicon fertilization guidelines.
14.00 - 14.15	**Jean Riotte**	Origin of silica in rice plants and contribution of diatomaceous earth fertilization: insights from isotopic Si mass balance in a paddy field.
14.15 -14.30	**Sreenivasan T. Sandhya**	Alkalinity ratio and the release of extractable silicon from silicate slags in rice soil.
14.30 -14.45	**Latha P. C.**	Silicate solubilization and plant growth promoting potential of *Rhizobium sp*. isolated from rice rhizosphere
14.45 - 15.00	**Regan Crooks**	Effect of silica fertiliser on dissolved silicon in soil solution based on the chemical properties of various soils.
15.00 - 15.15	**Vladimir Matichenkov**	New approaches in testing active forms of silicon in soil, plants and silicon-rich materials.
15.15 - 15.30	**Zancajo Victor M. R.**	Multimodal structural and functional analysis of sorghum tissues and sorghum biosilica.
15.30 - 15.45	**AryaLekshmi V.**	Silicon adsorption isotherm characteristics in tropical rice soils of Kerala.
15.45 - 16.00	**Patil A. A.**	Suitability of extractant for soil available silicon and silicon response toupland paddy grown on inceptisols and vertisols.
16.00 - 16.30	**TEA BREAK AND POSTER PRESENTATION**	

SESSION II

Sub Theme III : **Mechanism of silicon uptake and accumulation in plants**

Chair : **Naoki Yamaji**, *Co-Chair* : **Maria Greger**

16.30 - 17.00	Key Note : **Yamaji Naoki**	A cooperative transport system for silicon in plants.
17.00 - 17.15	**Sakurai Gen**	Analysis of the expression dynamics of silicon transporter gene using mathematical model in rice.
17.15 - 17.30	**Rupesh Deshmukh**	Genomics intervention to understand silicon transport in plants.
17.30 - 17.45	**Coskun Devrim**	What makes a silicon transporter? The search for key residues that confer plant silicon permeability, accumulation, and benefits.
17.45 - 18.00	**Kumar Santosh**	Correlative fluorescence and electron microscopies showing programmed cell death in sorghum silica cells.
18.00 - 18.15	**Greger Maria**	Plant uptake of silicon nanoparticles.
18.15 - 18.30	**Haijun Gong**	Isolation and characterization of silicon transporter gene *Lsi 1* in *Solanum lycopersicum* L.
19.00 - 20.00	**CULTURAL PROGRAMME**	
20.00	**DINNER**	

THURSDAY 26th OCTOBER 2017

SESSION III

Sub Theme IV : **Role of silicon in abiotic stress management**

Chair : **Yongchao Liang**, *Co-Chair* : **Nikolic Miroslav**

09.00 - 09.30	Key Note 1 : **Yongchao Liang**	Silicon and abiotic stress in higher plants progress and perspectives.
09.30 - 10.00	Key Note 2 : **Nikolic Miroslav**	Silicon influence on plant ionom and mineral element transporters.
10.00 - 10.15	**Camargo M. S.**	Silicon fertilization alleviates the deleterious effects of water deficit in sugarcane cultivars.
10.15 - 10.30	**Garg Neera**	Emerging recognition of silicon as ameliorator of abiotic stresses in legumes.
10.30 - 10.45	**Biju Sajitha**	Silicon potentiates photosynthetic efficiency and biochemical defenceresponses of lentil against drought stress.
10.45 - 11.00	**Bosnic Predrag**	Silicon mediates sodium transport and homeostasis in maize under mild NaCl stress.
11.00 - 11.15	**GROUP PHOTOGRAPHY**	
11.30 - 11.45	**TEA BREAK**	
11.45 - 12.00	**Vaculík Marek**	Silicon-induced alleviation of antimonate (SbV) toxicity in maize.
12.00 - 12.15	**Zexer Nerya**	Insights to silicon-dependent drought tolerance by testing a sorghum mutant defective in silicon uptake.
12.15 - 12.30	**Bhandari Purnima**	Silicon nutrition augments plant vigour, ionic homeostasis and defense mechanisms in mycorrhizal *Cicer arietinum* L. genotypes under salt stress.
12.30 - 13.30	**LUNCH BREAK**	

SESSION IV

Sub Theme V : **Role of silicon in biotic stress management**

Chair : **Bélanger R. R.**, *Co-Chair* : **Padmakumari A. P.**

13.30 - 14.00	Key Note : **Bélanger R.R.**	Recent progress in defining the protective role of silicon against plant diseases.
14.00 - 14.15	**Cai Kunzheng**	Deciphering the role of silicon in enhancing tomato resistance to bacterial wilt *via* proteomics and transcriptome approaches.
14.15 - 14.30	**Padmakumari A. P.**	Silicon in rice stem borer management - an overview.
14.30 - 14.45	**Rupesh Deshmukh**	Silicon increases tolerance against powdery mildew and drought stress in transgenic tomato expressing the *Lsi1* gene from wheat.
14.45 - 15.00	**Abbai Ragavendran**	Silica nanoparticles enhances the tolerance of *Panax ginseng*meyer against the root rot causing fungus, *ilyonectriamors-panacis* by regulating sugar efflux into apoplast.
15.00 - 15.15	**Hou Maolin**	Improved resistance to the brown planthopper in rice plants amended with silicon and the underlying mechanisms.
15.15 - 15.30	**Basdew I. H.**	The enzymatic effect of preharvest silicon applications and postharvest hot water treatments in an attempt to minimize disease development in citrus fruit.
15.30 - 16.30	**TEA BREAK AND POSTER PRESENTATION**	

SESSION V

Sub Theme VI : **Silicon fertilizers on performance of plants**

Chair : **Prakash N. B.**, *Co-Chair* : **Fabricio Rodrigues**

16.30 - 16.45	**Peter Prentice**	Efficacy of silica in increasing yields in morocco.
16.45 - 17.00	**Krzysztof Ambroziak**	Foliar application of pH neutral silicon product and its effect on abiotic stress mitigation in field crops.
17.00 - 17.15	**Elena Bocharnikova**	New generation silicon fertilizers – greenhouse and field tests.
17.15 - 17.30	**Tubana Brenda**	Potential of Armurox®, a soluble silicon and peptides biostimulant, as a foliar source of silicon in wheat.
17.30 - 17.45	**Michel Preti**	MOSA: stabilized monosilicic acid, a new window of opportunities for efficient and effective supplementation of Silicon by root or leaf.
17.45 - 18.00	**Arkadiusz Artyszak**	Effect of foliar fertilization with silicon on selected physiological parameters, yield and technological quality of sugar beet.
18.00 - 18.30	**INTERNATIONAL STEERING COMMITTEE MEETING**	
19.00	**CONFERENCE DINNER**	

FRIDAY 27th OCTOBER 2017

MID CONFERENCE TOUR

07.00	**Departure from Bengaluru**
09.30 - 11.00	**Visit to Experimental Plots and Jaggery Park at ZARS, VC Farm, Mandya**
12.30 - 13.30	**LUNCH AT MYSORE**
14.00 - 16.30	**Visit to Mysore Palace**
17.00	**Departure from Mysore**

SATURDAY 28th OCTOBER 2017

SESSION VI

Sub Theme VII : **Influence of silicon on plant growth and development**

Chair : **Kazuyuki Inubushi**, *Co-Chair* : **Elbaum Rivka**

09.00 - 09.30	KEY NOTE 1 : **Elbaum Rivka**	Silicic acid and silica biology studied in a low-silicon sorghum mutant.
09.30 - 10.00	KEY NOTE 2 : **Inubushi K.**	Effect of silicate amendment on environment and yield in Southeast Asia.
10.00 - 10.15	**Mayanglambam Homeshwari Devi**	The critical silicon dose in seedling root-dip method in acid soils dependent on rice cultivar and soil type.
10.15 - 10.30	**More R. R.**	Bioavailability of silicon by silicate solubilizing micro-organisms for increasing yield and quality of sugarcane.
10.30 - 10.45	**Lux Alexander**	Silicification of *Cocos nucifera* and *Phoenix dactylifera.*
10.45 - 11.00	**Valentin Kindomihou**	The tropical fodder silicification as influenced by burning: Cases of *Andropogon schirensis*, *Brachiaria falcifera* and *Hyparrhenia subplumosa* from Guinean Benin.
10.00 - 11.15	**Siti Nordahliawate M. Sidique**	Beneficial effects of silicon on the growth and biotic stress of Melon (*Cucumismelo* L.) var. Glamour Sakata.
11.15 - 11.45	**TEA BREAK AND POSTER PRESENTATIONS**	
11.45 - 12.00	**Phonde D. B.**	Studies on soil silicon status in vertisols and silicon nutrient management in sugarcane.
12.00 - 12.15	**Sriramachandrasekharan M.V.**	Response of Banana to Silicon Nutrition in *Typic Ustifluvent* Soil.
12.15 - 12.30	**Pengbo Zhang**	Silicon fertilizers impact on greenhouse gas emission.
12.30 - 13.30	**LUNCH BREAK**	

PANEL DISCUSSION : FUTURE SCENARIO OF SILICON IN AGRICULTURE

Chair : **Datnoff E. Lawrence**, *Co-Chair* : **Lux Alexander**

13.30 - 14.00	**Datnoff E. Lawrence**	Why is silicon still not used routinely for managing plant health and enhancing plant growth under greenhouse and field conditions?
14.00 - 14.08	**Bruce Cairns**	Future scenarios of silicon in agriculture: An Australian perspective
14.08 - 14.16	**Henk Marten Laane**	Silicon in agriculture: The future
14.16 - 14.24	**Nagabovanalli B. Prakash**	Status and prospects of utilization of different silicon sources: An overview of the results from seven international conferences on silicon in agriculture and future thrust
14.24 - 14.32	**Tania Raugewitz**	Proven performance, economic incentive, and consistent terminology required for long-term grower adoption
14.32 - 14.40	**Tewatia R. K.**	Silicon in Indian agriculture: Policy and promotional issues
14.40 - 15.30	**GENERAL GROUP DISCUSSION**	
15.30 - 16.00	**TEA BREAK**	
16.30 - 17.30	**VALEDICTORY FUNCTION**	

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KEY NOTE

SHORT ORAL

POSTER PRESENTATION

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KEY NOTE

SHORT ORAL

POSTER PRESENTATION

SESSION V

Sub Theme VI : Silicon fertilizers on performance of plants

SHORT ORAL

SESSION VI

Sub Theme VII : Influence of silicon on plant growth and development

KEY NOTE

SHORT ORAL

POSTER PRESENTATION

Plenary Lectures

Biogeochemistry of silicon in agriculture: A review

Jean Dominique Meunier
CEREGE, CNRS, IRD, Coll. France, Aix Marseille Université, 13545 Aix en Provence, France (meunier@cerege.fr)

ABSTRACT

Assessing the pools of Si in soils that are bioavailable for plants (=PAS) and beneficial for crops is a key issue that requires a better knowledge of the biogeochemical cycle of Si in the cultivated fields. The comprehension of the cycle of Si in the natural ecosystems has been considerably improved since the 1980's. The role of plant Si recycling is now well documented. The rapid recycling of plant Si is controlled by the specific composition of Si in shoots represented by amorphous (opal A) silica particles also called phytoliths. Based on laboratory experiments it was shown that phytoliths are, depending on pH conditions, one of the best source of PAS amongst the soil silicates. Studies of the status of Si have suggested that land occupation including agriculture affect PAS. The decrease of the phytolith pool observed in the cultivated land may confirm the hypothesis of Savant et al. (1997, Commun SoilSci Plant Anal, 28, 1245-1252) that the decline of yield is due to PAS depletion. This is the reason why reinjection of the straw in the field should be encouraged in order to limit the depletion of PAS. The application of Si fertilizer is known to increase the yields but the consequences for the pedology and geochemical properties of soils at the long term are still not well documented. For instance, some Si fertilizers contain high amount of heavy metals and should therefore be used with caution or banned.Besides, in order to evaluate the critical PAS level below which Si fertilization could be relevant, several procedures have been suggested. These are based on empirical positive correlation between a given extractant and plant parameters such as Si uptake or grain yield. However, the significance of the PAS obtained by the extractants are still not well constrained. The concentration of dissolved Si depends on environmental condition (pH, temperature…) and the ability of Si pools to release Si into solution. Both solubility of silica minerals and desorption processes may explain the positive correlation observed between PAS and pH. The significance of the Si extractants used for estimate the PAS requires a better understanding of the kinetics laws that govern the release of Si in soil solutions. The use of Si isotopes and Ge/Si ratios, proven to be useful for tracing the source of dissolved Si (phytoliths vs non biogenic silicates), are expected to bring new insights into the understanding of different Si pools contributing to PAS. Acknowledgements:The author would like to thank CEFIPRA (project 5109-1) and ANR (project ANR-14-CE01-0002) for their support.

Keywords: Silicon, biogeochemistry, agriculture, plant available silica, phytolith

Establishing the biological role of dietary silicon

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ABSTRACT

Silicon (Si) is a major constituent of the mammalian diet and, on average, we ingest between 20-50 mg of Si per day from the Western diet. This is mainly from cereal crops and cereal-based products, some fruits and vegetables and from drinking water. Following ingestion, dietary silicon is generally well absorbed as orthosilicic acid [$Si(OH)_4$] and the differences in uptake between foods and between dietary Si supplements is probably due to differences in silicon speciation. Mechanism of uptake of silicon from the gastrointestinal tract has not been established,althoughit is generally assumed that due to its small size and neutral charge, $Si(OH)_4$ is absorbed by passive diffusion. Following absorption, the majority of absorbed silicon is readily excreted in urine and faeces, but a small unknown proportion is retained as supplementation leads to increases in fasting serum and bone silicon levels. It is in the kidneys that silicon is most likely (homeostatically) regulated, since long-term dietary silicon depletion in rats leads to a reduction in urinary silicon excretionto conserve tissue Si levels. As such, silicon responsive genes in the kidney have been investigated and a silicon transporter has recently been reported. How and what mediates the expression of this transporter, we are currently investigating. Dietary Si appears to have beneficial effects on the connective tissues including bone. Higher intake of dietary Si is associated with higher bone mineral density, especially in premenopausal women and men and less so in post-menopausal women, except those taking, or have previously taken, hormone replacement therapy. Conversely, depletion of silicon from the diet of animals leads to either mild changes in bone mineral composition and inhibition of growth plate closure or to more severe symptoms such as abnormal bones and connective tissues. Mechanism of action of silicon in bone and other connective tissues is yet to be established but the overwhelming data suggests a possible role in the extracellular matrix. Indeed, exposure of dermal fibroblast cells or osteoblast cells to $Si(OH)_4$ results in increased cell proliferation and matrix synthesis, aiding wound closure and bone healing. Thus dietary silicon appears to be important for bone and connective tissue health, but establishing its exact role and mechanism of action remains elusive.

Keywords: Silicon; Diet; Biological role; Transporter; Connective tissues; Mechanism of action

Session - 1

Sub Theme - I

Biogeochemistry of Silicon Cycle in Agriculture

&

Sub Theme - II

Chemistry and Analysis of Silicon in Soil, Plants and Fertilizers

Keynote

Understanding the dynamics of silicon in plant and soil are essential for establishing silicon fertilization guidelines

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ABSTRACT

While the positive role of silicon in crop production is well-known; only a few regions in the world practice silicon fertilization routinely. One of the most prevalent reasons is a lack of understanding on how to best estimate monosilicic acid (H_4SiO_4) in the soil along with the factors affecting its availability to plant. A series of field, greenhouse, and laboratory-incubation studies were conducted at Louisiana State University AgCenter since 2011 with a long-term goal of establishing silicon fertilization guidelines for a variety of field crops grown on the highly diverse soils of Louisiana. Most of these soils (Alfisols, Entisols, Histosols, Inceptisols, and Ultisols) were formed from sediments deposited by rivers and wind, and they come in a variety of soil textures and pH ranging from slightly to moderately acidic. The field and greenhouse trials provided insights on potential silicon sources and critical silicon level in soil. Samples collected from these trials were also used to standardize the testing procedure for estimating plant-available silicon in soils. The release pattern of H_4SiO_4 as affected by soil properties, source, and size of slag materials were studied too. The correlation analysis showed that the amount of silicon extracted from soil by 0.5 M acetic acid procedure exhibited a stronger association with plant Si content and uptake than the amount of silicon extracted by other solutions. The quadratic and linear-plateau regression analysis between a variety of plant variables (*i.e.*,yield, silicon uptake, silicon content) and estimated silicon in the soil suggested that the critical silicon value for Louisiana soils ranged from 35 to 50 mg kg^{-1}. The outcomes of multiple field trials suggested that 0.9 to 3.6 Mg slag material ha^{-1} application rate (equivalent to 100 to 400 kg Si ha^{-1}) resulted in increases in yield and improvement in nitrogen use efficiency. The benefits of silicon fertilization were mostly observed in crops planted on soils with an initial Si content < 60 mg kg^{-1} but there were some exceptions, e.g. rice grown on one heavy textured soil with an initial Si content of 156 mg kg^{-1} had a 500 kg ha^{-1} increase in grain yield. These unexpected responses were partially explained by the kinetics of H_4SiO_4 in soil solution are affected by soil properties and silicon source. High rate of sorption and polymerization of H_4SiO_4 can take place when a highly soluble silicon source is applied to a soil low in H_4SiO_4. Thus, plant response to silicon fertilization is expected in silicon-deficient soils with high amount of organic matter and clay. Our research also showed that an elevated level of H_4SiO_4 will reduce the amount of arsenic taken up by rice. The amount of H_4SiO_4 released using slag materials with mixed granular sizes was ~50% lower than the fine granular size (d” 1 mm) and ~100% higher than large granular size (d” 5 mm). An initial soil test-based decision tool for silicon fertilization has been established for soils in Louisiana but refinements are required to warrant both agronomic and economic outcomes of this nutrient management strategy.

Keywords: Monosilicic acid; Critical silicon level; Silicon sources; Soil properties; Plant silicon uptake

Short Oral

Silicon adsorption isotherm characteristics in tropical rice soils of Kerala

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ABSTARCT

Silicon (Si) sorption isotherms have been used to characterize the Si status and to establish fertilizer requirements of soils. The soils of Kerala are predominantly acidic with high amounts of exchangeable Al and low plant available Si. An awareness of Si deficiency in soil is now recognized as a limiting factor for crop production; particularly in soils that are seemed to be low or limiting in plant available Si. Application of Si fertilizer has a significant potential benefit on growth and yield of plants. Such additions, however, bring drastic changes in ionic equilibrium and affect the rates of ion supply to plant roots. There is a linear relationship between Si requirement by plants and Si sorption by the soil. Adsorption-desorption processes help us in understanding the mechanism and extent of its movement through soil and water bodies. Therefore, adsorption isotherm equations (Freundlich, Langmuir, Temkin etc.) have been used to characterize adsorption behaviour of Si in five different wet land rice soils of Kerala. The soil samples *viz., Kole, Kuttanad, Pokkali*, Sandy and Lateritic soils were collected from five different locations representing the major rice growing soils of Kerala. Among different soils, *Pokkali* and *Kuttanad*s oils were extremely acidic in nature. Higher organic carbon content was observed in *Kole, Kuttanad* and *Pokkali* soils. Sandy soils of Chalakudi recorded lowest organic carbon. The thermodynamic characteristics of Si adsorption were determined by fitting these data into the thermodynamic equation. Isotherm equations *viz*., Temkin and Freundlich, (r^2> 0.5) gave good fit with the experimental data and not fitted to Langmuir equation (r^2< 0.5) at 25 ^{0}C. The soil parameters *viz*., EC, OC, CEC, AEC and clay content of the soils showed significant correlation with constants of the isotherm equations (*P*< 0.01). Any of the adsorption equation could not describe Si adsorption at 40 ^{0}C. The data for all the soils could be described by the linear form of Freundlich equation. A significant correlation was found between the clay content, electrical conductivity and AEC of soil with Freundlich constant (K_F). The highest adsorption intensity of *Kole* land soil could be ascribed to high clay content or organic matter of soil or both. The organic matter can act in two ways, either by sorbing Si or by blocking sorption sites of inorganic particles. Si-adsorption behavior varied significantly between different types of soil. Soil minerals also can influence Si adsorption. Sandy soils with quartz and feldspar showed lesser Si adsorption intensity. As per correlation coefficient, the data was better fitted to Freundlich model as compared to Temkin model indicating that adsorption mechanism was related to non-ideal, reversible and multilayer adsorption with non-uniform distribution of ad-sorption heat and affinities over the heterogeneous surface. Temkin equation was most accurate in describing Si adsorption in *Kole* land soil followed by lateritic and *Pokkali* soils, whereas data obtained from sandy soils of Chalakudi could not be fitted into Temkin equation. This finding was further supported by the significant positive correlation of Temkin constant (B) with OC, CEC and clay content. The positive values of Temkin parameter (B) explained the exothermic nature of Si adsorption. This study showed that there are significant differences in the adsorption of Si between different type soils.

Keywords: Adsorption, Equilibrium, Intensity, Isotherms, Silicon

Origin of silica in rice plants and contribution of diatomaceous earth fertilization: insights from isotopic silicon mass balance in a paddy field

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ABSTRACT

Field experiments were carried out with and without application of diatom earth (DE) under rice and bare conditions to assess the origin(s) of silicon in rice plants (CEFIPRA Project n°5109-1). Water (irrigation borewell and rain) and dissolved silica (DSi) inputs to each plot were monitored, as well as the water composition at the ground surface to assess the above ground processes affecting DSi. Depth profiles of soil pore water compositions were obtained from soil coring, up to 20cm, during the reproducing stage, for quantifying DSi removal within the soil layer. DSi removal was estimated from a simplified water budget calculated by three ways, (1) the actual evapotranspiration, (2) a chlorine mass balance and (3) a sodium mass balance. The d^{30} Si signatures were determined in all compartments (DSi, ASi, clay fraction and rice) to establish an isotopic mass balance at soil-plant scale and constraint the silicon sources to the rice.

According to the evolution of above- ground water composition (Na, Cl and DSi), about one third of the DSi flux brought by borewell irrigation (560 mmol Si. m^{-2}) to bare plots and half of DSi in rice plots were removed from solution within minutes or hours following irrigation. No influence of DE addition could be observed on the above-ground DSi balance. The fast removal of above-ground DSi in both bare and rice plots is compatible with DSi adsorption onto Fe oxyhydroxides but not with diatom blooms. Adsorption can lead to an increase of d^{30} Si in DSi up to 4 ‰, suggesting that high d^{30} Si of some tropical rivers DSi may not only result from vegetation uptake in humid zones (paddy fields or swamps), but also from DSi adsorption onto particles during water stagnation. In rice and rice+DE experiments, the isotopic fractionation factor (^{30}e) between bore well and stagnant water compositions is closer to -1 %, i.e. the value expected for DSi uptake by rice if Rayleigh model is considered. Therefore, the analysis of our rice plots suggests that above-ground DSi removal would be dominated by plant uptake upon adsorption.

Within the soil layer, pore water DSi decreases much faster in rice plots than in bare ones, demonstrating the efficiency of DSi rice uptake upon adsorption. At 20cm depth, the soil leaching fluxes range from 27-46 mmol Si m^{-2} (rice) to 40-84 mmol Si m^{-2} (bare+Si) according to the ways water budgets are calculated. Irrigation-DSi to plant silicon would then represent 24 to 36% in rice plots (1460 mmolSi/m^2 in biomass) and 15 to 23 % in rice+DE ones (2250 mmolSi/m^2). If this uptake followed a Rayleigh fractionation model, the corresponding DSi-d^{30} Si would range from 0.93 to 1.32 ‰ in rice experiments and from 0.89 to 1.34 ‰ in rice+DE plots. By difference, the complementary soil silicon source taken up would then range from 1.23 to 1.37 ‰ and from 0.95 to 1.07 %, which discards clay fraction (-1) and primary minerals (-0.38) as silicon source but rather points to amorphous silica and to a possible but small contribution of DE in rice+DE plots.

Keywords: Rice; Silicon; Water flux; Mass balance; isotopes

Silicate solubilization and plant growth promoting potential of *Rhizobium* sp. isolated from rice rhizosphere

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ABSTRACT

Silicon (Si) is a beneficial plant nutrient which plays a vital role in maintaining plant growth and enhancing tolerance to both biotic and abiotic stresses of several plant species, including rice (*Oryza sativa* L.) which is one of the staple food crops of the world. Recent studies indicate that yield of rice may be affected seriously if adequate silica is not available. This has led to increased being accorded towards management of bio available Si in soil and to improve Si nutrition of crops. The polymeric insoluble silica present in soils needs to be solubilized and released into the soil solution in the form of monosilicic acid which is the bioavailable form of silicon absorbed by plants. A novel strategy to increase soil silica is to exploit naturally occurring bacteria involved in weathering of soil silicates. In the present study, a silicate solubilizing bacterium isolated from rhizosphere soil of rice identified as *Rhizobium* sp was characterized for plant growth promoting traits and tested for its ability to solubilise insoluble inorganic and biological silicate sources for improving Si uptake by plants.

A screening for silicate solubilising capabilities of the bacteria using various insoluble silicates which are generally present in soils indicated its ability to release soluble silica from both inorganic and insoluble silicate materials of biological origin. A differential rate of solubilisation of insoluble inorganic silicates was observed for the isolate with the highest soluble silica in supernatant being recorded from magnesium tri silicate followed by calcium alumino silicate, potassium aluminium silicate and kaolin. The bacteria was found to release, at the end of 7 days of incubation, 3.0, 1.84, 1.63, 1.22, 0.87, 0.19 and 0.13 µg Si/ µg cell protein respectively from inorganic silicate sources like magnesium tri silicate, calcium alumina silicate, kaolin, potassium alumino silicate, quartz, fuller's earth and bentonite. The release of soluble Si from biological silicate sources like siliceous earth, rice husk, rice straw, and diatomaceous earth ranged from 0.14, 0.13, 0.10 and 0.08 µg Si/ µg cell protein respectively. The isolate also produced indole acetic acid in the presence of trytophan (2.51 µg indole acetic acid/µg cell protein) and 1- amino cyclopropane carboxylic acid (ACC) deaminase activity of 0.95 µg α-ketobutyrate/peg cell protein demonstrating the capability of plant growth promotion by producing phytohormones.

Effect of bacterial inoculation on growth and silicon uptake by swarna rice seedlings under hydroponics condition was studied. Inoculated and un inoculated were tested for plant silica uptake using potassium alumino silicate and diatomaceous earth as in soluble silicate sources showed highest silica content up to 10.08 and 4.90 % in bacterial treated seedlings when compared to un inoculated control 8.54 and 3.57. Bacterial inoculated root solutions showed silica content of 87.48 and 35.36 µg/ml for potassium alumina silicate and diatomaceous earth when compared to uninoculated control (57.63 and 26.14 µg/ ml). Further more SEM analysis of roots indicated successful colonization of roots by the bacterium.

The present study reveals that rhizophere isolate *Rhizobium* with multiple plant growth promoting traits has the potential to colonize roots and release Si nutrient required for plant growth from different insoluble Si sources with a consequential increase in plant silica uptake. Hence the isolate can be utilized as a prospective plant growth promoting rhizobacteria to increase rice crop production under various biotic and abiotic stresses.

Suitability of extractant for soil Available silicon and silicon response to upland paddy grown on inceptisols and Vertisols

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ABSTRACT

Several extractants are being employed in different countries for determination of extractable soil silicon based on the crop response and its uptake mostly for low land acidic type of soils. Hence considering the need for evaluation of simple and rapid silicon extractant for upland alkaline type of soils, the field experiment was laid out in split plot design having fourteen treatment combinations replicated thrice. The main treatments were soil types Inceptisols and Vertisols; sub treatments were levels of silicon (Si), T_1: Absolute control, T_2: GRDF (100:50:50 kg ha^{-1} N:P_2O_5:K_2O + 5 t ha^{-1} FYM), T_3: GRDF + Si @ 25 kg ha^{-1}, T_4: GRDF + Si @ 50 kg ha^{-1}, T_5: GRDF + Si @ 100 kg ha^{-1}, T_6: GRDF + Si @ 150 kg ha^{-1} and T_7: GRDF + Si @ 200 kg ha^{-1}.The silicon extractants were 0.5 M Acetic acid (1:2.5), 0.5 M Acetic acid (1:10), 0.1 M Citric acid (1:50), *N* NaOAc-HOAc (pH 4.0) (1:10), 0.5 M NH_4OAc (pH 4.8) (1:10), 0.01 M $CaCl_2$ (1:10), Distilled water (1:10), Tris buffer (pH 7.0) (1:10), 0.19 M Na_2CO_3 (1:20) and0.5 M $NaHCO_3$ (pH 8.5) (1:20).

The soil type Vertisols showed significantly highest grain yield (37.01 q ha^{-1}) and straw yield (42.13 q ha^{-1}) of upland paddy over the Inceptisols. The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest grain yield (41.85 q ha^{-1}) and straw yield (47.63 q ha^{-1}) of upland paddy over all the levels of silicon. The significantly highest total nutrient uptake was recorded by the soil type Vertisols *viz.,* P, K, S and Si (41.11, 96.09, 17.15 and 235.49 kg ha^{-1}, respectively) over the Inceptisols. The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest total nutrient uptake *viz.,* N, P, K, S and Si (148.37, 46.47, 115.81, 18.94 and 283.56 kg ha^{-1}, respectively) over all levels of silicon.

The assessment of suitable silicon extractant was done by correlating extractable silicon with nutrient uptake and yield. Among the ten silicon extractants tested, Tris buffer pH 7.0 (1:10) in Inceptisols showed positively highest and significant correlation with grain yield (r=0.870**), grain Si uptake (r=0.887**), grain N (r=0.849**), grain P (r=0.886**) and grain K (r=0.813**) and straw yield (r=0.852**), straw Si uptake (r=0.919**), straw N (r=0.857**), straw P (r=0.873**) and straw K (r=0.885**). However, in Vertisols 0.5 M Acetic acid (1:2.5) showed positively highest and significant correlation with grain yield (r=0.810**), grain Si uptake (r=0.852**), grain N (r=0.862**), grain P (r=0.858**) and grain K (r=0.900**) and straw yield (r=0.850**), straw Si uptake (r=0.929**), straw N (r=0.903**), straw P (r=0.898**) and straw K (r=0.896**).

Keywords: Silicon extractants; upland paddy; yield; nutrient uptake; Inceptisols; Vertisols

Effect of silica fertiliser on dissolved silicon in soil solution based on the chemical properties of various soils

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ABSTRACT

Increasing the silicon (Si) supply in soil solution enhances Si uptake by rice plants (*Oryza sativa* L.). In this study, we evaluated soil factors associated with the effects of silica fertilizer (SF) application on Si supply (monosilicic acid) in soil solution. Six soils with a wide range of chemical properties were incubated with or without SF for 30 – 60 days. The amount of dissolved Si in the soil solution and the soil properties were analysed. These soils were taken from field trials of the Silica Fertiliser in four different countries.

The amount of dissolved monosilicic acid determined by extraction with a 0.01M $CaCl_2$ solution varied with the application rate of the Silica fertiliser, time, soil pH and soil mineralogy.

These results suggest that the effects of Silica Fertiliser on Si supply in the solution were affected by Si dissolution from the applied Silica and the Si adsorption capacity of the soil. These results also suggest that soil incubations have implications for determining likely field responses to Silicon Fertilisers in various crops.

Keys Words: Silica; Silicon; Agrisilica; Soil solution; monosilicic acid

Alkalinity ratio and the release of extractable Si from silicate slags in rice soil

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ABSTRACT

An experiment was conducted to study the effect of alkalinity ratio of silicate slags on the release of extractable Si in wetland rice soils. The study was undertaken with the assumption that the balanced ratios and amounts of calcium (Ca) and magnesium (Mg) and Si influences the release of Si from the source material. Alkalinity ratio (A/Si) is the ratio of the sum of Ca and Mg contents of the slag expressed as CaO to total Si content. Slags were applied at 250 and 500 kg Si ha^{-1} to acidic, neutral and alkaline rice soils and incubated for 120 days under submergence. Soils were destructively sampled at four intervals and analysed for 0.01 M $CaCl_2$and 0.5 M acetic acid extractable Si. In a separate greenhouse study rice was grown in pots till harvest with same slag treatments in all three soils and yield was recorded. Based on the alkalinity ratio (A/Si) and relative yield of rice 15 slags were classed into two groups as slags with A/Si < 3 and A/Si >3. Slags significantly increased both $CaCl_2$ and acetic acid extractable Si in all the three soils, however the trend of release of extractable Si was different for different soils. Slags with A/Si < 3 significantly increased the 0.01 M $CaCl_2$ extractable Si content and those with A/Si > 3 decreased extractable Si content below control in all the soils. A significant increase in acetic acid extractable Si was noticed with the application of Si sources with A/Si > 3 than sources with A/Si < 3 in acidic and neutral soils. Their application also increased the soil pH and increase in pH was higher in acidic soil compared to neutral and alkaline. 0.5 M acetic acid extracted nearly double the amount of Si than 0.01 M $CaCl_2$ from the treated soils and 0.5 M acetic acid extractable Si increased with the rate of application irrespective of slags. The relative release of extractable Si to that of control treatment in soil was significantly increased by slags with A/Si < 3. Application of slags increase Si content and uptake in rice in all the three soils. Application of Si sources with A/Si < 3 recorded higher straw and grain yield in all the soils. It was found that the A/Si ratio of slags and soil types can influence the release of Si from slags. Silicate slags with A/Si value < 3 was found to increase available Si content in soil, uptake and yield in rice.

Key words: Silicate slags; Alkalinity; extractable silicon; wetland; Rice

New approaches in testing active forms of silicon in soil, plants and silicon-rich materials

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ABSTRACT

Increase in studies on practical implementation of Si-rich substances in agriculture and ecology is accompanied by increasing volume of Si analyses. So, the demand for fast, simple, cheap, and highly informative methods of Si determination in the soil-plant system and Si-rich materials is actual. Many extraction techniques have been developed to measure the Si content in soil, plant tissue, and Si-rich mineral as well as to assess Si bioavailability and to predict its plant uptake. The results of various methods are difficult to interpret and compare. The only plant available form of Si is monosilicic acid, which is chemically active and can react with other components in the soil and plant cells. Due to its chemical and biological activity, monosilicic acid affects numerous chemical, biochemical, and physical processes in the soil-plant system, including soil fertility level and productivity of the cultivated plants. Besides monosilicic acid, any soil solution contains polymers of silicic acid and organo-Si compounds. The Si concentration measured by any extraction method depends on preparation of soil or plant sample for analysis. For example, drying soil sample reduces the concentration of mono and poly-silicic acids *via* the adsorption of both the soluble Si compounds on mineral surfaces followed by subsequent dehydration and the formation of the films of amorphous silica. Consequently, the analysis of dried soil or plant sample to determine the content of monosilicic acid,as the most active form of soluble Si,usually does not reveal the actual amount. On the other hand, the concentration of monosilicic acid in the soil solution is controlled by several main factors: (1) solubility of Si-rich substances in the soil; (2) soil moisture fluctuation; (3) absorption by plants and soil microorganisms. The monosilicic acid concentration does not give the accurate estimation of Si bioavailability as well as does not characterize completely the Si status in the soil-plant system or in the tested Si-rich materials. New approach to a complex evaluation of the Si status in the soil, plant tissue (apoplast and symplast), and Si-rich materials was elaborated and tested in greenhouse and field tests. The comparison study of the combined water extraction from fresh soil sample and acid (0.1 n HCl) extraction methods and other commonly used methods was conducted. As compared with other methods tested, the elaborated method showed higher correlation coefficients between the measured Si and the Si plant uptake (0.71 to 0.98) and therefore reflected more appropriately the actual Si status in the soil-plant system.

Multimodal structural and functional analysis of sorghum tissues and sorghum biosilica

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ABSTRACT

The formation of biosilica has been widely studied, however, the biochemistry and physiology of plant silica deposition is not well understood yet. We intend to elucidate the chemical interactions of the plant cell with silica by addressing the effect of cell wall composition and the role of organic compounds on silica deposition. With that purpose, plants of *Sorghum bicolor* (L.) Moench (wild type; line BTX-623) and *sblsi1* mutant deficient in silicic acid uptake were grown either in soil or hydroponically with diverse amounts of silicon supplementation in the form of sodium silicate. In order to relate the organic compounds involved in silicification with the silica properties, phytoliths from mature wild type plants were extracted using different approaches and analysed using solid state 29Si Magic Angle Spinning NMR, Raman spectroscopy and Synchrotron X ray diffraction. In order to obtainin formation on the cell wall composition, Raman imaging and SEM-EDX were used respectively to locate organic compounds and elements in plant tissue cross sections. We identified differences in protein, aromatic phenol and cellulose composition in plants with and without silica. We also found signatures of organic compounds in the extracted silica that may be involved in the silicification. Moreover, our results indicate that cells with different morphologies deposit hydrated silica in uneven amounts (Figure 1). We also detected that extraction methods of phytoliths alter the silica molecular structure and its condensation degree. Silicification in grasses is a spatially and temporally controlled process, however, there is no agreement whether it is a consequence of active or passive mechanism. As we recognized heterogeneity of the silica distribution in plant tissues, we hypothesize that silica deposition may involve both, active and passive mechanisms, which likely are, tissue and functionally dependent. In future research, we aim to address this problem more in depth.

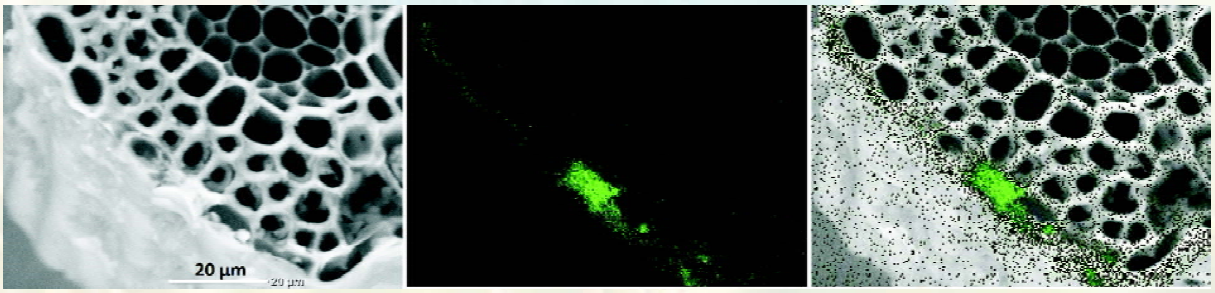

Figure 1. a)Scanning electron micrograph of a mature sorghum leaf cross-section, witha silica cell marked with *. b) Silicon map of the same region obtained by energy dispersive X-rays showing the spatial distribution of silicon, the silica cell heavily silicified and silica deposits in epidermal cells. c)Overlay of the two images.

Key words: biosilicification; SEM-EDX; Raman spectroscopy; phytoliths.

Poster Presentation

Do termites influence silicon dynamic in tropical soils? A case study in Bandipur National Park (Karnataka, South India)

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ABSTRACT

Silicon (Si) is the second most abundant element in earth crust. In addition to crystalline and secondary silicates, Si also occurs as readily soluble or plant available Si, adsorbed Si, amorphous silica (ASi) and short range ordered silicates. Available silicon in the form monomeric silicic acid [$Si(OH)_4$] in soil can be pumped by plants roots, transported by xylem and concentrated in plants leaves. When the concentration of $Si(OH)_4$ is high, deposition of poorly crystalline Si in the form of phytoliths (SiO_2) can be observed. However, phytoliths remains in soil for a long time after the plant death, although their evolution is influenced by water movement and/or soil biodiversity activity.

Fungus-growing termites are undoubtedly the most important decomposers and bioturbateurs in Indian arid and semi-arid ecosystems. In these environments, termites build mounds that host their colonies and that are made of soil collected from deep-soil layers (> 2 m). To the best of our knowledge, how termites modify the quantity and quality of Si within their colonies has never been studied in the past. The present work is a step in this direction.

Si pools were measured in termite mounds and their adjacent soil environment (n = 3), as well as at different soil depths in a Ferralsol and a Vertisol until 2m deep.

We differentiated the plant available silicon (0.01 M calcium chloride extractant), adsorbed silicon (0.5 M acetic acid), amorphous Si (ASi - 1 % Na_2CO_3 method) and the amount of phytoliths (sodium polytungstate extraction).

Preliminary results show an increasing concentration of adsorbed silicon with the depth in both the Ferralsol and the Vertisol. Termite mounds seem to have low amount of available silicon as observed in first layers of the soil profile (Ferralsol and Vertisol). Our results also showed that the amount of plant available silicon is constant in the soil profile. The variation in the adsorbed silicon also suggested that termite mound soils come from the first soil layers.

Keywords: Vertisol, Ferralsol, Phytoliths, Silicon, Termite mounds

First results of trace metals associated with silicon contents in two phenological stages of wheat (Triticum aestivum) in the southeast of the Pampean plains, Argentina.

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ABSTRACT

Silicon as a constituent of the solid and liquid fraction of the soil is an essential element in the relationship between plant-soil-environment. In addition, it plays an important role in the development of certain crops that are producers of silicophytoliths. Internationally, it has been reported that the biomineralizations of amorphous silica have the capacity to retain trace metals within their matrix, present at the time of their formation. This interaction of silicon with other toxic elements such as lead, cadmium etc., has a direct influence on all members of the food chain including man and his quality of life. The level of degradation in the soils of the Pampas plain is high, related to the agricultural activity for more than 150 years; that´s why it is fundamental to deepen the study of biomineralizations as heavy metal retention agents, especially in the study area, where the application of agrochemicals is so intense. So the aim of this work is to evaluate the silicon and trace metals contents in plants, soils and solution of agricultural soils cultivated with wheat (*Triticum aestivum)* in southeastern Buenos Aires. Field tests were carried out with the application of two silicate fertilizers (one powder: Silfix and another liquid: Quicksol). Samples of surface soil and plant material were extracted in two phenological stages (vegetative and post - harvest). The available silicon contents and its contents in plant as well as the amounts of Cd, Cu, Pb, Zn, Mn, Ni, Cr and Fe in the soil solution, in the plant material and in the soil samples were determined using standard methodology. The contribution of Si to the soil solution would be similar for both types of applied fertilizers. The values of trace elements present in the soils are within those commonly registered for the zone and the values pertaining to the soil solution are all low (<0.7 mg/Lt) and lower than the allowed limits. The silicon content in the plants increases with time, presenting 5 gr.Si/m2 in vegetative state and 100 gr.Si/m2 in post-harvest. Regarding to the presence of such metals in the plant material, it can be said that for the plants of the first stage they do not exceed the limit values established for none of the elements except Ni (13.6 ppm) and Cr (5.65 ppm); while for the plants of the later stage the values for these elements (42.77 and 4.87 ppm, respectively) are again exceeded, as well as Cu (16.18 ppm). Although this work shows the first results in relation to the effect of silicon fertilization and its relation with heavy metals at crop level and in typical Argiudolls of Southeastern Buenos Aires; it´s necessary to deepen the studies in order to know the effect of the silicon fertilization on the vegetal development, the quality and the biogeochemistry of soils in natural environments and agro ecosystems, as well as their possible impact on human health. This work was supported by PICT 1583/2013 AGENCIA and EXA 741/15-UNMDP; PIP 11220130100145CO.

Keywords: Silicophytolits; Heavy metals; Soil solution; Typical argiudolls

Silicon fertilization and its role in physical and chemical soil properties in Southeastern Buenos Aires

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ABSTRACT

Silicon is a major component in soils. In addition to playing an important role in the conformation of matrix aggregates and consequently in structural stability; is an essential element for the development of certain crops producing silicophytoliths. Although there are studies that report the effect of silicate fertilization on crops such as rice, there is no researches in soils of the Pampean Plain that have suffered the negative effects of intense agricultural activity for more than 150 years. Within this agricultural activity stands out the cultivation of wheat (*Triticum aestivum*), with an average annual production of 350 tons over the last 45 years. Therefore, the aim of this work is to evaluate the content of silicon and its role in the physical and chemical properties of agricultural soils cultivated with wheat in southeastern Buenos Aires. Field tests were carried out with the application of two kinds of silicate fertilizers (one powder: Silfix and another liquid: Quicksol). Surface soil samples were taken and morphological, physical (texture and structural stability) and chemical properties (pH, organic matter, phosphorus and available silicon content) were determined in two plant stages (vegetative and post - harvest), using standard metodologies. One-way analysis of variance were performed to determine the effect of fertilization on the variables measured in each trial. The results indicate that the contribution of Si to the soil solution would be similar for both types of applied fertilizer (from 598 to 728 ppm.), as well as its dynamics of behavior over time. Such fertilization would not significantly affect the organic matter content of the soils analyzed. With regard to pH values, a positive relationship between pH values and the availability of silicon in solution could be inferred. Silicon fertilization could modify the availability and/or dynamics of the available phosphorus in the analyzed soils, presenting an inverse relationship since the availability of the phosphorus (P) decreases as the silicon content increases. Plots that received silicon fertilization showed values of available P that ranged from 13 to 20 ppm presenting half of the content when compared to control plots (from 20 to 42 ppm). The composition of the fertilizers, as well as their granulometric characteristics, could influence the slight modifications registered in the structural stability and the texture of the fertilized soils, presenting more adequate values for both variables those plots that received the fertilizer Quicksoil. Regarding the structural stability variable, it is worth noting that the decrease in that property correlates with a higher content of silicon in solution, which could be related to a higher release of silicon to the soil solution due to the lower stability of the aggregates. Although this work shows the first results between the effect of silicon fertilization and the physico-chemical properties of typical Argiudolls of Southeastern Buenos Aires; it is necessary to deepen the studies in order to know the effect of silicate fertilization on plant development, soil quality and biogeochemistry in natural environments and agroecosystems. This work was supported by PICT-1583/2013-EXA 741/15-UNMDP; PIP 11220130100145CO.

Keywords: Silicophytoliths; Silicon biogeochemistry; Pampean plain; *Triticum aestivum*

Distribution of available silicon under different land use system in tropical soils

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ABSTRACT

Silicon is the second most abundant element in soils and fourth largest element in plants and soil solution contains silicon mainly as silicic acid (H_4SiO_4) at 0.1-0.6 mM concentration. Evidences converse that silicon plays a vital role in plant growth, mineral nutrition, mechanical strength and resistance to fungal diseases and reduces the toxicity of some excess soil nutrient elements. Soil profile study was carried out in different land use systems of tropical soils covering coffee, rubber, coconut, forest and rice. Two profiles were dug out in each land use and available silica (Snyder, 2001) and other soil physical and chemical properties were analyzed for the soil collected from different layers of the profile. Overall the surface soils of rice land use found to have less available silicon (10.6 ppm) compared to forest land use system (85.3 ppm), coffee (83.1 ppm), rubber (80.4 ppm) and coconut (80.2 ppm). The available silicon was increasing with depth irrespective of the land use. High weatherable minerals fraction in the immediate vicinity of lower layers soil, contributes the high available silicon. The weighted average of sub-soils showed that coffee land use system found high available silicon (169 ppm) compared to rice (158 ppm), coconut (136.1 ppm), forest (130.7 ppm), and rubber (128.1 ppm). Present study showed that significant negative correlation exists between available silicon and available phosphorus (-0.620), available iron (-0.511) and organic carbon (-0.629), while positive correlation with per cent clay (0.581) owing to high clay illuviation in tropical soils.

Keywords: Available Silicon, Land use systems, Rice, Rubber, Coconut, Coffee and Forest

Silica production and phenological stages in soybean, wheat and maize crops developed in soils from Pampean region, Argentina

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ABSTRACT

Amorphous silica biomineralizations (silicophytoliths) constitute a significant source of silicon to the soil-plant-atmosphere system, since they dissolve faster than silicate minerals. The knowledge of the silica production of plant communities in an specific area is essential for the comprehension of Si cycle in this environment. Pampas region, in Argentina, is a vast area where the intensification of land use by agriculture caused negative effects on the soils, and also has modified and replaced the natural vegetation. In order to understand how this agricultural practices affect the terrestrial silicon cycle, we aimed to analyze the silica content/production in three of the most important crops developed in pampean region, and its relation with phenological stages. We selected vegetative and reproductive organs from at least nine individuals of three crops (soybean, maize and wheat) in three phenological stages, cultivated in fields from SE Pampean region. Biomass production was also calculated from each crop. Plants were subjected to calcination technique (Labouriau, 1983), and silica content was calculated as dry weight. The potential input of amorphous silica in each stage of each crop was calculated as kg/ha. Silicophytoliths obtained after the calcination technique were described under optical and electronic microscopes, and related to anatomy. Silica content in soybean ranged between 0.9-3.1 % (% dry weight), depending on the type of organ and stage, and it was higher in the final developing stage. The highest silica content was observed in leaves from the last phenological stage. The potential input of amorphous silica was higher in the two last developing stages (1.01, 25.2 y 14.29 Kg/ha). In wheat, silica content ranged between 2.9-13.8 %. The highest contents were observed in leaves (13.8 %) and inflorescences (13.3 %) from the last phenological stage. The potential input of amorphous silica increased toward the last stage (26.76, 105.01 and 737.9 kg/ha). In maize, silica content ranged between 0.9-10.5 %, depending on the organ and stage, and it increased in the last phenological stages. The organ with higher silica content was the leaf in the last stage (10.5 %). Silica calculated as kg/ha increased toward last stages (0.13, 240.7, 215.8 kg/ha). In the three crops, the principal tissue that became silicified was the epidermis, along with xylem. The morphologies of silicophytoliths observed were first described in soybean, and coincides with previous research in wheat and maize. Silica content was higher in wheat and maize (Poaceae) in comparison with soybean (Dicotyledon), and increased in the last developing stages, as it was expected. The results obtained in this work constitute the first data of silica content in crops from Argentina.

Keywords: Silicophytoliths, silicon cycle, agroecosystem

Estimation of amorphous silicon content in tropical rice and sugarcane soils of Karnataka, India

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ABSTRACT

The amorphous silica (ASi) pool has gained (??) increasing attention in recent years due to substantial depletion in agricultural soils attributed to exportation of Si in harvested products. However, the scientific database on ASi concentration in soils of tropical regions are very limited. As rice and sugarcane are major silicon (Si) accumulator crops, intensive cultivation of these crops would lead to the depletion of ASi content in soil.

The main aim of this investigation was to analyze ASi content in soil by two techniques: physical extraction by heavy liquid flotation (sodium polytungstate, 2.3 g cm^{-3}) and wet alkaline extraction (1 % Na_2CO_3 method) for two surface and profile soil samples collected each from rice and sugarcane growing field, where rice and sugarcane was being grown for a decade, representing two different agro climatic zones *viz.*, southern dry zone and central dry zone of Karnataka, South India with precipitations of <700 mm yr^{-1} and <600mm yr^{-1}, respectively.

To extract the ASi by heavy liquid flotation method, sodium polytungstate ($Na_6H_2W_{12}O_{40}\cdot H_2O$) solution (density 2.30 g cm^{-3}) as described by Vandevanne *et al.* (2015) was used. Sodium polytungstate was used for extraction of ASi particles from surface and sub-surface soil samples only. Results revealed that the ASi content (Phytolith) was higher in both surface soils of rice and sugarcane of southern dry zone compared to central dry zone soils. The ASi content decreased in the sub-surface rice soil of southern dry zone, whereas it increased in the subsurface soils of central dry zone. However, the ASi content showed a decreasing pattern in the sub-surface soils of sugarcane in both the agro-climatic zone.

To assess the status of ASi by wet alkaline extraction, we applied the 1 % Na_2CO_3 method previously described by DeMaster (1981), Sacconeet *al.* (2007), Clymans *et al.* (2011), Cornellis *et al.* (2011), and latest by Meunier *et al.,* with a modification, where the ASi concentration in the 1 % Na_2CO_3 extract was determined after 3, 4, 5 and 6 hour of digestion. We used the correction proposed by DeMaster (1981) to estimate the contribution of amorphous Si forms to Na_2CO_3 extractable Si. The concentration of ASi wasestimated by extrapolating the linear part of the plot to zero. Our results indicated that ASi content was higher in surface soils of rice compared to sugarcane soil. However, in case of rice profile the ASi content either increased or decreased in the sub-surface, whereas the concentration of ASi decreased in the sub-surface of sugarcane profile. But the vertical distribution of ASi content as a function of depth showed irregular trend irrespective of agro-climatic zones under study.

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Key words: Amorphous silicon, Rice, Sugarcane, Agro-climatic zone

Silicophytoliths: their role in the degradation and silicon biogeochemical cycle of Molisolls in the southeast of the pampean plains, Argentina

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ABSTRACT

The study area is located at the central-east part of the province of Buenos Aires, inside the so-called Chaco-Pampean Plain. The vegetation that covered the Pampas throughout the Late Cenozoic to have been mainly a grass steppe, which is one of the major producers of silicophytoliths. Silicophytoliths are amorphous silica biomineralizations deposited in plant tissues; following degradation of the tissue, the silicophytoliths are incorporated into the soil, where they can be preserved for thousands of years; but a high percentage of them are altered and disappear from the soil system. Thus, silicon is incorporated into the soil solution and the local hydrological system, forming part of the biogeochemical silicon cycle in humid temperate environments. The quantitative and qualitative analysis of the silicophytolith (status, type of alteration) in the most representative Molisolls under natural conditions and agroecosystem were performed. The quantity of silicophytoliths by the number per gram of soil and by ton per hectare in the different soil horizons was defined: In mollic epipedons(A horizon), we found 18 to 28,000,000 silicophytoliths per gram of soil, and 60 to 100 tons of silicophytoliths per hectare. In the B horizon, we found less than 3,000,000 silicophytoliths per gram of soil. In the parent materials, the C horizons gave 1,500,000 silicophytoliths per gram of soil. In these environments, there is a greater than 80% decrease in the average total content of silicophytoliths among the illuvial horizons with respect to the eluvial mollic horizons. The silica in the soil solution, moving from 453 to 1,243 mM/liter; in surface water oscillates between 100 and 1,000 /liter, according to whether the water comes from streams or ponds and the season of the year, rainfall and drought. And, in ground water with medium values of 840+ to -230 mM/liter. The agricultural (wheat, maize crops and pastures), of these areas are important providers of silicophytoliths. Studies show that the use and agricultural management of these soils generate a substantial loss of pelitic fractions. But, these fractions may have been reincorporated by these crops since more than 170 years ago. Also taphonomical, mineralo-chemical and chemical studies of the soil solution show that the soil matrix is enriched in amorphous silica from the chemical degradation of silicophytoliths. Therefore, silicophytoliths originally provided by the natural grasses and later reincorporated by the main crops into the system, compensate the losses of silt and very fine sand by wind and water erosion. The fluxes in the complex biogeochemical system of silicon in temperate humid grasslands, show that much of the silicon/amorphous silica re-circulate in the unsaturated zone, where they contribute to form an amorphous silica enriched matrix of aggregates, which increases and maintains the structural stability of soils. This work demonstrates the importance of silicophytoliths in the preservation of the physical and chemical properties of these productive soils, and the relevant role in the terrestrial silica biogeochemical cycle in the Pampean Plain of Argentine.

This work was supported by PICT-1583/2013; EXA 741/15-UNMDP; PIP 11220130100145CO.

Keywords: Agroecosystem, Late Cenozoic, Taphonomical processes

Pools of silicon in soils of Karnataka and their contribution to rice

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ABSTRACT

Five major pools of silicon (Si) such as mobile Si, adsorbed Si, Si bound to organic matter, Si occluded in pedogenic oxides/hydroxides and amorphous Si were extracted from three soils (one each from low, medium and high content of plant available Si) using a sequential extraction method. The different pools of Si extracted from soils were in the order of amorphous Si > occluded Si > organic Si > adsorbed Si and mobile Si. The mobile Si and adsorbed Si pools were the smallest pools of Si and ranged from 14.45 to 44.60 mg kg^{-1} and 4.90 to 89.40 mg kg^{-1}, respectively. The content of organic Si pool ranged from 233.7 to 619.18 mg kg^{-1} and the occluded pool of Si ranged between 476.26 and 1740.35 mg kg^{-1}. Irrespective of the soils, amorphous Si was found to be the largest pool of Si ranging from 8019 to 16667 mg kg^{-1}. A pot culture experiment was conducted using the bulk soil samples with rice as test crop. Among the different Si pool soccluded, mobile and adsorbed pools of Si showed significantly higher correlation and regression with Si content and its uptake by rice grown in these soils for a period of 60 days. Thus, occluded, mobile and adsorbed pools of Si were considered as major contributors of Si to rice.

Keywords: Sequential extraction; Si pools; Plant available Si; Si content; Si uptake

Session - 2

Sub Theme - III

Mechanism of Silicon Uptake and Accumulation in Plants

Keynote

A cooperative transport system for silicon in plants

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ABSTRACT

Flowering plants have two different types of transporters for silicic acid;Lsi1-like and Lsi2-like transporters (Ma and Yamaji, 2015). Lsi1 facilitates bidirectional passive transport of silicic acid across the plasma membrane. Lsi1-like protein forms a distinct subgroup (NIP III) of plant aquaporin and is conserved in both monocot and dicot with few exceptions such as *Brassicaceae* including Arabidopsis. On the other hand, Lsi2 mediates active efflux transport of silicic acid from the cell to apoplast driven by proton gradient across the plasma membrane. Genes encoding Lsi2-like protein are also conserved in most angiosperm, although only few of them has been functionally characterized. Since first report on Lsi1 in rice (*Oryza sativa*) presented in Uberlandia, Brazil 2005, our knowledge about molecular mechanisms of Si transport in plants has been greatly improved, especially in rice, a Si-accumulating plant.

In rice roots, a pair of Si transporters is localized at two cell layers; Lsi1 at distal side and Lsi2 at proximal side of both exodermis and endodermis. Due to two Casparian-stripes, apoplastic barriers at both the exodermis and endodermis, and development of aerenchyma between these two layers, Lsi1 and Lsi2 form a cooperative transport system for Si; influx of Si from the outer side by Lsi1 and efflux to the inner side by Lsi2. A mathematical modeling revealed that this two-step cooperation of Lsi1 and Lsi2 is the most cost-effective and optimal for directional Si uptake in the rice roots. Although such set of Lsi1 and Lsi2 is also identified in some upland crops such as barley, maize and pumpkin, the tissue localization in the roots is different from rice, probably because of their different root structures and Si requirements.

After uptake by the roots, most Si is translocated to the shoot and deposited as silica mainly at the surface of the aerial parts. In graminaceous plants, Si transporters localized in the nodes play a pivotal role for the distribution of Si between different organs in the above-ground part. In case of rice, three different Si transporters, Lsi6 (Lsi1-like channel), Lsi2 and Lsi3 (Lsi2 like efflux transporter) are cooperatively involved in this process. Lsi6 mediates unloading of Si from xylem of enlarged vascular bundles, which are connected from a lower node to a leaf. Lsi2 and Lsi3 are involved in re-loading of Si to the xylem of diffuse vascular bundles, which are originated in the node and connected to an upper node or panicle. A mathematical modeling demonstrated that together with these three transporters, distinct node structures including extended area and differentiation of transfer cells in xylem (with Lsi6) of enlarged vascular bundles, existence of apoplastic barrier at the bundle sheath (with Lsi2) of enlarged vascular bundles, and dense plasmodesmata in parenchyma tissues (with Lsi3) between vascular bundles, are also required for the preferential distribution of Si to the panicles. This process contributes to the highest Si accumulation in husk, which is important for protecting rice from various biotic and abiotic stresses.

Short Oral

What makes a silicon transporter? The search for key residues that confer plant silicon permeability, accumulation and benefits

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ABSTRACT

Tremendous progress has recently been made regarding the molecular-genetic determinants of Si uptake in plants. Lsi1 (Low silicon influx 1), a member of the NOD26-like Intrinsic Protein III (NIPIII) subgroup of Major Intrinsic Proteins (MIPs; a.k.a. 'aquaporins'), is a Si-permeable plasma-membrane channel identified in roots of numerous Si-accumulating species, including rice (*Oryza sativa* L.), barley (*Hordeum vulgare* L.), pumpkin (*Cucurbitamo schata* L.) and soybean (*Glycine max* L.). The selectivity of Lsi1 for Si appears to be controlled by at least two regions forming the central pore of each subunit: (1) four amino acids (AAs; typically GSGR, with the exception of the STAR motif in horsetail (*Equisetum arvense*) forming the aromatic/arginine (ar/R) selectivity filter and (2) two highly conserved NPA motifs separated by precisely 108 AAs. The objective of this work is to determine if these molecular features could serve as predictors of the ability of a plant to accumulate Si,and to enable a simple classification system on this basis. To this end, we investigated the Si permeability of a number of putative Lsi1s coming from both Si accumulators and non-accumulators. To test functionality, we cloned Lsi1s and heterologously expressed them in the *Xenopuslaevis*oocyte system to measure Si transport. We discuss our findings and suggest that a functional Lsi1 transporter is the first key determinant for Si accumulation *in planta*.

Keywords: *Lsi1*; NPA-NPA distance; Selectivity filter; Stress resistance; Tissue accumulation

Analysis of the expression dynamics of Silicon transporter gene using mathematical model in rice

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ABSTRACT

Rice (*Oryza sativa*) can take up large amounts of silicon compared with other plants. In rice roots, the passive transporter *Lsi1 (OsLsi1)* and the active transporter *Lsi2 (OsLsi2)* are involved in Si uptake. Both are polarly located in the plasma membranes of the exodermal and endodermal cells, where Casparian strips are located, and efficiently transport Si in to vascular bundle from soil. On the other hand, it was reported that the expression of these transporter genes show a diurnal variation. It was also reported that the expression of *Lsi1* and *Lsi2* genes is controlled by Si accumulation in the shoots, not in the roots. However, the functional reason why rice has such expression dynamics has not been well understood. In this study, we propose a new mathematical model that simulate Si transport in the whole plant using empirical data and knowledge from previous modeling studies. Using the newly developed model, we examined the factors and mechanisms affecting the expression of Si transporter genes and investigated the reason why the rice has diurnal change of the transporter gene expression level in the point of view of investment efficiency. Our modeling suggests that a considerable reduction in the expression level of Si transporter genes during the night increases investment efficiency (the amount of Si accumulated in top leaf divided by the total expression level of Si transporter genes). Our study suggests that rice has a system that maximizes the investment efficiency for Si uptake.

Plant uptake of silicon nanoparticles

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ABSTRACT

In our latest work[1] we found that plants took up silicon from both soluble potassium silicate as well as SiO_2-nanoparticle (SiNP) when used as fertilizers to soil. The more soluble the Si, the more Si available, thus more Si was taken up when silicate was added compare to the SiO_2-particle addition. The objective of this work was therefore to find out how Si uptake and transport in plants differ depending on the Si solubility and Si nanoparticle sizes.To soil and nutrient solution, respectively, Si was added as potassium or sodium silicate or Si-nanoparticles in various sizes 7-1500nm. The firmly bound and available Si in soil was analysed after 80 days treatment. The plant uptake of Si as well as the translocation of Si in plants where followed when grown for about one month in soil or nutrient medium. Also the form of Si present in plants after uptake was analysed. Results showed that independent if silicate or SiNP was added to the soil or the solution, plants took up Si. When added SiNP to the plant growth medium, plants contained SiNP, which indicated that they took up SiNP as NPs. The smaller the NPs the more Si was taken up. When silicate was added, plants did only contain soluble Si but no SiNPs. The soluble Si was translocated to the shoot more than the SiNPs, which stayed to the highest extent in the roots. These findings were shown in both lettuce and wheat.The uptake of Si in fenugreek was similar when added as silicate and as SiNP. However, with increasing silicate addition the translocation of Si to the shoot increased, while this was not shown with increasing SiNP addition[2]. The silicon transporter *PST* was more upregulated when silicate was added compared with SiNP[2].In conclusion, the mobility of silicate is higher than ofSiNP and the smaller SiNP the more soluble and available.

[1]Greger, M. and Landberg, T., 2015. Silicon reduces cadmium and arsenic levels in field-grown crops. *Silicon*, pp.1-5.

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Keywords: plant uptake; silicate: silicon nanoparticles

Isolation and characterization of silicon transporter gene Lsi1 in Solanum lycopersicum L.

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ABSTRACT

Silicon is beneficial for plant growth and development, especially under adverse environmental conditions. The uptake mechanism of silicon in plants has been mostly studied in high silicon-accumulating plant species, while much still remains unknown in low silicon-accumulating plants. We isolated a silicon transporter gene named *SlLsi1* in tomato ('Micro-Tom') by in silico cloning, which is homologous to *Lsi1* in rice, barely, maize and pumpkin. Heterologous expressionin *Xenopuslaevis* oocytes and a rice mutant defective in silicon uptake showed that SlLsi1 had a specific transport activity for silicic acid.Overexpression of *SlLsi1* in tomato also increased the silicon concentration in the shoot. Expression pattern analysis showed that *SlLsi1* was mostly expressed in the root, and its expression was not affected by silicon supply. Transient expression of *SlLSi1-GFP* in onion epidermis and tomato protoplasts indicated that *SlLsi1* is localized at the plasma membrane. *SlLsi1-GFP* fusion expression showed that *SlLsi1* was expressed on the exodermis of root tip. These results indicate that SlLsi1 is a silicon influx transporter that is involved in radial transport of silicon in the root. Compared with that in other plants, the low capacity of silicon accumulation in tomato may be partly attributed to the lack of *SlLsi1* in the root endodermis, which is a barrier for silicon uptake.

Keywords: Tomato (*Solanum lycopersicum* L.); Silicon; Silicon transporter

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Correlative fluorescence and electron microscopies showing programmed cell death in sorghum silica cells

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ABSTRACT

Plants roots grow in silicate environment and absorb silicon as mono-silicic acid, a neutral molecule at most soil pH. Silicic acid moves with water inside the plant body and as water is lost through evapo-transpiration, it polymerizes in the plant body as solid and amorphous silica. Grasses deposit up to 10% of their dry weight as silica mostly in the cell wall of various cell types and inside the lumen of silica cells present on both sides of leaf epidermis. We recently showed that silicification in silica cells is a physiologically controlled process and takes place in viable cells only (Kumar et al., 2017). Few authors hypothesized that silicic acid is first concentrated in the vacuoles of silica cells and from there is excreted to the cell wall in senescing cells. We tested this hypothesis by tracking the fate of vacuoles in silica cells in the youngest developing leaf using a fluorescent dye that stains the cytoplasm of viable cells but does not stain the vacuoles. We correlated our results on the laser scanning confocal microscopy with the scanning electron microscopic (SEM) studies that gave us information on silica deposition in leaves of similar age and developmental stage. In the elongation zone, silica cells had large two to three vacuoles that occupied almost the whole volume of the cell. Silicification in silica cells did not start until they were mature. We found mature silica cells with substantially smaller vacuoles and yet they were not silicified as the whole cytoplasmic volume was stained with the viability dye. In contrast, we also found silica cells with large vacuoles and slightly shrunk cytoplasm, suggesting initiation of silica deposition in those cells while still vacuolated. Using SEM we did not detect silica signal first appearing from inside the cell lumen corresponding to the position of vacuoles. Based on this, we propose that vacuoles in silica cells do not carry silicic acid. Using the viability stain we found few silica cells in the leaf elongation zone displaying compromised membrane permeability, thus these cells are in the process of death before being silicified. We further found up to 5 % silica cells non-silicified or only partially silicifiedin mature leaves where all silica cells were dead. These results suggest that cell death ceases the silicification process in silica cells and that silica cells can die at any stage of silicification. We earlier reported that all silica cells eventually die in a sorghum mutant unable to uptake silicic acid from soil. Taken together these results suggest that all silica cells are genetically programmed to die irrespective of their silicification status and further strengthen our hypothesis that silica cells secrete a biological factor able to precipitate silica in the paramural space.

Reference: Kumar, S., Milstein, Y., Brami, Y., Elbaum, M. and Elbaum, R. (2017), Mechanism of silica deposition in sorghum silica cells. New Phytol, 213: 791–798.

Keywords: Silica cell; silicification; programmed cell death; vacuoles

Genomics intervention to understand silicon transport in plants

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ABSTRACT

Increased availability of annotated genome sequences provides an opportunity to understand a plant's genetic predisposition to accumulate silicon (Si). Silicon uptake is primarily regulated by a Si-transporter aquaporin (AQP) functionally categorized as nodulin 26-like intrinsic protein III (NIP-III). In this work, genome-wide analysis of AQPs performed in 30 plant species revealed the presence of NIP-III exclusively in species known to accumulate high concentrations of Si in their leaves (>1%). However, a NIP-III found in tomato, a low-accumulating species, appeared to contradict this association. Indeed, it contained all known conserved features necessary for Si permeability such as a G-S-G-R ar/R selectivity filter, six transmembrane domains, and two NPA motifs. Further analysis revealed however the presence of a 108 amino acid (AA) spacing between NPA motifs in Si accumulating species whereas tomato's NIP-III has 109 AA. To determine if the NPA spacing impacted Si transport's functionality, we evaluated several NIP-III mutants with varying NPA spacing through the oocyte assay. Results showed that deviation from 108 AA spacing of a single amino acid, upward or downward, significantly affected the Si transport activity of NIP-IIIs. Using these improved diagnostic features, two Si-transporter NIP-IIIs were identified in strawberry, another species reported as a low accumulator. To verify the genetic predisposition, a set of diverse strawberry cultivars was evaluated for Si uptake. An experiment conducted under high tunnel conditions showed significant Si accumulation in strawberry plants (up to 3 %) and Si-derived powdery mildew resistance. The study demonstrates the applicability of genomics to understand Si uptake and derived benefits in plants.

Keywords: Phylogenetic distribution, Evolution, Conserved features, Genome-wide analysis, Solute transport

Poster Presentation

Identification of natural variation of silicon transport in rice

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ABSTRACT

The global demand of rice (*Oryza sativa* L.) needs continuous supply and increased yield to ensure the world's food security As a beneficial element, silicon (Si) alleviates biotic and abiotic stresses in rice which helps to maintain yield. Despite the advantages of high concentrations of Si in rice, the high concentration of shoot Si in rice causes problem for its further use as a bi-product (e.g. producing biofuel from rice straw). In addition, rice straw is a source of feed for ruminants, however, the high concentration of Si in rice straw causes low digestibility. It has been also demonstrated that arsenite, classified as a class I carcinogen, is taken up by silicic acid transporters in rice.

To date four Si transporters (*Lsi1*, *Lsi2*, *Lsi3* & *Lsi6*) have been identified which are involved in Si influx and efflux in rice. In this study, a number of experiments were conducted to improve the understanding of Si biology in rice. An experiment was conducted to determine the concentration of Si in different organs of rice grown under aerobic and anaerobic conditions. The experimental results indicated that a significant difference of ($P < 0.001$, $F = 27.40$, $R^2 = 78.20$ %) of Si concentration between different organs of the plant in aerobic (husk = 46.80 mg g^{-1}, root = 3.50 mg g^{-1}, n = 4) and anaerobic condition (husk = 65.50 mg g^{-1}, root = 4.40 mg g^{-1}, n = 4) where cultivation method also had a significant effect ($P < 0.001$). The shoot Si analysis of fifty diverse *Oryza sativa* from the Rice Diversity Panel 1 in a field grown experiment indicated a significant genotypic difference of shoot Si in rice ($P < 0.001$; $F = 5.80$; $R^2 = 55.30$ %; df = 49). The shoot Si data was further used for Genome-wide Association mapping of Si transporter in rice using 700K SNPs. The haplotype analysis within 10 kb of previously identified silicon transporters (*Lsi1*, *Lsi2*, *Lsi3* & *Lsi6*) was also conducted to examine the phenotypic variation of shoot Si concentration in rice.

Keywords: Rice; Silicon; SNPs; Transporter, Candidate gene

Session - 3

Sub Theme - IV

Role of Silicon in Abiotic Stress Management

Keynote

Silicon and abiotic stress in higher plants: progress and perspectives

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ABSTRACT

Despite the fact that silicon (Si) is the second most abundant element after oxygen both on the earth's surface and in soils, convincing evidence is still lacking that Si can meet the definition of essential elements for higher plants that was established by Arnon and Stout in 1930s. Nevertheless, over the last hundred years, especially over the last three decades it has been well documented that Si is a beneficial or agronomically-essential element for the healthy growth and development of many terrestrial plants. These beneficial effects are more distinct in plants exposed to various forms of abiotic (e.g. aluminium stress, heavy metals stress, salt stress, drought stress, high and low temperature stress, UV radiation stress, mineral-nutrient deficiency etc.) and biotic stress (fungal and bacterial diseases, and insect pest attack etc.). This review focuses on overall updated knowledge of Si-mediated alleviation of abiotic stresses including metal stress, salt stress, drought and low-temperature stress and mineral nutrient deficiency etc. Yet, vast relevant research work has mainly focussed on the possible mechanisms by which abiotic stress is mitigated by Si at a physiological or biochemical level. For the metal tolerance, in general, there are two mechanisms, i.e. external (*ex planta*) mechanism and internal (*in planta*) mechanism, proposed for explaining why and how Si can regulate plant resistance and/or tolerance to metal toxicity. Growing evidence suggests that Si is involved in regulating the expression of genes responsible for many plant metabolic processes, especially under heavy-metal-stress conditions. For the salt tolerance, it seems to suggest that (1) silica deposited on apoplast as SiO_2 opal or phytolith can enhance water retention by inhibiting transpirational water loss, thus reducing salt-induced osmotic stress and (2) soluble Si in symplast may be actively involved in physiological and biochemical metabolisms by regulating the expression of genes related to the biosynthesis of hormones (ABA and JA etc.), antioxidant defense enzymes, H^+-pumps and osmolytes to rebalance ion stoichiometry, reduce membrane permeability and improve membrane structure and stability, hence improving salt tolerance in plants. The mechanisms for Si-mediated tolerance to drought and low-temperature stresses include promoting photosynthetic enzymatic activities, photochemical efficiency and photosynthetic rate, maintaining nutrient balance, improving water retention by decreasing water loss from leaves and increasing water uptake by roots, and scavenging reactive oxygen species by improving the capabilities of antioxidant defence. Compared with rapid and great progress made in dissecting the molecular mechanisms of Si uptake and transport, less work has been done on Si-mediated tolerance to varying forms of abiotic stress at a molecular level. To better understand the mechanisms underpinning Si-mediated resistance to abiotic stress, future work should focus on mechanistic investigations of Si and abiotic interactions at the molecular level with an emphasis on transcriptomic or proteomic studies.

Key words: Abiotic stress; Antioxidant defense; Metal stress; Salt stress; Silicon

Silicon influence on plant ionom and mineral element transporters

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ABSTRACT

The plant ionomics is the study of essential and nonessential mineral element composition of plants (the ionom) at cellular, tissue or organismal level. The plant ionomic profile is affected by various factors, including plant (e.g. species, genotypes, organ, developmental change) and environment (e.g. soil, fertilizers, stress conditions). Over the past decade rapid progress has been made in understanding the mechanisms through which silicon (Si) mediates mineral excess and/or toxicity stress. However, the effect of Si on the mineral element uptake and consequently the plant ionome is still unclear, in particular under conditions of limited nutrient availability.

Firstly, I will present recent results of my research group demonstrating that Si application modulates the ionomic profile of various plant species (e.g. rice, barley, wheat, maize, cucumber, sunflower, soybean, grapevine and tomato) grown under both normal and stress conditions. In the second part of my talk I will review the current knowledge of Si influence on the expression of (a) root and shoot metal transporter genes under excess of cadmium (Cd), manganese (Mn) and copper (Cu) (Li *et al*., 2018; Kim *et al*. 2014; Che *et al*., 2016; Farooq *et al*., 2016); (b) transporter genes involved in the uptake, long-distance transport and homeostasis of iron (Fe) under low Fe conditions (Pavlovic *et al*., 2013, 2016); (c) transporter genes for inorganic phosphorus (Pi) root uptake under low P conditions (Kostic *et al*., manuscript submitted); and (d) transporter genes involved in shoot homeostasis of sodium (Na^+) (see Bosnic et al., this proceedings) and B (Akcay & Erkan, 2016) under saline stress.

In conclusion, the role of Si in modulation of plant ionome, including also nutrient and other mineral element uptake and utilization, appears to be more indirect by transcriptional regulation of genes responsible for both root acquisition and tissue homeostasis. Further understanding of how exactly Si regulates the expression of mineral element transporter genes will help to improve crop productivity, yield quality and food safety in stress conditions.

Keywords: Environmental stress, Ionomics; Mineral element transporters; Silicon

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Short Oral

Silicon nutrition augments plant vigour, ionic homeostasis and defense mechanisms in mycorrhizal *Cicer arietinum* L. genotypes under salt stress

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ABSTRACT

Salinity is one of the most imperative environmental factors that limit crop production in arid and semiarid regions. Among the leguminous crop species, chickpea (*Cicer arietinum* L.), is the third most important food legume grown in the world and is considered highly sensitive to salt stress. Over the past decades, various studies have highlighted the promising role of silicon (Si) in the alleviation of abiotic stresses. Although not an essential element for plants in general, Si has been demonstrated to induce favourable effects in terms of biomass accumulation in many plant species, especially monocots. However, very few studies have highlighted the constructive role of Si in imparting salt resistance in the case of nitrogen fixing leguminous species due to their inability to accumulate significant amounts of Si in their tissues passively. Aiming to shed further light onto the beneficial role of Si, studies were aimed to investigate the effect of exogenous supplementation of Si in modulating plant vigour, ionic homeostasis and antioxidant defense pathways in differentially salt tolerant chickpea genotypes exposed to long term salinity**.** Further, mycorrhizal inoculations were used along with Si nutrition as amultidisciplinary approach in order to enhance the beneficial effects of Si in other wise low Si accumulating species.

Pot trials were conducted in two differentially tolerant chickpea genotypes – HC 3 and CSG 9505 which were supplemented with 4 NaCl concentrations (0, 60, 80 and 100 mm), 2 Si levels (in form of potassium silicate - 0 mm and 4 mm), with or without *F. mosseae*. Present investigations revealed that with increasing salt concentrations, toxic ion contents got amplified that correlated negatively with decreased plant biomass. In addition, salinity induced oxidative stress by accumulating stress metabolites (MDA, H_2O_2). Addition of Si and/or AM fungus counteracted the negative effects of salinity by significantly reducing the uptake of Na^+ and upgrading plant defense response (activities of SOD, CAT, APOX, GSH-ASA cycle), ultimately, leading to better growth performance under stressful conditions. Comparatively, AM was found to be more efficient in improving growth attributes and defense responses while benefits of Si were directed towards reducing Na^+ levels thus maintaining favourable ionic homeostasis. Interestingly, study further highlighted the ability of *F. mosseae* in enhancing Si content in stressed chickpea plants, thus recording superior beneficial effects of both in +Si+AM treated plants than +Si/+AM plants. Moreover, the benefits of Si nutrition were more discernible in HC 3 that displayed better ability for mycorrhizal colonization, thus accumulated higher Si contents than CSG 9505. Conclusively, these results support Si along with AM fungi as a potential candidates in the regulation of salt stress via imparting functional complementarity under such deteriorated soil conditions.

Keywords: Antioxidants; *Cicerarietinum* L.; Legumes; Salt stress; Silicon; Mechanism(s)

Silicon potentiates photosynthetic efficiency and biochemical defence responses of lentil against drought stress

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ABSTRACT

High temperature and solar radiation are determinant for drought, which can be considered as the most important environmental constraint to crop production including lentil. Even though lentil (*Lens culinaris*, Medik.) is a hardy crop, since is more tolerant to water stress, the plant productivity can decrease from 6.0 - 54 % under drought conditions and can even lead to total crop failure. Application of silicon (Si) has been shown to be a promising technique to improve drought tolerance; however the physiological mechanisms and interactions involved are not fully understood, especially in legumes. Consequently, the present study investigated the effect of Si in drought stressed lentil plants to minimize the detrimental effects of drought on relative water content (RWC), photosynthetic efficiency, concentration of osmolytes, membrane damage, production of reactive oxygen species, the activity of antioxidant enzymes, plant growth and yield. Seven lentil genotypes, ILL 6002 and Indianhead (drought-tolerant), Flash, PBA Jumbo 2 and Nipper (moderately drought-tolerant), and PI 468898 and ILL 1796 (drought-sensitive) were subjected to three different water levels (100, 50 and 0% field capacity) at the onset of the reproductive phenological stage. The Si was applied to the soil before sowing the seeds. The experiment was carried out in a growth chamber under controlled conditions. Potted plants were kept in a randomized complete design with five replicates per genotype. Results from physiological measurements showed that RWC, which was the main factor related to reduced growth in response to drought, increased significantly with Si application under drought. Drought stress significantly decreased the chlorophyll (*a+b*) content, net photosynthetic rate (*P*n), transpiration rate (*T*r) stomatal conductance (*g*s), internal CO_2 concentration (*C*i) electron transport rate (ETR) and the photochemical efficiency of PSII (Ö*PSII)* in lentil crops measured by gas exchange and chlorophyll fluorescence. Under drought, Si applied plants showed significantly higher values of *P*n, *T*r, *g*s, *C*i, ETR and Ö*PSII*. Proline, and glycine betaine increased primarily in drought-stressed lentil crops but Si addition significantly decreased their concentrations under drought stress. Drought stress caused great membrane damage, as assessed by lipid peroxidation, but Si application significantly reduced the membrane damage. Drought stress significantly increased the production of reactive oxygen species, superoxide radicals (O_2"·) and hydrogen peroxide (H_2O_2) and induced oxidative damage, while added Si reversed these effects. Furthermore, the addition of Si significantly stimulated the efficiency of the glutathione ascorbate (GSH-AsA) cycle by increasing the concentrations of glutathione (GSH) and ascorbate (AsA) as well as the activities of antioxidant enzymes like superoxide dismutase (SOD; E.C.1.15.1.1.), ascorbate peroxidase (APX; E.C.1.11.1.11.), catalase (CAT; E.C.1.11.1.6.), guaiacol peroxidase (G-POD; E.C.1.11.1.7.) glutathione reductase (GR; E.C.1.8.1.7) and dehydroascorbate reductase (DHAR; E.C.1.8.5.1) in drought stressed lentil. Even though drought stress significantly lowered the plant growth and yield in all the studied genotypes, Si treatment enhanced the plant biomass and yield. In conclusion, Si could ameliorate adverse effects of drought stress in *lentil crops* likely by increasing photosynthetic efficiency, reducing oxidative stress and osmotic stress.

Keywords: *Lens culinaris*, Osmolytes, Antioxidant enzymes, Reactive oxygen species, Glutathione ascorbate cycle, Stomatal conductance.

Silicon mediates sodium transport and homeostasis in maize under mild NaCl stress

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ABSTRACT

It has been hypothesized that halophytes reutilize sodium (Na^+) as "cheap" osmoticum and hence accumulate more Na^+ in shoot tissue, while glycophytes restrict Na^+ accumulation in shoot and subsequently accumulate more Na^+ in root. Although both types show similar mechanisms involved in maintaining Na^+ homeostasis, halophytes are more efficient due to the different expression profiles of Na^+ transporters. Yet, the role of silicon (Si) in the expression of the Na^+ transporters involved in the uptake, transport and homeostasis of Na is still unclear.

Maize (*Zea mays* L., hybrid ZP-560) plants were grown in the nutrient solution with 40 mM NaCl, which simulates conditions more relevant for salinized agricultural soils, without or with Si supplied in the form of silicic acid at 1.5 mM. We examined the expression of key genes involved in the transport of Na^+, including root uptake (influx) and extrusion (efflux), xylem and phloem loading/ unloading and vacuolar transport. This was paralleled by measurements of Na concentration in the various tissues, compartments and organelles.

The addition of Si significantly decreased Na accumulation in the root apex and cortex of maize plants exposed to mild NaCl stress (40 mM) through up-regulation of the expression of both efflux Na^+ transporter gene *ZmSOS1* and protein kinase *ZmSOS2* involved in positive regulation of SOS1 transporter. Lower accumulation of Na^+ in the root tissues of Si-treated plants was also caused by down-regulation of the expression of influx transporter gene *ZmHKT1;1* involved in Na^+ uptake by the root symplast. However, significantly increased concentration of Na^+ in the xylem parenchyma (central cylinder), xylem sap and concomitantly in the leaf tissues was recorded in Si-fed plants. This seemingly paradoxical behavior for glycophytes can be explained by Si-mediated up-regulation of both *ZmSOS1* and *ZmSOS2* involved in xylem loading of Na^+, and also by down-regulation of *ZmHKT1;1* responsible for unloading of Na^+ in the root xylem parenchyma. Albeit higher Na accumulation was recorded within the leaf tissue of Si supplied plants, we clearly demonstrated higher vacuolar to chloroplast Na^+ sequestration ratio in the mesophyll cells (visualized by confocal microscopy using Sodium Green dye), which was further supported by higher expression of the tonoplast transporter gene *ZmNHX5* for Na^+ loading into the vacuole. Consequently, Si-fed plants showed a lower level of lipid peroxidation in the leaf tissue, increased chlorophyll content and improved shoot growth performance. Fractionated extraction of Na in the leaf tissue further demonstrated that Si-fed plants were also capable to bind more Na^+ to the cell walls. Furthermore, we show for the first time that Si significantly increased shoot-to-root Na^+ recirculation via phloem; Si-mediated phloem transport was further confirmed by up-regulated expression of leaf *ZmHKT1;1* responsible for Na^+ loading into the phloem.

In conclusion, our results highlight the complexity of Si role in transport and homeostasis of Na^+ in maize. Hence, Si shifts typical glycophyte behavior of maize response to mild salinity stress towards that characteristic for halophytes.

Keywords: Homeostasis; Maize; Salt stress; Silicon; Sodium transporters

Silicon fertilization alleviates the deleterious effects of water deficit in sugarcane cultivars

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ABSTRACT

One of major challenges to achieve higher sugarcane yield is to surpass the deleterious effects of water deficit (WD), especially in sandy soils typical of expansion areas. The intensity of crop yield damage caused by WD depends on the growth phase and cultivar. These effects can be prevented by choosing planting times for which the most critical growth phase does not coincide with the most likely water deficit periods. However, this is not a feasible strategy in Brazil because sugarcane planting occurs nearly year-round. Other alternative is the use of drought-tolerant cultivars, but they are insufficient in supply for all areas. Silicon (Si) may be a potential alternative, but there is little information about the effects against water deficit in sugarcane. So, the objective was to investigate the effects of Si fertilization and WD imposed at summer for sugarcane cultivars using physiological evaluations, biomass and Si content in the plants.

The experiment was conducted in a completely randomized factorial design with four replications. Factors included absence (well-watered, WW) and presence of WD, two silicon rates (0, and 600 kg ha^{-1} Si; Si- and Si+), and four sugarcane cultivars: two drought-tolerant (RB86-7515, SP83-2847) and two drought-sensitive ((RB85-5453, RB85-5536). Ca-Mg silicate was used in treatments with Si (+Si) and lime and $MgCl_2$ were used in those without Si (-Si).

Pots (20L) were filled with a Typic Quartzipsamment soil (93% sandy). One sugarcane plant was transplanted into each pot on May 13, 2014. The water deficit was imposed by establishing 55% soil field capacity in summer (October, 2014) during 28 days, when water potential, electrolyte leakage (EL), relative water content (RWC), leaf area (LA), SPAD index, biomass dry weight (DW), Si uptake and water-use efficiency (WUE) were evaluated.

The lowest values of Ø, RWC, SPAD, LA and DW were observed for WD compared to the WW treatment. SP83-2847 exhibited better performance for physiological aspects and Si uptake, and RB85-5536 showed inferior results. Si fertilization decreased EL and increased y, RWC and WUE, but it did not influence the LA and SPAD values of sugarcane leaves. Drought-tolerant cultivars exhibited superior values than others in the absence of Si. In addition, similar DW and Si uptake were observed for all cultivars when Si was applied in the soil.

Si is as an alternative tool to alleviate the effects of water deficit through physiological alterations and increased biomass dry weight of the sugarcane.

Key words: silicate, drought, nutrition, abiotic stress

Emerging recognition of silicon as ameliorator of abiotic stresses in legumes

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ABSTRACT

Silicon, after oxygen is the second most prevalent mineral element on the earth's crust. Plant roots generally take up Si in the form of silicic acid [$Si(OH)_4$]. Following uptake by the roots, Si gets translocated to the shoot where it is polymerized to form silica gel. Recently, several studies have demonstrated that exogenous Si fortification induce favourable effects on plant growth under salt as well as metal stress. The mechanisms adopted by Si in alleviating abiotic stresses include deposition of Si into the epidermis cell walls as a hydrated amorphous polymer (opal) forming *silica–cuticle double layers*, thus improving light perception, imparting hardiness to plants, maintain ultra-structure of leaf organelles and improve plant endogenous nutrient profile. Consequently, it is now being recognized as 'quasi-essential or beneficial' element for plants because deficiency of Si has been validated to result in various cellular dysfunctions. Although all plants contain Si, a wide variation in Si accumulation exists between species, where graminaceous plants have been reported to take up much more Si while legumes are considered as low Si accumulators due to their inefficiency in taking up this quasi-essential element actively. However, few studies have been carried out to explore the beneficial effect of Si in imparting salt and metal tolerance especially in legumes. In the present talk, I will discuss various mechanisms by which Si mitigates these stresses in legumes.

A series of experiments were conducted in the pot house, Department of Botany, Panjab University, Chandigarh with an aim to explore the ways by which Si modulates salt and metal-induced responses in the two legume species - *Cicer arietinum* and *Cajanus cajan* and their genotypes, respectively. Several agronomic parameters including root as well as shoot biomass, nodulation and nitrogen fixation, oxidative stress markers, defense response in terms of enzymatic and non-enzymatic antioxidants as well as osmolyte synthesis were investigated. The experimental findings revealed a negative correlation between various agronomic parameters with elevated salt/metal stress. Exogenous Si fortifications not only reduced the toxic ion contents (Na^+, As, Cd, Zn) and the resultant oxidative burst but also improved plant productivity even under highest salt as well as metal concentrations. Such beneficial effects of Si could be ascribed to improved plant water status, enhanced antioxidant activities as well as efficiency of enzymes involved in proline metabolism that shifted the dynamics of oxidative destruction towards favourable defense response. One of the highlights of the study pointed that the beneficial effects of Si could be compounded through introduction of arbuscular mycorrhizae in the rooting medium that not only amplified plant endogenous Si contents, but also imparted enhanced tolerance to otherwise low Si accumulating leguminous species even under stressful conditions. Moreover, significant variations were visible even at genotypic levels within the same species where stress tolerance of a genotype could be directly correlated to its ability for better Si uptake. In conclusion, investigations highlighted the beneficial effects of Si nutrition in restoring the symbiotic efficiency, thus productivity of economically important legumes grown in contaminated soils.

Keywords: Genotypes; Heavy metal; Legumes; Salinity; Silicon; Tolerance mechanisms

Silicon-induced alleviation of antimonate (SbV) toxicity in maize

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ABSTRACT

Silicon (Si) has often been found to alleviate phytotoxic effects of various toxic elements like cadmium (Cd), lead (Pb) or aluminium (Al). In our study we investigated whether it can also mitigate negative effects of the metalloid antimony (Sb) on plant growth. Young maize seedlings (*Zea mays*, L., hybrid Valentina) were hydroponically grown in the presence of various antimonate ($Sb(OH)_6^-$) concentrations (0-30 mg kg^{-1}) and one concentration of Si (2.5 mM). Antimonate did not influence root biomass but retarded root growth, leading to shorter and thinner roots. The increase in root mass density was in line with a decrease in root cortical aerenchyma. Silicon addition mitigated the negative Sb effects on root growth and architecture and enhanced aerenchyma formation. It did not affect root Sb concentrations, but with increasing Sb exposure level it first increased and then reduced the small fraction of Sb that was translocated into the shoots. In turn, antimonate reduced Si accumulation by the roots, but did not inhibit root-to-shoot trans-location of Si. The simultaneous occurrence of positive and negative interactions between Sb and Si indicates that they involved multiple mechanisms.

Acknowledgements: The work was supported by Slovak Research and Development Agency under the contract APVV SK-AT 2015-0009 and by grant VEGA 1/0605/17.

Keywords: antimony; maize; root anatomy and architecture; silicon

Insights to silicon-dependent drought tolerance by testing a sorghum mutant defective in silicon uptake

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Conference theme: Role of Si in biotic and abiotic stress management

ABSTRACT

Silicon intake increases plants ability to cope with drought stress, however, the mechanism underlying this phenomenon is still unclear. In order to study the effects of silicon on sorghum (*Sorghum bicolor*) under drought, we utilized a sorghum mutant plant lacking the key silicon root channel – Low silicon 1 (*Lsi1*). The *sblsi1* mutant plants absorb a minute amount of silicon to the shoot, in comparison to wild type plants, while its root silicon content is 10% that of the WT. When grown in a greenhouse, WT sorghum plants reacted later to imposed drought conditions compered to *sblsi1* mutant plants. The mutant showed significant reductions in momentary and accumulated whole plant transpiration, photosynthesis rate, and stomatal conductance. These reductions were found only in water stressed plants. Similar leaf water contents and root system between the two genotypes suggested that the water uptake was balanced with transpiration because of early stomatal closure. In order to rule out the role of *SbLsi1* channel in water conduction,and improvementof root conductivity, we will use a functional phenotyping platform to continuously measure transpiration rates in parallel to root water fluxes. These data will allow the calculation of whole plant water content. In addition, root hydraulic conductivity after drought will be compared between the genotypes, by applying suction to cut stems and collecting root sap. Our results will indicate whether the presence of silica in the WT shoot alters stomatal conductance, suggesting an influence on the plant hormonal state.

Poster Presentation

Silicon improves the quality of fruits of Solanum lycopersicum Mill. subjected to saline stress

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ABSTRACT

Water and soil salinity are problems that greatly affect agricultural activity, especially in arid and semi-arid areas. This condition reduces growth, development and production of crops, besides these affect the quality of the fruits. Silicon is considered as a beneficial element that improves the conditions of plants subjected to different types of stress. The objective of the present work was to evaluate the effect of silicon application in the nutrient solution on fruit quality of plants subjected to saline stress.

The experiment to evaluate silicon on fruit quality of tomato plants had nine treatments, the result of the combination of three electrical conductivities (2, 5 and 8 dS m^{-1}) and three levels of silicon (0, 60 and 120 ppm). The tomato variety (*Solanum lycopersicum* Mill.) used was Cuauhtémoc F1. The experiment was carried out using coconut fiber and nutrient solutions for tomato, proposed by Castellanos (2011) for different stages of plant development. Seedlings were transplanted in October 2016 and the harvest was started 67 days after the establishment, for a period of 92 days, where four samples of fruits were carried out. The evaluated variables were: firmness, total soluble solids, pH, titratable acidity and maturity index.

Silicon decreased the titratable acidity values (linear effect pd"0.05) and increased the values of maturity index (linear effect pd"0.05), under low electrical conductivity conditions (2 dS m^{-1}). In a moderate salinity condition (5 dSm^{-1}) the variables benefited by silicon addition were total soluble solids (linear effect pd"0.01) and titratable acidity (quadratic effect pd"0.05), while at high conductivity (8 dSm^{-1}) the values of total soluble solids (quadratic effect pd"0.01), pH (linear effect pd"0.01) and maturity index (linear effect pd"0.05) were increased. Due to the above, the addition of silicon to the nutrient solution can contribute to improve the quality of the fruits of tomato plants subjected to saline stress.

Keywords: Soilless; Greenhouse; Production

Castellanos, J. &Ojodeagua, J.L. (2011). Formulación de soluciones nutritivas. In: Castellanos, J. ed., 1st ed. Mexico: Intagri, S.C., p.147.

Effect of silicon on tolerance of wheat (*Triticum aestivum* L.) at different growth stages to salt stress: Case study for management of irrigation water

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ABSTRACT

To face the limited resources of fresh water in Egypt, this study was undertaken as an attempt to figure out the growth stage (s) of wheat revealing higher tolerance to salinity with silicon addition at which saline water instead of good quality water could be used for irrigation with no greater risk in crop production.

Local wheat cv. Gimmiza 11, commonly grown in North Delta Valley was seeded in an inert washed sand packed in plastic pots with an outlet for free drainage. Irrigation started with one-fifth strength nutrient solution till seedling establishment, followed by the full- strength solution which maintained bi-weekly in amounts exceeded the sand saturation percent by 30%. Treatments consisted of 4 salinity levels: 0, 60, 90 and 120 mM NaCl and 2 silicon levels: 0 and 0.78 mM Si as Na_2SiO_3. $9H_2O$. Both NaCl and Si treatments were added into the full-strength nutrient solution (pH 6.0) and replicated 4 times in a complete randomized design. Some physiological, chemical and biochemical traits for salt tolerance were evaluated at seedling, tillering, booting and milky growth stages and used as indexes for assessing salt stress tolerance of each stage with Si addition.

Salinity stress increased leaf Na^+ content, catalase (CAT) and superoxide dismutase (SOD) activities and decreased K^+, K^+/Na^+ ratio, biomass yield and chlorophyll content at all growth stages. Comparing growth stages under salinity stress, booting and milky stages demonstrated higher K^+ and K^+/Na^+ ratio and lower Na^+ content in leaf as well as lesser shoot fresh and dry weight losses as compared with seedling and tillering stages. Silicon addition exerted remarkable reduction in leaf Na^+ and greater enhancement in K^+ content, K^+/Na^+ ratio and shoot biomass along all stages as compared to plants grown in saline culture deprive Si, and that was greatly prevailing at booting and milky stages. However, leaf Na^+ content was not significantly affected with Si application under non saline conditions. Concentration of chlorophyll a was higher at booting stage and lower at seedling and milky stages whenever salt stress was low (60 mM NaCl). Application of silicon enhanced both chlorophyll a and b along all the growth stages under any level of salinity and that was highly remarkable at booting stage. Though CAT and SOD activities were increased with increasing salinization along the 4 growth stages, they exhibited greater stimulation at booting stage when Si was applied. Therefore, silicon greatly enhanced salt tolerance of wheat as growth proceeds towards maturity particularly at booting and milky growth stages. Accordingly, saline water could be used safely for irrigation at booting stage (consume much water) when good quality water is not available for supplemental irrigation.

Key words: *Triticum aestivum*, salinity, silicate, growth stages, antioxidants.

Effect of silicon in the initial stages of Zn-deficiency in rice plants

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ABSTRACT

Zinc is an essential mineral nutrient required for plants. It is the second most abundant transition metal in organism (after iron) and it has a vital role in a variety of physiological and metabolic processes by beeing directly involved in the function of enzymes as part of its catalytic site. Zinc deficiency is the most common crop micronutrient deficiency, and can decrease crop yields and nutritional quality.

Previous studies have demonstrated a beneficial effect of silicon on plants alleviating multiple environmental stresses by affecting the antioxidant enzyme levels. In cucumber plants grown under micronutrient (Fe, Mn and Zn) deficiency, silicon has been proved to partially mitigate the Zn-deficiency symptoms. In rice, silicon is especially important for a high production. In this study, we assay the effect of silicon in the initial stages of Zn deficiency in rice plants in hydroponics. Our study shows that silicon can increase zinc content in roots and alter the levels of superoxide dismutase activity, an antioxidant enzyme.

Keywords: Silicon, Zinc deficiency, Rice

Role of silicon in modulating growth, mycorrhizal and rhizobial symbiosis as well as yield in *Cajanus cajan* genotypes under arsenate and arsenite stress

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ABSTRACT

Arsenic is a ubiquitous metalloid which accumulates in the environment due to natural and anthropogenic activities. Arsenic is generally present in the soil in two highly toxic and interconvertible forms i.e. Arsenate- As V and Arsenite - As III which have negative impact on growth, nitrogen fixation and productivity of legumes. Legumes are less tolerant to As stress since they depend upon nitrogen fixation for nutrient balance (N, P) and ultimate yield. Exogenous application of Silicon (Si) and Arbuscular Mycorrhiza (AM) have been reported to ameliorate toxic effects of As stress. However, the benefits of Si as well as AM vary between as well as amongst the different plant species, with legumes in general, reported to be low Si accumulators but strong AM colonizers. Present study was aimed to evaluate the relative roles of Silicon and *Rhizophagus irregularis* on growth, nodulation efficiency, nutrients and ultimate yield in *Cajanus cajan* (pigeon pea) genotypes (Tolerant- Pusa 2002 and Sensitive-Pusa 991) under As V (25 and 50 mg/kg and As III stress (5 and 10 mg/kg). Significant and variable amounts of As was accumulated in response to both As V and As III treatments at both organ as well as genotype levels, with higher accumulation in the roots than shoots under As III stress. Increase in As contents were accompanied by significant decline in root and shoot biomass, nutrient content, nodulation potential, nitrogen fixing efficiency as well as ultimate grain yield, with higher decline observed in Pusa 991 compared to Pusa 2002. Si as well as AM had a positive impact under both As V and As III stress and were able to promote plant growth and nodulation by restricting As uptake and further translocation to above ground parts. The beneficial effects of Si were lower than *R. irregularis* due to the ability of both genotypes for stronger AM colonization when compared with their capacity for Si uptake. However, Pusa 2002 was more tolerant to the presence of As V and As III in the soil by establishing superior AM as well as rhizobial symbiosis along with higher Si contents when compared with Pusa 991. Among the two exogenous applications, Si displayed a more positive role in ameliorating As III stress while AM was more effective under As V stress. The plants supplementation with both Si and AM complemented each other by improving Si uptake as well as AM colonization under both As V and As III stress which resulted in enhanced growth, nutrients, nodule development as well as the resultant yield in a genotype dependent manner. The study thus highlighted the enhanced beneficial effects of Si in ameliorating As V and As III stress in pigeon pea plants through AM inoculations.

Keywords: Arsenic; Genotypes; Mycorrhizal symbiosis; Nodulation; Silicon; Yield

Silicon nanoparticle effects on arsenic and cadmium plant uptake

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ABSTRACT

We found that plants accumulated less arsenic (As) and cadmium (Cd) in edible plant parts of potato, carrots, wheat and onion when added soluble potassium silicate compared with SiO_2-nanoparticles (SiNP) when used as Si fertilization of soil[1]. The more soluble the Si, the more Si available to plants, thus more Si was taken up and affected the accumulation of As and Cd. Silicate is more soluble than SiO_2-nano particles (SiNP). We believe that the size of SiNP would also be important for the Si solubility and thus for the effect on the metal accumulation. The objective of this work was therefore to investigate the effect by the Si nanoparticle sizes on As and Cd uptake by plants. To alum shale soil, containing 117 mg/kg As and 5.6 mg/kg Cd, Si was added as potassium silicate or Si-nanoparticles in various sizes (7-500 nm) and run for 80 days. The availability of As and Cd in soil was analysed. Wheat and lettuce was planted and grown in the soil for four weeks. The plant uptake of As and Cd in root and shoot was analysed with AAS. Results showed that the smaller the SiNPs and the higher the Si concentration, the lower the solubility of Cd and As in the soil. Thus the plant availability of As and Cd in soil decreased with less SiNP size. The effect of Si on the As and Cd uptake depended on plant species. The effect by SiNP sizes was largest on Cd accumulation in wheat shoot and on As accumulation in lettuce roots, where it decreased significantly with lower SiNP size. Thus, the effect by Si on plant As and Cd uptake depended largely on SiNP sizes and Si solubility in soil.

[1]Greger, M. and Landberg, T., 2015. Silicon reduces cadmium and arsenic levels in field-grown crops. *Silicon*, pp.1-5.

Keywords: arsenic, cadmium, plant uptake; silicate: silicon nanoparticles

Silicon effect on micronutrients localization in rice roots grown in Fe deficient and control conditions at two different pH values

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ABSTRACT

Iron (Fe) is an essential nutrient for plant development and its low availability, especially in calcareous soils with alkaline pH, results in a reduction of plant productivity. Rice plants have developed a dual mechanism to prevent Fe deficiency in which Fe (III) is taken up as a complex with Fe-chelating compounds (mugineic acid family phytosiderophores) and Fe (II) is taken up directly by transporters of membrane (*OsIRT1* and *OsIRT2*) expressed in the roots in response to Fe-deficient conditions.

Silicon (Si) is the second most abundant mineral element in the earth´s crust. Despite Si is not considered as an essential element for plant development, beneficial effects of Si are evident in high Si-accumulating plant species such as rice plants, where Si are regularly applied for a healthy growth and high and stable production. Moreover, Si ameliorates various biotic (resistance to pathogens and insects) and abiotic (nutrient imbalance, salt, freezing, lodging, radiation, high temperature, drought) stresses in many plant species. Recently, several studies have been conducted to elucidate the mechanism of how Si affects Fe deficiency in plants at pH < 7.0 whereas limited information is available at pH >7.5 (calcareous soils) where the most serious Fe deficiencies are present.

The objective of this study was to compare the localization of micronutrients (Fe, Mn, Cu and Zn) in rice root cross sections depending on Fe status, Si supply and pH of nutrient solution using laser ablation-ICPMS. Elemental images obtained by LA-ICP-MS will allow to study the elements distribution along rice root microstructures. Since a different metal distribution inside the plant tissue due to the Si application and the Fe status was already observed in a previous experiment, differences in micronutrients localization may be also observed.

Results showed changes in the micronutrients localization of rice root cross section depending on one or several studied factors. The localization of 63Cu was affected by Fe status, Si supply and pH of nutrient solution. The localization of 55 Mn was modified by Si supply at pH 6.0 and pH 7.5 in Fe deficiency. Also the Fe status altered the localization of 55 Mn especially at pH 7.5. The localization of 66Zn was affected by Fe status and Si supply at pH 6.0 but not at pH 7.5. 56Fe was only analyzed at pH 7.5 and neither the pH nor the Si supply produced marked changes in its localization.

Keywords: Silicon, Fe-deficient, rice, micronutrients

Effect of silicon on drought tolerance of wheat (Triticum aestivum L., cv. Venturero)

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ABSTRACT

Many scientific groups have worked on various aspects of silicon in plant biology and have shown various benefits of this element in plants, especially under stress conditions. Our previous studies showed importance of Si for drought tolerance of sorghum (Lux et al. 2002; Hattori et al. 2005). Positive role of Si treatment was shown in other plant species exposed to drought, alleviation of various abiotic stresses was demonstrated in many other studies. In the present work we used wheat (*Triticum aestivum* L. cv. Venturero). This cultivar is ancient medieval wheat imported to Mexico by conquistadors from Spain. It is characterized by high drought tolerance, as experimentally confirmed in Mexican institute Collegio de Postgraduados, Chapingo. It grows well in conditions of Slovakia (Central Europe) and tolerates low winter temperatures. The drought periods in our region of wheat cultivation are repeatedly occurring during the vegetation period in the last years. They are probably connected with the global changes of the climate and require selection of cultivars tolerant to lack of water. More measures increasing drought tolerance are required and application of Si may be one of them.

Evaluation of Si effect on drought tolerance was studied in pot experiments. Two water regimes were applied and cultivation in perlite/or sand with low biologically accessible Si was used. In Si + treatment sodium silicate was applied. Growth parameters and some physiological characteristics of plants in individual treatments were evaluated and compared. The effect of Si on development of some generative organs was also studied. The preliminary data show positive effect of Si treatment on this wheat cultivar.

Keywords: drought tolerance; Si application on plants; *Triticum aestivum* L. cv. Venturero; wheat

References: Hattori *et al.* 2005. Physiologia Plantarum 123, 459-466; Lux et al. 2002.Physiologia Plantarum 115, 87-92

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Effect of Silicon and Potassium on performance of *Sesamia inferens* (Walker) in wheat under field conditions

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ABSTRACT

Pink stem borer (PSB), *Sesamia inferens* (Walker) is an emerging pest of wheat in India due to change in the tillage systems. Earlier PSB has been causing economic damage to rice crop only but recently its damage increasing on wheat and maize crop. It causes "dead hearts" in vegetative stage and "white ears" in reproductive stage. The importance of this insect is increasing in rice-wheat cropping system because of mild winters and reduction in the time gap between harvesting of rice and sowing of wheat crop. The indiscriminate use of insecticides causes pest resurgence and environmental hazards besides increasing the cost of cultivation. Hence, an attempt has been made to study the nutritional (Si and K) basis of induced resistance for the management of PSB in wheat under field conditions. Field experiment was conducted during Rabi 2016-17. The experiment was conducted in Randomised Block Design with twelve treatments (Si and K) replicated thrice. The sources of Si and K were diatomaceous earth for soil Si, silicic acid for foliar Si and potassium chloride for K. The treatment details as follows: T_1-K_{30} + Foliar Si (0 ml/l); T_2-K_{30} + Foliar Si (2 ml/l); T_3-K_{30} + Foliar Si (4 ml/l); T_4-K_{30} + Soil Si (0 kg/ha); T_5-K_{30} + Soil Si (150 kg/ha); T_6-K_{30} + Soil Si (300 kg/ha); T_7-K_{60} + Foliar Si (0 ml/l); T_8-K_{60} + Foliar Si (2 ml/l); T_9-K_{60} + Foliar Si (4 ml/l); T_{10}-K_{60} + Soil Si (0 kg/ha); T_{11}-K_{60} + Soil Si (150 kg/ha); T_{12}-K60 + Soil Si (300 kg/ha). Soil Si was applied as basal along with the fertilizers. Foliar silicic acid was applied for three times at an interval of two weeks. The first spray was given on 21 DAS of wheat seeds. The observations were recorded on % white ear (WE) in each treatment. Experimental results revealed that the minimum % WE damage of 14.00 was observed in T9-K60 + Foliar Si (4 ml/l) which was significantly superior over all treatments followed by T_{12}-K60 + Soil Si (300 kg/ha) with 20.33 % WE. T_5-K_{30} + Soil Si (150 kg/ha) and T_{11}-K60 + Soil Si (150 kg/ha) were next best treatments with 23.00 and 23.67 % WE, respectively with statistically at par with each other. The maximum % WE damage (42.33) was noticed in T_7-K_{60} + Foliar Si (0 ml/l) followed by T_1-K_{30} + Foliar Si (0 ml/l) with 41.67 % WE which were statistically at par with each other. The biochemical analysis of Si in soil and plant samples is in progress.

Keywords: Wheat, *Sesamia*, Silicon, White ear, Stem borer

Fighting Arsenic Toxicity in Rice Grains using Ortho Silicic acid: A Case Study

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ABSTRACT

Arsenic, a heavy metalloid, is finding its route to human food chain through intake of ground water contaminated with arsenic as well as through the consumption of food (grains, vegetables and fruits) grown on areas with high levels of arsenic. It is suspected that 6 million people are exposed to arsenic contaminated ground water (>50 µg/L). Even if we assure the arsenic free safe water for drinking, the question of irrigating soils with arsenic laden groundwater will continue for years to come. Additionally, feeding of rice straw to cattle's provides alternate route of entry of arsenic to the food chain. Arsenic exists in the soil in two forms viz. inorganic and methylated forms. Among these, inorganic arsenic (Arsnite and Arsenate) has been reported to the most toxic for human health and has been classified as Class 1 carcinogenic material. Arsenic content in rice is emerging as important trans boundary concern globally as rice is traded locally, nationally and internationally. Silicon mediated alleviation of heavy metal toxicity is widely accepted in plants. Presence of excess silicic acid (only form of bio available silicon), gives competition for Arsenic uptake and its further translocation due to the involvement of NIP aquaporins sharing the *Lsi1* transporter for Silicon in the uptake pathway.

Present study is aimed to assess the impact of commercial formulation of stabilized Ortho silicic Acid (Privi Silixol), liquid formulation with 1.4 % OSA and granular formulation with 5% OSA, in reducing accumulation of arsenic in rice grains. Application of arsenate (As^{V}, 10 and 50 mg/l) and arsenite (As^{III}, 10 and 25 mg/l) affected plant growth in dose dependant manner. Application of silicon, either foliar or in soil, to arsenic stressed plants alleviated the arsenic induced growth inhibition. Foliar application of the product @ 4 ml/l and 8ml/l water exhibited showed almost similar positive response in plant growth against arsenate and arsenite, while the soil application of OSA was more affective at lower dose of 4 g/l. Significant difference was observed in growth and yield parameters upon As exposure. Results indicated that 25 mg/l As^{III} and 50 mg/l As^{V} drastically decreased the plant growth and subsequently hampered the yield by reducing all attributes (tillers, panicles). The application of OSA formulations along with the arsenic sources improved the growth and yield of rice plants and also resulted in less arsenic accumulation in grains. Dose dependent Arsenic accumulation was observed under different treatments of As^{V} and As^{III}, with As^{V} being more harmful than As^{III}. The accumulation of arsenic in grains was found to be least when the product was applied foliar compared to soil application of the formulation. Interesting the flag leaf exhibited more arsenic levels in the Silicic acid applied plants compared to the control. The observations have been validated following field trials in arsenic rich soils of Punjab and West Bengal. The results confirm that application of Privi Silixol reduces the negative impacts of arsenic contamination not only in terms of economic yields of the crop but also improves the quality of grains. Detailed studies are in progress to understand the underlying mechanism involved in arsenic silicic acid interactions.

Keywords: Antioxidants · Arsenic accumulation · Ortho silicic acid · Rice · Trace element

Silicon nutrition alleviates cadmium and zinc induced toxic responses by modulating proline biosynthesis in mycorrhizal *Cajanus cajan* (L.) Mill sp. genotypes

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ABSTRACT

Cadmium (Cd) and Zinc (Zn) belong to the group IIB of the Periodic Table. Among them, Cd is a non-essential element and is highly toxic for plant growth even at low concentrations. On the other hand, Zn is regarded as essential trace element for normal plant growth at low concentrations but becomes toxic at elevated levels. Role of silicon (Si) amendment in mitigating heavy metal stress has gained importance in the recent years. However, the benefits accrued through Si supplementations have been reported to vary amongst different plant species both at inter and intra specific levels due to their differential capacity for Si uptake. In general, legume species are considered low Si accumulators as most of the Si is taken up passively. Recent reports have indicated high Si content in AM inoculated plants. Present work was aimed to compare the roles of Si and/ or AM - *Rhizophagus irregularis* in modulating plant biomass and grain yield with special reference to their role in proline biosynthesis under Cd (25, 50 mg/kg) and Zn (600, 1000 mg/kg) stress in two *Cajanus cajan* (pigeonpea) genotypes (Tolerant-PUSA 2002, Sensitive-PUSA 991). Plants were subjected to Si (potassium silicate - 300 mg/kg) supplementation alone as well as in combination with *R. irregularis*. Both metals had a negative correlation with root and shoot dry mass with Cd inducing higher toxicity symptoms than Zn. PUSA 991 was more vulnerable to the presence of both metals in the rooting medium and displayed higher negative effects on growth, mycorrhizal colonization as well as productivity when compared to PUSA 2002. Although AM inoculation was more beneficial in improving the overall growth of plants than Si nutrition, the effects of the two treatments varied with relatively higher benefits of Si amendment on shoot biomass while that of AM in improving root biomass. The positive impact of both the treatments could be correlated to their ability in boosting the activities of anabolic enzymes namely glutamate dehydrogenase (GDH) and pyrroline-5-carboxylate synthetase (P-5-CS) responsible for proline biosynthesis along with a decline in proline dehydrogenase (ProDH) activity under both metals. *R. irregularis* was relatively more efficient in reducing metal uptake and modulating proline metabolism when compared with Si treatment in PUSA 2002 which could be correlated to its higher mycorrhizal responsiveness as well Si uptake. Establishment of mycorrhizal symbiosis in Si amended soils was highly beneficial in further restricting metal uptake, increasing Si contents in both roots and shoots along with enhancing proline biosynthesis which ultimately resulted in improved plant growth and yield parameters in a concentration and genotype dependent manner. Thus, the study highlighted the role of proline biosynthetic enzymes as important stress markers for evaluation of metal tolerance (Cd, Zn) in AM inoculated and Si amended soils in pigeonpea genotypes.

Keywords: Cadmium; Pigeonpea; Proline; *Rhizophagus irregularis;* Silicon; Zinc

Effect of Si fertilizers on productivity and quality of rice grown on polluted areas, field tests in the Xiangjiang River Basin

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ABSTRACT

Environmental pollution by heavy metals and metalloids can be a result of the wastes from industry, mining, incineration of garbage, agrochemicals, and watering fields with wastewater. Cadmium and other heavy metals and metalloids accumulate in the products harvested from contaminated fields and make risk for human health. More than 1630 companies and mines whose business is related to heavy metals are located in the Xiangjiang River Basin (Hunan Province, China), which is one of the seven mayor tributaries of the Yangtze River. Over the past few decades many authors reported that Si-rich substances can mitigate a negative influence of heavy metals and metalloids on growth of various plants. For the last 3 years 30 field tests of different Si-rich materials (Si product A, Si product B, diatomite, zeolite, Ca-Si slag, and liquid Si fertilizers) were initiated in the Xiangjiang river basin. Silicon-rich materials were applied in combinations with conventional NPK fertilizers, lime, and gypsum. The Si status and the contents of As and Cd were monitored in the paddy soil-rice systems. The tested Si fertilizers provided 10 to 80 % increases in the rice yield. The plant resistance to diseases and insect attacks was enhanced as well. Usage of Si-rich materials reduced the As and Cd contents in rice grain (by 30 to 70 %) and reduced the mobile forms of pollutants in the soil (by 10 to 50 %). Reducing effect of the tested Si-rich substances on the soil As and Cd mobility was enhanced by their combined application with lime or gypsum. The total root contents of As and Cd in the rice plants were increased by 5 to 30 %, probably due to increasing plant resistance to pollutant toxicity. The following mechanisms of the Si effects on the contaminants behavior in the soil-plant systems were distinguished and investigated: (1) pollutant adsorption on solid Si-rich materials in the soil, (2) interaction between contaminants and monosilicic acid in the soil solution or in the sap of plant tissue, (3) precipitation by monosilicic acid or capsulation by polysilicic acid in the root apoplast and in the stem and leaf symplast, (4) increasing antioxidant enzyme activities and alleviation of the lipid peroxidation in plant, resulting in alleviating pollutant-induced oxidative damages. These investigations are used for elaborating advanced and precision technologies for agriculture and environmental protection.

Session - 4

Sub Theme - V

Role of Silicon in Biotic Stress M-anagement

Keynote

Recent progress in defining the protective role of silicon against plant diseases

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ABSTRACT

Among all the benefits associated with silicon (Si) fertilization, its protective role against fungal diseases in numerous crops is arguably the most commonly described. In spite of the many scientific reports to that effect, controversies and inaccuracies still surround the mode of action by which Si exerts its properties. Many conditions regarding the optimal exploitation of Si in agriculture are still ill-defined or poorly understood. For instance, it appears that the beneficial effects of Si will vary according to the plant species on which it is applied, the form under which it is applied, whether it is applied as a foliar or root fertilizer, and whether the pathogen has a biotrophic phase in its life-cycle. To complicate things further, it is still unclear how Si will contribute *in planta* to fending off fungal infections. Current and future research efforts should therefore converge toward a common objective of defining the reproducible conditions maximizing the benefits of Si so that it can become an integral part of sustainable agricultural practices.

The latest advancements in genomics and high throughput sequencing offer incredible opportunities to better understand Si properties. For instance, the discovery of Si transporters in rice has offered the blueprint to classify a plant's ability to accumulate Si on the basis of the presence or absence of *bona fide* transporters. This makes it possible to determine if Si absorption by plants is directly linked to its efficacy, a correlation that should improve the use of Si. In the same manner, mutant plants deficient or improved in Si absorption represent privileged material to study the effect of Si accumulation on its efficacy, the specificity of Si toward certain pathogens and its mode of action. In this context, a recent study with Arabidopsis plants improved for Si accumulation showed that, while markers of priming and induced resistance were contiguous with Si feeding, the biochemical role of Si remained uncertain, a black box that has long defied scientists. Yet, it appears unlikely that Si, whether assisting against biotic or abiotic stress, would have multiple biochemical functions, given that strictly correlative data have been presented to date. However, new tools in genomics and transcriptomics now allow the exploitation of biological material that was hitherto unavailable to unravel the elusive mode of action of Si. Meeting this challenge will undoubtedly promote a better use of Si for agricultural purposes.

Short Oral

Silica nanoparticles enhances the tolerance of *Panax ginseng* Meyer against the root rot causing fungus, *Ilyonectria mors-panacis* by regulating Sugar Efflux into Apoplast

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ABSTRACT

Panax ginseng Meyer (Korean ginseng) is in the spotlight of Oriental medicine and is proclaimed as the king of medicinal plants owing to its adaptogenic characteristics. It has a perennial life cycle and the transition from vegetative phase to reproductive phase occurs at the third year. Ginsenosides are triterpenoid saponins which are proven to be the major pharmacologically active compounds and their accumulation in roots increases with age. Ginseng root rot is a devastating disease caused by the fungus, *Ilyonectria mors-panacis* that generally attacks younger roots (~2 years), leading to defects in root quality, ginsenoside accumulation and also life cycle of the plant. Hence, there is an imperative need to develop strategies resulting in tolerance against ginseng root rot. The protective role of silicon during pathogen infestation is well documented in other plant systems and a previous study demonstrated that silica nanoparticles are absorbed and accumulated more than the bulk silica in maize. However, the role of silica in ginseng-root rot pathosystem is unknown. In the present study, we evaluated the effect of silica nanoparticles (N-SiO_2) in *Panax ginseng* during *I. mors-panacis* infection. Long term analysis (30 dpi) revealed a striking 50 % reduction in disease severity index upon 1mM and 2mM treatment of N-SiO_2. However, N-SiO_2 did not have any direct antifungal activity against *I. mors-panacis*. Candidate genes and metabolites approach revealed Jasmonic acid (JA) mediated sterol accumulation as one of the key transcriptional reprogramming event orchestrated by N-SiO_2 during the fungal infestation. Moreover, membrane bound sugar efflux transporter, SWEET (Sugars Will Eventually be Exported Transporters) was identified in ginseng and as expected, its expression was suppressed upon N-SiO_2 treatment in root rot pathosystem. Furthermore, the total and reducing sugars in the apoplastic fluid clearly revealed that N-SiO_2 regulates sugar efflux into apoplast. In a nut shell, N-SiO_2 administration induces transcriptional reprogramming in ginseng roots, leading to regulated sugar efflux into apoplast via JA mediated sterol accumulation leading to enhanced tolerance against *I. mors-panacis*. Besides, this is the first report indicating the protective role of silica nanoparticles in ginseng-root rot pathosystem, thereby uncovering novel features of ginseng mineral physiology and at the same time, enabling its usage to overcome root rot.

Keywords: Silica, Phytonanotechnology, *Panax ginseng*, *Ilyonectria mors-panacis*, JA signaling, Phytosterols, Sugar efflux

The enzymatic effect of preharvest silicon applications and postharvest hot water treatments in an attempt to minimize disease development in citrus fruit

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ABSTRACT

Postharvest damage as a result of infection by *Penicillium digitatum* has plagued the citrus industry for decades. Although fungicides are used in an attempt to curb disease, difficulties with accurate application of the fungicides, resistance problems, cost, and objections to fungicide residues by international markets, have all combined to limit the viability of using postharvest fungicides as the sole control strategy. This has become particularly true for the South African citrus industry. In this study, we investigated the effects of preharvest silicon applications to citrus trees, and whether this treatment is able to influence antioxidant production and green mould tolerance in citrus fruit, postharvest. This was coupled with hot water treatment of citrus fruit followed by the application of a biological coating (with a yeast called B13). Citrus trees were treated with two different formulations of silicon as well as well as two control drenches (potassium sulphate, and, water). Fruit from experimental trees were inoculated with spores of *P. digitatum*, and subjected to hot water treatments at 60°C, 62°C and 64°C for 20 sec each. Fruit were left for 24hr, followed by extraction and spectrophotometric analysis of exudates from the fruit peel. Exudates were assayed for the presence of flavonoids, antioxidants and phenolics. Preharvest treatments comprising of either a potassium silicate liquid formulation (KSil-Liq) or potassium silicate granular formulation (KSil-Slow), combined with postharvest hot water treatments, yielded higher concentrations of antioxidants, phenolics and flavonoids (Figures 1a, b, c). Fruit that received only water or potassium sulphate as a preharvest treatment, exhibited significantly lower levels of protective compounds, even after hot water treatments. Furthermore, it appears that the pretreatment of trees alone, is not sufficient to yield significant amounts of protective enzymes (Figures 2a, b, c), without the exposure of fruit to hot water treatments. This could infer that the hot water treatment acts as an auxiliary catalyst to the fertilizer pretreatments. We also found that silicon-based preharvest treatments, combined with postharvest hot water + yeast treatments, conferred greater resistance against green mould in citrus fruit with the percentage protection of fruit ranging from 95-100 %. It has been postulated that silicon uptake primes the plant by enhancing its resistance to biotic and abiotic stresses and that the hot water treatment acts as a second protective trigger which leads to production of pathogenesis-related proteins, oxidative enzymes and phytoalexins which act as the protective armor of the fruit. Most importantly, we were able to find positive correlations between silicon-pretreatments and hot-water postharvest treatments and antioxidant and pathogenesis-related protein expression.

Deciphering the role of silicon in enhancing tomato resistance to bacterial wilt via proteomics and transcriptome approaches

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ABSTRACT

Silicon plays an important role in enhancing plant resistance against soil-borne pathogen such as bacterial wilt caused by *Ralstonia solanacearum,* but the mechanism is not completely understood. In the present study, the role of Si-mediated resistance to bacterial wilt in tomato was explored through proteomics approach and transcriptome sequencing technology. Proteins from the tomato roots with or without Si addition were extracted and identified by two-dimensional gel electrophoresis (2-DE) and liquid chromatography-mass spectrometry (LC-MS/MS). Results showed that Si addition significantly reduced bacterial wilt incidence, 53 protein spots were identified at least two-fold differences in abundance on 2-DE maps under *R. solanacearum* inoculation and/or Si application. Among these proteins, 40 were significantly altered (6 were up-accumulated and 34 were down-accumulated) by *R. solanacearum* inoculation only. And 26 were changed (16 were increased and 10 were decreased) when Si was added to *R. solanacearum*-inoculated tomato plants. More than half of the changed proteins (62 %) were associated with energy/metabolism including glycolytic pathway and TCA cycle. Five proteins were grouped into defense-response, of which four were membrane-associated proteins. Regarding soil microbial community analysis, high-throughput pyrosequencing was used. 16S rDNA gene (V3+V4 region) and internal transcribed spacer region were selected for the analysis of the composition of soil bacterial and fungal communities by Si addition and *R. solanacearum* infection, respectively. The results showed that soil bacterial and fungal diversity index were not significantly changed by Si, but the PCA analysis revealed significant difference in bacterial and fungal community structures between Si and no-Si treatments. Total 39 bacterial operational taxonomic units (OTUs) and eight fungal OTUs were significantly changed by Si addition. Furthermore, the Si-added soil harbored a lower abundance of soil-borne pathogens such as *Pseudomonas*, *Fusarium*, which provide a better survival environment for tomato growth. These findings provide new insights into molecular mechanisms responsible for Si-mediated resistance of tomato against *R. solanacearum*.

Keywords: Silicon;Tomato; *Ralstonia solanacearum*; Soil microbial community; Proteomics; Transcriptome

Improved resistance to the brown planthopper in rice plants amended with silicon and the underlying mechanisms

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ABSTRACT

Silicon (Si) amendment to plants is emerging as a novel approach for pest management. The brown planthopper (BPH), *Nilaparvata lugens* (Stål), is a migratory and destructive sucking insect pest of rice, *Oryza sativa* L. Chemical control is presently the principal management for the insect pest. We tested if Si addition to rice plants can afford resistance to the pest and the possible mechanisms.

With Si addition to potted rice plants at 0.16 (low) and 0.32 (high) g Si/kg soil, silisification of rice stems/sheaths was increased, indicated by both increased Si content and more and larger silica cells. As a result, Si application significantly decreased BPH population growth rates while increased population doubling time, indicating that Si amendment affords enhanced plant resistance to BPH.

Using electric penetration graph (EPG), we recorded the piercing behaviors of BPH on rice plants. It was found that Si amendment extended non-probing event of BPH over that in the control. High Si addition rate prolonged the stylet pathway and the time needed to reach the first phloem puncture, shortened durations of phloem ingestion, and decreased the proportion of individuals that produced sustained phloem ingestion. BPH female feeding on and preference for plants with the high Si addition rate were also reduced. These results indicate that Si amendment, especially at the high rate, impairs BPH feeding and thus may help confer enhanced rice plant resistance to BPH.

Reduced feeding by phloem feeders can result from callose deposition on sieve plats. We show that Si is involved in the modulation of callose deposition. Histological analysis showed that BPH infestation triggered quick and strong callose deposition in Si-amended plants. qRT-PCR analysis revealed that expression of callose synthase gene *OsGSL1* was up-regulated more in the initial stage of BPH infestation, while expression of callose hydrolase gene *Gns5* was up-regulated less in Si-amended than in non-amended infested plants. The dynamic expression levels of *OsGSL1* and *Gns5* in response to BPH infestation in Si-amended plants allows sieve tube occlusions to be maintained more and thus contributes to the reduced feeding by BPH on Si-added plants.

Differential herbivory-induced responses in plants with Si addition or not were also recorded. Si addition suppressed the increase of malondialdehyde concentration while encouraged increase of H_2O_2 concentration in BPH-attacked plants. Higher activities of catalase and superoxide dismutase were recorded in Si-amended than in non-amended BPH-infested plants. BPH infestation activated synthases for secondary metabolites, polyphenol oxidase and pheny-lalanine ammonia-lyase, and â-1,3-glucanase, but the activation was greater in Si-amended than in non-amended plants. These findings demonstrate that Si amendment interacts with BPH infestation to induce stronger plant defense responses, which may be one of the reasons for reduced BPH population performance on Si-amended rice plants.

Taken together, our results reveal that Si amendment to rice plants enhances plant resistance to BPH through reduced feeding, possibly resulted from strengthened physical barrier and increased callosic sieve plates, and stronger induced plant defense responses. Our findings highlight the potential of Si amendment as an alternative for BPH management.

Key words: Silicon; Herbivore; Rice; Plant resistance; Phloem feeder; Piercing behavior

Silicon in rice stem borer management - An overview

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ABSTRACT

Yellow stem borer (YSB), *Scirpophaga incertulas* (Walker) (Lepidoptera: Crambidae), is the most important monophagous pest of rice in all rice growing regions of Asia and South east Asia (Khan et al., 1991) and attacks all stages of the rice crop (Bandong and Litsinger, 2005). Damage by this insect is caused throughout the crop growth stage *i.e.* dead hearts in vegetative stage and white ear heads in reproductive stage and results in yield losses that may vary from 10-90 % (Muralidharan and Pasalu, 2006) depending on stage of the attack. Most of the life cycle is within the plant and the insect is present outside for a very short time making the control of this pest very difficult. Even after repeated application of insecticides, it is still difficult to manage YSB because of its cryptic behavior. Hence, there is always a search for viable alternative strategies to manage this pest without increase in cost of cultivation.

Silicon has been implicated to reduce damage by rice pests. In an endeavour to look for ecofriendly alternatives for pest management, the effect of silicon solubilisers like histidine, lysine, glycine, glutamine and imidazole along with sodium silicate was studied in the rice hybrid DRRH1. The plants were grown in pots and the silicon solubilisers were applied to soil at vegetative phase. Neonate yellow stem borer larvae were released on to the plants @ 10 larvae per pot. Observations on total tillers, dead hearts, white ears and larval survival at harvest was quantified. The results indicated that the deadheart damage, white ear damage and larval survival were significantly low in imidazole and sodium silicate pots as compared to other treatments. Application of glycine, lysine and histidine did not affect the larval survival and were not effective in reducing the damage at the applied dose. Observation on the efficiency of the PSII system revealed that a variation in the response was observed with reference to silicon solubilisers though application of imidazole and sodium silicate gave protection upto a week after infestation.

Evaluation of imidazole in more than ten rice varieties over years both in pot and field studies had consistently reduced the stem borer damage. Application of imidazole twice at two critical stages of crop growth *viz.,* vegetative and booting stage alone and in combination with rice husk ash, an other natural source of silicon had reduced the damage by stem borer. The reduced larval damage could be attributed to both deposition of silicon in the stem region and wearing of larval mandibles. As Si has been proven to affect many other insects, it can be integrated as a viable component in the management of rice pests.

Key words: Yellow Stem borer; silicon solubilisers; rice; damage; imidazole

Silicon increases tolerance against powdery mildew and drought stress in transgenic tomato expressing the Lsi1 gene from wheat

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ABSTRACT

Silicon (Si) is known to provide many benefits to plants, more particularly under stress conditions. The magnitude of observed benefits is seemingly dependent on the ability of a given plant to uptake Si. In this context, tomato is regarded as a poor candidate for Si fertilization because it lacks functional Sitransporters, namely *Lsi1*. In the present study, transgenic tomato (cv. Ailsa Craig) plants expressing a Si-transporter gene from wheat (*TaLsi1*) were produced and tested for Si uptake and tolerance to powdery mildew (*Oidium lycopersici*) and drought stress. Initially, leaves of the transgenic tomato plants treated with Si exhibited severe necrotic symptoms. These symptoms were attributed to the constitutive expression of *Talsi1*. Indeed, when the expression of *TaLsi1* was restricted to the roots through a grafting approach,the necrotic symptoms disappeared completely. Under these conditions, evaluation of Si uptake revealed a two-fold increase in transgenic plants compared to controls. When water stress was imposed by restricting irrigation over seven days, transgenic plants showed a significant reduction in leaf-wilting score. Under drought stress, leaf water potential in the transgenic plants amended with Si was much higher (-0.78 ± 0.13 MPa) than in control plants (-1.09 ± 0.04MPa) amended with Si. In the same manner, grafted plants (transgenic and controls) grown with and without Si were monitored over 20 days for powdery mildew development. In both transgenic and control plants, Si amendments significantly lowered the incidence of powdery mildew, with TaLsi1-transgenic plants showing a nearly complete absence of disease. The present study demonstrates the efficacy of a transgenic approach to improve Si uptake in low-accumulating species. The benefits obtained as a result of increasing Si uptake in plants offer a promising outlook to improve biotic and abiotic stress tolerance in crops ina sustainable manner.

Poster Presentation

Foliar spray of a source of soluble silicon to control asian soybean rust on soybean

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ABSTRACT

Asian soybean rust (ASR), caused by the fungus *Phakopsora pachyrhizi*, is one of the most important foliar diseases affecting soybean production worldwide. This study investigated the efficiency of spraying a new source of soluble silicon on ASR development. The treatments used in this study were: deionized water (control), fungicide (13.3 % epoxiconazole + 5 % pyraclostrobin; 0.5 L/ha; Opera, Basf S.A.), FertiSil (20 g/L; PQ Corporation, Brazil),GiroAgro's Silicon (GASi) (1 L/ha, pH 12; GiroProdutosAgrícolasLtda, Brazil), GASi (1 L/ha, pH 6.5), GASi(2 L/ha, pH 12), GASi(2 L/ha, pH 12) + fungicide.Deionized water, the fungicide as well as the solutions of GAS iand of GASi+ fungicide were sprayed on the adaxial and abaxial leaves of each plant (20 ml per plant) until runoff. Plants at the V4 growth stage were inoculated with a suspension of urediniospores of *P. pachyrhizi* (1.5×10^5 urediniospores/mL) at 24 hours after spray. The ASR severity was evaluated on the first and second leaves of each plant per replication of each treatment at 8, 11, 14, 17 and 20 days after inoculation using a diagrammatic scale. The area under disease progress curve (AUDPC) for each plant per replication of each treatment was calculated using the trapezoidal integration of the ASR progress curves. The AUDPC was significantly reduced by 37.2, 37.4, 60.8, 27.7, 79.9 and 82.1%, respectively, for the treatments FertiSil, GASi(1 L/ha, pH 12), GASi(2 L/ha, pH 12), GASi (1 L/ha, pH 6.5), fungicide and GASi (2 L/ha, pH 12) + fungicide in comparison to the control treatment. The AUDPC was significantly higher by 60.2, 59.7 and 84.4 %, respectively, for the treatments FertiSil, GASi (1 L/ha, pH 12) and GASi(1 L/ha, pH 6.5) in comparison to the treatment GASi(2 L/ha, pH 12). There was no significant difference among the treatments FertiSil, GASi(1 L/ha, pH 12) and GASi(1 L/ha, pH 6.5). It can be concluded that the spray of soybean plants with the GASi, at the rate of 2 L/ha,contributed to reduce the ASR symptoms.This information may be valuable in areas where soybean is grown as a monoculture and where high yielding, but susceptible, cultivars cannot be grown because of the occurrence of severe ASR epidemics.

Keywords: Alternative disease control;Biotrophic pathogen; Fungal disease; Induced resistance, Plant nutrition

Foliar spray of soluble silicon to control blast on rice

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ABSTRACT

Blast, caused by the fungus *Pyricularia oryzae*, is the most important foliar disease affecting rice production worldwide.This study investigated the efficiency of spraying different sources of soluble silicon on blast development.The treatments used were: deionized water (control), Verde AgriTech's Nano Product (VANP) (10 g/L), VANP (30 g/L) and aqueous potassium silicate (APS) (2.1 g/L). Deionized water and the solutions of VANP and APS were sprayed on the leaves of plants (30 ml/ plant) at five days before inoculation with *P. oryzae*. A conidial suspension of *P. oryzae* was sprayed on the adaxial surface of the leaves of plants at 35 days after emergence. After inoculation, plants were kept in the dark in a mist chamber (25 °C) for 24 h. Plants were then transferred to a greenhouse (relative humidity of 80 ± 5 % and temperature of 25 ± 3 °C). The fourth and fifth leaves (from the top to the base) of each plant (per replication for each treatment) were marked and used to evaluate blast severity at 48, 72, 96 and 120 h after inoculation. The area under blast progress curve (AUBPC) for each leaf was computed using the trapezoidal integration of the blast progress curve over time. The foliar Si concentration was significantly high for the treatments VANP (10 g/ L), VANP (30 g/L) and APS (0.12, 0.26 and 0.06 dag/kg, respectively) in comparison to the control treatment (0.02 dag/kg). In comparison to the APS treatment, the foliar Si concentration significantly increased for VANP (10 g/L) and VANP(30 g/L) treatments. The AUBPC was significantly reduced by 57, 74 and 37 %, respectively, for the treatments VANP (10 g/L), VANP (30 g/L) and APS in comparison to the control treatment. The AUBPC was significantly reduced by 32 and 58 %, respectively, for the treatments VANP (10 g/L) and VANP (30 g/L) in comparison to the APS treatment. The AUBPC was significantly reduced by 38 % for VANP (30 g/L) treatment in comparison to VANP (10 g/L) treatment. It can be concluded that the spray of rice plants with VANP (30 g/L) contributed to reduce blast symptoms. This information may be valuable in areas where high yielding, but susceptible, cultivars cannot be grown because of severe blast epidemics.

Keywords: Alternative disease control; Fungal disease; Plant nutrition

Efficacy of foliar application of silicon (OSAB) on powdery mildew (*Oidium neolycopersici*) diseasereduction in tomato

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ABSTRACT

Silicon (Si) is found beneficial in many crops by promoting the growth and development of plants under abiotic and biotic stresses. A pot culture experiment was conducted using susceptible tomato variety ArkaVikasto evaluate the effectiveness of OSAB (silicon source) against powdery mildew disease (*Oidium neolycopersici*) under glasshouse condition at Department of Plant Pathology UAS, GKVK, Bengaluru. Tomato seedlings (20 days old) were transplanted to individual pots containing sterilized soil. The conidial suspension (4×10^5 conidia mL^{-1}) was prepared using sterile water along with Gelatin (0.1 % w/v) as adhesive, and artificially inoculated by spraying on to tomato leaves(at 5 days after transplanting) as a fine mist using an aerosol sprayer.TheOSABwas applied thriceat ten days interval starting from a day before artificial inoculation. The disease severity as Per cent Disease Index (PDI) at seven days interval starting from seven days after inoculation and epidemic components *viz*., number of lesions per plant (14, 21 and 28 days after inoculation-DAI), and number of conidia per lesion (35 DAI) were recorded along with dry weight and silicon content.

The siliconwas applied as foliar application at two concentrations (2 and 4 mL L^{-1}) for control of powdery mildew disease on tomato. The results revealed that, OSAB @ 4 mL L^{-1} recorded lowest powdery mildew disease severity (35.24 PDI) with 55.95 per cent reduction over untreated control (80.00 PDI) whereas, OSAB @ 2 mL L^{-1} recorded powdery mildew disease severity of 59.05 PDI with 26.20 per cent reduction over untreated control at 49 DAI. The OSAB @ 4 mL L^{-1} recorded 7.48 per cent less disease severity over standard fungicide check, Difenoconazole 25% EC @ 0.5 mL L^{-1}(39.09 %) at 49 DAI. The lowest Area Under Disease Progress Curve (AUDPC) was recorded with foliar application of OSAB @ 4 mL L^{-1} (690.13) and 2 mL L^{-1} (1016.63) whereas, untreated control recorded highest AUDPC value of 1873.34. The lowest number of lesions per leaf (64.33) and number of conidia per lesion (6000) was recorded with OSAB @ 4 mL L^{-1} whereas, highest lesions per plant(338.33) and conidia per lesion (35,333.33) was recorded in untreated control. Further, the highest dry weight (16.58 g) and silicon content (1.15 %) in leaf was recorded in foliar application of OSAB @ 4 mL L^{-1}.

The results reveal that, the foliar application of silicon as OSAB directly reduced the disease severity and epidemics components whereas increased the silicon content in leaf. This clearly depicts that, the increased silicon content in tomato leaf conferred the resistance topowdery mildew disease (*Oidium neolycopersici*).The results suggest that, silicon as OSAB may be useful for managing the powdery mildew disease of tomato as an ecofriendly alternative to the fungicides.

Keywords: Silicon, Powdery mildew, tomato, Arka Vikas

Abrasion of midgut epithelial tissues of yellow stem borer larvae upon feeding on silicon treated rice plants

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ABSTRACT

Silicon (Si) is one of the most abundant elements in the earth's crust and plays an important role in conferring plant resistance to a range of abiotic and biotic stresses. Si is known to affect herbivore performance by interfering in feeding due to defacing of mandibles and it is known to activate defence related pathways in crop plants against pathogen infections. No information is available on effect of Si on histology of larval midgut which is the main digestion and absorption part of insect digestive system.An experiment was designed with five treatments of different sources of Si and four replications to study the effect of Si on histology of midgut tissues of yellow stem borer in BPT 5204 ricevariety at ICAR-IIRR, Hyderabad. The treatments details as follows: T1-Rice husk ash (RHA) @ 85 mg of Si/kg of soil; T2-Imidazole @ 65 mg of Si/kg of soil; T3-RHA+ Imidazole (once) @ 85+65 mg of Si/kg of soil; T4-RHA+Imidazole (twice) @ 85+65 mg of Si/kg of soil; T5-Untreated control. All the treatments were applied to pots planted with rice plants @ 5 plants per pot at 30 days after transplanting. Two neonate larvae per plant were released at seven days after first treatment imposition. Second dose was applied at booting stage in T4 treatment. Thirty days after larval release, larvae were recovered from all the treatments by destructive sampling of plants and stored in 70 % ethanol. Midgut portion of larvae were separated by dissecting out the larval cuticle. Microtomy studies were carried out to study the larval midgut histology and slides with microtome sections were photographed in microscope fitted with camera. Microtome sections of midgut tissues revealed that Peritrophic membrane was completely detached and destructed in T4-RHA+Imidazole (twice) treatment. The cellular granules were discharged due to rupturing of columnar cells. Disorganization of epithelial cells was noticed. In T3-RHA+Imidazole (once) treatment, upper part of epithelium was completely detached from remaining part due to abrasion in the midgut sections of the larvae. The peritrophic membrane was completely ruptured and high vacuolation was observed in midgut sections of larvae recovered from T2-Imidazole treated plants. In contrast to Si treatments, larval midgut sections from untreated control treatments showed compact columnar cells, intact peritrophic membrane and no vacuolation.

Keywords: Midgut; Stem borer; Silicon; Peritrophic membrane; rice

Influence of silicon on purple blotch disease (Alternaria porri (Ellis) Cif.) in onion (Allium cepa L.)

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ABSTRACT

Influence of silicon on incidence and severity of purple blotch disease in onion was assessed by conducting field experiments at College of Horticulture Bengaluru. Silicon was applied to soil at the time of planting in the form diatomaceous earth or as foliar spray of soluble silicic acid to the plants of two varieties of onion *viz.* Bellary Red (Highly susceptible) and Arka Kalyan (moderately resistant). In both the varieties, incidence and severity of disease was least in treatment receiving two sprays of silicic acid @ 4 ml L^{-1} which was superior to standard check (3 sprays of mancozeb @ 0.25 %) or other treatments of silicon followed by soil application of silicon @ 300 kg ha^{-1} . Silicic acid spray @ 4 ml L^{-1} reduced the disease incidence and severity by 34.88 and 28.93 per cent respectively in Bellary Red variety whereas in Arka Kalyan variety it was reduced by 44.32 and 45.72 per cent respectively over untreated control. Further, average bulb weight (Arka Kalyan - 58.33 g, Bellary Red -63.40 g) and total bulb yield (Arka Kalyan- 31.61 t ha^{-1}, Bellary Red- 37.46 t ha^{-1}) were also significantly higher with foliar application of silicic acid @ 4 ml L^{-1} over all other treatments. Hence, silicon application could be used as one of the ecofriendly strategies of purple blotch disease management in onion.

Efficacy of foliar application of silicic acid on yellow mite *Oligonychus sacchari* McGregor (Acari: Tetranychidae) on two sugarcane commercial varieties

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ABSTRACT

Sugarcane is grown extensively throughout the world including more than 100 thousand hectares in Khuzestan province, the principal area of sugarcane production in Iran. Sugarcane (inter specific hybrids of *Saccharum*) is a strategically important cash crop that has economic and social impact in many countries. As a monoculture system, sugarcane is sensitive to a wide range of biotic stresses including insect herbivores and pathogens. Sugarcane mite *Oligonychus sacchari*is one of the most detrimental arthropod pest associate with sugarcane during summer and occurs during late spring to mid-summer, which its activity begins from grass weeds and then transmitted to sugarcane fields. Affected leaves will become discoloration and in heavy infestation whole plant will dry. Under field conditions control of this pest is mainly based on chemical pesticides and cultural practices. Another strategy proposed for controlling sugarcane pests is the application of silicic acid as a biostimulant component of an integrated crop management program for alleviating many biotic and abiotic stressors.Direct effects include inhibiting pest's growth, development, and reproduction. Experiments were carried out during 2014-2015 and 2015-2016 at Salman Farsi Agro-industry Farms (48°35'E, 31°8'S), Ahvaz-Iran. A complete block design with four blocks was used. Each experimental plot consisted of four rows, 10 meter long and 1.8 meter spaced (between two furrows) in different points of field (54 m^2 for each plot). The two varieties (CP57-614 and CP48-103) were treated silicic acid as foliar application. Five treatments including one spray (0.5 lit/ha), two spray (0.5 and 1 lit/ha 3 weeks after spray 1), three spray (0.5, 1 and 1 lit/ha 4 weeks after spray 2), four spray (0.5, 1, 1 and 1 lit/ha 4 weeks after spray 3) and control were applied. In each plot, fifteen leaves were selected at random from bottom, mid and top of plant and number of living mites and dry leaves were recorded. Samples were collected 7, 14, 21 and 28 days after the forth application of silicic acid. The results showed that all treatments had significant reduction in mite population and leaf dryness versus control. Among different treatments of silicic acid, four application of silicic acid was more efficient than other treatments on mite damage and leaf dryness. It shows that silicic acid is a promising product for management of mite damage and can be incorporated with other management strategies in sugarcane IPM.

Keywords: Silicic acid; Sugarcane IPM; *Oligonychus sacchari*; Varieties; Management

Effectiveness of silicon application on mycotoxins reduction in maize

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ABSTRACT

Silicon is the second most abundant element in the Earth crust. It's beneficial role in plant growth was discovered years ago but mostly using soil application of solid compounds. INTERMAG R&D team developed technology of liquid product (OPTYSIL) manufacturing for foliar application. OPTYSIL induces resistance of plants to stress and supports the natural defense system. Cell walls become more resistant to enzymes produced by pathogens. Mycotoxins in maize are poisonous compounds produced mainly by Fusarium fungi. They have a huge impact on economics by causing loses in harvested crops making them useless for food and feed production.

The aim of this work was to evaluate impact of liquid silicon application on leaf onmycotoxins reduction on maize kernels. The effect of the application of liquid silicon based fertilizer OPTYSIL (Si) on toxins reduction was conducted in Department of Mycology of Institute of Plant Protection - National Research Institute.

Field plots were sprayed with 3 different dosages of OPTYSIL – 0.5; 1.0 and 2 liters per hectare. Sprays were done three times at BBCH 14, BBCH 17 and BBCH 19/ 39. 50 grams samples of kernels were collected from each plot, milled and assessed for content of deoxynivalenol (DON) and zearalenon (ZEA). Immunoenzymatic assay elisa, Veratox HS test were used for detection and measuring amount of DON and ZEA. On the final part of each tests photometer Stat 303 Plus was used for measuring color of sample and amount of toxins.

Amount of mycotoxin contamination in different plots was highest on check – 2710 ppb of DON and 73.4 ppb of ZEA. We found clear dose response on DON contamination which resulted 25.5; 30.6 and 47.6 ppb with the rate of 2, 1 and 0,5 l of OPTYSIL respectively. Reduction of ZEA was even higher and resulted 2.7; 1.6 and 5.8 ppb for corresponding rates.

Silicon based liquid product OPTYSIL have significant efficacy in mycotoxin reduction and should be applied on maize crops as a standard spray.

Session - 5

Sub Theme - VI

Silicon Fertilizers on Performance of Plants

Short Oral

Effect of foliar fertilization with silicon on selected physiological parameters, yield and technological quality of sugar beet

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ABSTRACT

In the field experiment conducted in Sahryñ (50° 41 'N and 23° 46' E, Poland), in the years 2015-2016 foliar fertilizer Optysil (94 g Si in 1 dm^3) was applied in dose of 0.5 dm^3/ha in three combination: once – (at 6 leaves - BBCH 16); twice (at BBCH 16 and than 7 days later); three times (at BBCH 16, than 7 and 14 days later). In every application 250 dm^3/ha of water was used. Effects of silicon nutrition were compared with control (without Si foliar application). There was a strong shortage of water during the sugar beet growing period in both years. Relative to the water needs of sugar beet from June to the end of August, the rainfall deficit was on average 54 % and 27 %, respectively in 2015 and 2016.

The hypothesis was that silicon limits the effects of drought, and the more number of sprays has a positive effect on yielding.

Parameters like photosynthetic active radiation (PAR), leaf area index (LAI) and normalized difference vegetation index (NDVI) were measured four times: the day before each application and 7 days after the third one. Measurements of NDVI were made by Green Seeker Hand held (Trimble, USA), PAR and LAI were measured by using an Accu Parceptometer (Decagon Devices, USA).

Foliar application of silicon improved significantly the LAI value and PAR absorption. Similarly foliar nutrition of Si resulted in the increase in root yield of 7.1-18.9 %, biological sugar yield of 7.1-17.0 %, and technological sugar yield of 6.1-14.1 % compared to the control. It had no significant effect on sugar and sodium content in roots, but significantly increased the content of amino-á-N and potassium. The best results were obtained after three times silicon spray.

Table 1. Effect of silicon foliar fertilization on yield and technological quality of sugar beet (means for 2015-2016)

Parameter/Combination	Control	1 x 47 g Si/ha	2 x 47 g Si/ha	3 x 47 g Si/ha
Root yield, t/ha	56.5 a	60.5 ab	62.6 ab	67.2 b
Biological sugar yield, t/ha	11.2 a	12.0 ab	12.2 ab	13.1 b
Technological sugar yield, t/ha	9.9 a	10.5 ab	10.6 ab	11.3b
Sugar content, %	19.8 a	19.8 a	19.4 a	19.5 a
amino-α-N content, mmol/kg	34.2 a	41.4 b	45.1 b	45.0 b
K content, mmol/kg	32.7 a	35.6 b	37.21 b	36.4 b
Na content, mmol/kg	1.99 a	2.03 a	2.20 a	2.44 a

The same letters in rows indicate no significant differences (at 0.05 probability level)

Keywords: Foliar fertilization; LAI; NDVI; Silicon; Sugar beet

Potential of Armurox®, a soluble silicon and peptides biostimulant, as a foliar source of silicon in wheat

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ABSTRACT

The benefits of silicon fertilization have been gaining recognition in many crop production systems, specifically those in the grass family. Wheat (*Triticum aestivum*) is the fourth-most produced grain crop worldwide and a high silicon accumulator plant species. Because of the established benefits of silicon fertilization in crop production and known limitations of current application methods for soil-applied silicon amendments, there is a growing interest in using alternative liquid silicon formulations, as they are easier to handle and apply in large-scale crop production systems. Armurox® is a product containing soluble silicon and specific peptide compounds formulated by Bioiberica to promote silicon absorption by leaf surfaces. The overall goal of this study was to evaluate the potential of Armurox as foliar source of silicon and determine production and disease protection benefits in wheat. To reach these objectives, a two-year field study was conducted in Baton Rouge and Winnsboro, Louisiana, during 2015 and 2016, comparing a granular-silicon source of Si (slag; $CaSiO_3$, 12 % Si) and the liquid-silicon source (Armurox; 3.7 % Si, 4 % peptides). All treatments were replicated four times and arranged in a randomized complete block design. The effect of Si fertilization was evaluated using yield, silicon uptake, lodging rate, and leaf rust severity as metrics. Even though the amount of Si per hectare applied was nearly one thousand times less with foliar Armurox treatment (0.28Kg Si/Ha) than with granular Si (250 Kg Si/Ha), the scanning electron microscopy and electron dispersive x-ray analysis showed higher number of silicon bodies in both, the Armurox (0.77 % Si) and slag (0.91 % Si) treatments, compared to the untreated control (0.58 % Si). Similar results were observed for % Si content and Si uptake in wheat biomass and straw. When compared to the control, Armurox applied at the highest rate (4000 ml ha^{-1}) in 2015 for both locations significantly raised straw Si content from 1.86 % to 2.05 %, although the amount of Si applied was low, which suggests that applying a bioavailable form of Si (monosilicic acid and peptides) might be more important than the amount of Si applied.In reference to the control, Armurox treatments significantly reduced lodging by 43 % in 2015 in Winnsboro and leaf rust by 40 % for the first rating in April for both years in Winnsboro. Armurox applications early in the season resulted innumerically increased yields (12.5 % on average) for both locations, despite the effects of two consecutive years of excessive rainfall received in Louisiana before harvesting. In conclusion, Armurox may have played a role in improving management of silicon fertilization and overall wheat performance under field production conditions.

Keywords: Soluble silicon-source, Wheat productivity, Rust protection, Anti-lodging effect, Foliar silicon

New generation silicon fertilizers - greenhouse and field tests

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ABSTRACT

The efficiency of traditional Si-rich soil amendments (zeolite, diatomaceous earth, slag, *etc.*) is low, while price for such materials, except some types of slags, is high. Improving the efficiency of Si-based fertilizers is crucial for their wide practical implementation. New generation Si fertilizers should meet the crops demand for plant available Si in the form of monosilicic acid during their major growth period. The effects of two Si fertilizers (Si product B and Si product A) on the soil-plant system were tested in comparison with diatomite, zeolite, and Ca-Si slag from metal industry. Si product B and Si product A were high in monosilicic acid (100-400 $mgkg^{-1}$ of Si) and high in acid-extractable Si (200-1500 mg kg^{-1}). In traditional Si soil amendments, the water-soluble Si usually range between 20 and 80 mg kg^{-1} of Si as monosilicic acid and acid-soluble Si forms range from 100 to 800 mg kg^{-1} of Si. In greenhouse test, barley, corn, pea, and sunflower were subjected to salt and heavy metal toxicities as abiotic stresses. Both types of Si fertilizers had a high influence on the plant productivity. Si product B and Si product A significantly enhanced the biomass of cultivated plants (by 5-30 % for unstressed plants and by 50-125 % for salt- or heavy metal-stressed plants) and reduced the leaf pollutants. The tested Si fertilizers promoted enhancing natural plant immune system via stimulation or reinforcement of antioxidant system and decreasing the intensity of destructive processes in the plant cells under stress. Several field tests were conducted on rice in the Hunan Province, China. Si product B and Si product A considerably increased rice yield (by 5 to 100 %) and improved the grain quality via reducing the mobility of As, Cd in the soil by 25 to 50% and their accumulation by plants by 30 to 70 %. Based on the data obtained, the economic benefits of the tested Si fertilizers were evaluated. Si product B and Si product A demonstrated the high potential as commercial products in different countries.

Foliar application of pH neutral silicon product and its effect on abiotic stress mitigation in field crops.

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ABSTRACT

Silicon is the second most abundant element in the earth crust. It's beneficial role in plant growth was discovered years ago but mostly using soil application of solid compounds. However there are also some liquid foliar applied silicon products which are mostly used to mitigate the stress.

Among commercially available silicon products used in agriculture there are products either alkali pH or acidic pH. Acidic silicon products contains relatively low content of Si whilst the alkali one are not well miscible with other agrochemicals. Both are not easy to handle due to their pH level.

The reason for stability of silcon products at either low or high pH is related with chemistry of silicon. According to Ailer probability of orthosilicic acid (H_4SiO_4) to undergo polymerization at pH 1-2 or pH above 10.5 is very low. At the pH from 2-5 and 8-10.5 the orthosilicic acid makes oligo and polymeric species much easier. However at pH 5-8 orthosilicic acid converts to polymeric species and forms gel aggregates very quickly.

INTERMAG R&D team managed to developed stable liquid formulation of silicon product (OPTYSIL) for foliar application which pH is neutral.

It is already known that OPTYSIL induces resistance of plants to biotic stress and supports the natural defense system. In order to study the effect of Optysil on abiotic stress this work has been carried out. The aim of this study was to evaluate effect of foliar application of liquid pH neutral silicon product on plant growth and photosynthetic processes during abiotic stress.

Effect of water stress (drought and flooding) and coldness stress mitigation was evaluated in **Institute of Plant Physiology, Polish Academy of Sciences.**

In this study OPTYSIL was applied on leaves on winter wheat (*Triticum aestivum* L) and maize. Trials were conducted at controlled conditions in climate chamber.

During the trials the following data were measured: plant length, relative water content (*RWC*), water use efficiency (*WUE*), chlorophyll content (*SPAD*), osmotic potential and electrolyte leakage (*EL*). Additionally in order to evaluate whether or not plant stress affects photosystem the net *photosynthetic* rate *Fn* and the maximum quantum yield *Fv/Fm* measurements were also recorded.

The OPTYSIL was applied foliar at 0.5 l/ha before the stress occurred. Obtained results shows that compared to the control application of Optysil protects from intensive plant growth slow down during the occurred stresses. It also protects from plant water loss during the drought and decrease of transpiration. It has been proved that application of OPTYSIL protects from decrease of net *photosynthetic* rate.

During the flooding, application of Optysil helped to protect the plant cytoplasmic membrane from being damaged.

MOSA: stabilized monosilicic acid, a new window of opportunities for efficient and effective supplementation of Silicon by root or leaf

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ABSTRACT

Silicon is the second most abundant element in the earth's crust. It is found in varying concentrations in virtually all living tissue, plants, animals, and humans. Silicon is usually found as silicon dioxide (SiO_2) in concentrations of 50-70 % in most soils. Because of this prevalence, scientists generally ignored silicon's effects until recently. Though silicon exists in high concentrations in most soils, the majority is unavailable to plants and has to be converted by microbes (and possibly natural chemical reactions) into silicic acid ($SiOH_4$). Monosilicic acid (=MOSA) is the only bioavailable form of silicon. Analysis of the elementary Silicon in MOSA show concentrations between 0.8-1.2 % of Si. Although this concentration seems low compared to silicates (Si content 20-30 %) the Si in MOSA is under monomeric form, contrary to silicates where the Si is under SiO2 form. The Silicomolybdate acid yellow method shows that only monosilicic acid reacts with a molybdenum compound to form a yellow liquid at low pH. The silicon in MOSA reacts to a yellow liquid which indicates the presence of monosilicic acid. Silicon is responsible for strengthening cell walls, creating thicker stems and stalks, enhancing uptake of other nutrients and increasing the plant's natural resistance to pests and disease. As a monomer (single molecule) silicic acid is easily absorbed by the roots (or the leaves) and quickly transported throughout the plant via the xylem. During the transport through the xylem, monomeric silicic acid is polymerized (long chains of molecules) and then deposited in the outer cuticle of the cell wall. This layer of silicon forms a rigid structure on the outside of the cell. This layer is responsible for the many commonly known structural and pest resistant benefits of silicon. Crops grown with an ideal supply of monosilicic acid consistently demonstrate these effects: stronger and thicker stems, tighter node spacing, more lateral branching, increased Brix level, firmer fruits, higher nutritional value, fewer pest and fungal occurrences and absence of nutrient deficiencies. Foliar feeding is an excellent option for large-scale outdoor growing environments where root application is not cost-effective or possible. Foliar feeding delivers the monosilicic acid directly to the leaf and guarantees a quick transport of Silicon throughout the plant. Many studies show that foliar application, combined with other nutrients and crop protection products, enhances the overall effectiveness and minimizes chemical residues. Depending on type of crop and application, Agro-solutions developed foliar fertilizers and bio-stimulants based on monosilicic acid (MOSA) under the range of SILIFORCE. Formulas are based on the synergy with micro-elements and amino-acids. Products are manufactured conform GMP methods and ingredients are of pharmaceutical grade or foodgrade. MOSA is non-toxic, eco-friendly and can be used in organic farming. MOSA and SILIFORCE formulations are key elements in IPM programs and sustainable agriculture.

Keywords: Silicon, bioavailable, monosilicic acid, foliar, mineralization, plant health, crop quality

Efficacy of Silica in increasing yields in Morocco

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ABSTRACT

Intensive agriculture commonly depletes soil fertility. The continuous export of silicon from the farming system eventually leads to decreases in crop yield and increased crop susceptibility to diseases if the plant available silicon is not replaced. The beneficial effects of Silicon on plant growth and yields have been repeatedly demonstrated in the literature and are attributed to increased plant resistance to abiotic and biotic stresses.

This field-based investigation in Morocco demonstrates responses of a variety of crops to a natural Silicon source and makes recommendations for including Silicon fertilisers as a standard practice in crop production.

Over 30 field trials in 15 different crops were conducted in Morocco with independent research organisations from 2014 to the present. Most the crops trialed were dicotyledenous and all responded positively to applications of Silicon. Thirteen sugarbeet trials were conducted in Morocco, with varying application rates and timing of a Silicon Fertiliser.

This trial program included a replicated trial in sugar beet that was conducted in Tadla in Morocco. Silica was applied at rates of 150 Kg/ha; 200 Kg/ha; 250 kg/ha and 300 kg/ha in addition to the standard fertilization usually applied to sugar beet and a control which received only the standard fertilization. Compared to the control, sugar beet yields were numerically increased by up to 40 %. The 250 kg/ha treatment allowed a statistically significant yield increase of 4.8 t/ ha and an additional gross margin for the grower.

Keys Words: Silica; Silicon; Agrisilica; Morocco; sugar beet; yield

Session - 6

Sub Theme - VII

Influence of Silicon on Plant Growth and Development

Keynote

Silicic acid and silica biology studied in a low - silicon sorghum mutant

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ABSTRACT

Silicon is absorbed by plant roots as silicic acid. The mineral is moved with the water transpiration stream to the shoot, where it is polymerized into hydrated silica. Both silicic acid and silica have beneficial influence on plants, which is revealed when under stress. Since silica is omnipresent in soil, glassware, dust etc., its effect is sometimes elusive. To eliminate silica in plant tissues we took advantage of a sorghum mutant plant, defective in silicon uptake. We identified no significant variations in growth and development between the low-silicon and wild type plants. However, the mutant plants were more sensitive to drought stress. We found that under benign conditions leaves of the low-silicon plants contained lower concentration of cytokinin. The cytokinin low level could be restored in detached leaves that were exposed to silicic acid for 3 hours. We thus suggest that the reduction in silicic acid led to a reduction in the cytokinin level, which turned the mutant plants more sensitive to environmental stresses. While silicic acid seems to interact with the plant biochemistry, it eventually polymerized into hydrated silica. Leaf-silica first forms in epidermal hairs and silica cells, and later on impregnates cell walls. In young leaves, silica cells actively deposit the mineral only while being metabolically viable. Our results show that young leaves of the low silicon mutant are capable of depositing silica, if silicic acid is supplied to them. However, the silica cells are programmed to die and thus older mutant leaves will not accumulate the mineral in the silica cells. The formation of silica in the apoplast links it to cell walls. Further research is required to examine whether the polymerized silica has physiological roles, in addition to its structural roles.

Keywords: Cytokinin; Drought tolerance; Silica cells; Silicification

Effects of silicate amendment on environment and yield in Southeast Asia

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ABSTRACT

Degraded paddy soil lost iron oxide by reducing and leaching to become strongly reduced conditions during rice growing season, thus problem soil with lower rice yield. Therefore iron oxide-rich materials, such as slug or mountain soil, were applied in Japan as silicate amendment since 1940's. On the other hand methane, a strong greenhouse gas is also produced in paddy soil under strongly reduced conditions and emitted to the atmosphere, as 60 MtC annually as global scale (Inubushi et al., 1997). However, application of silicate amendment has not been tested to reduce methane emission in Southeast Asian paddy fields where dominant rice producing area, although promising studies were already reported in Japan (Furukawa and Inubushi, 2004) and Korea (Ali et al., 2008). In this paper, we first evaluated methane production potentials by incubation method and correlated with soil chemical properties such as available Fe, Si and organic matter contents. Then we measured methane emission and yield in7 Vietnam paddy sites in relation to available Si.

Totally 23 kinds of typical paddy soils were taken from Indonesia, Philippines, Thailand and Vietnam and incubated anaerobically in test tubes for 8 weeks at 30°C. Produced methane and CO_2 were quantified by FID and TCD-GC method, respectively, then correlated with soil C and N, mineralized N (MinN), and available Fe, Si contents. Methane emission was determined by chamber method (Inubushi et al., 1997) in the field amended with or without iron-fertilizer (steel making slag fertilizer). Rice yield was also investigated at harvest. Available Fe was determined by Kumada and Asami (1958). Available Fe Si was determined by incubation method (JSSSPN, 1997).

Methane production potentials were positively correlated with balance of mineralizable N contents and available Fe contents. Methane / CO_2 production was also positively correlated with ratio of mineralizable N contents and ferrous contents, which indicated that Takai theory (Takai, 1980) is also useful and soil Fe is important to estimate methane production in Southeast Asian paddy soils.

Methane emission decreased in 11 of 17 crop seasons in Vietnam paddy fields by amendment of iron-fertilizer. Yield increased in 14 of 17 crop seasons especially where the original Si level was low (Figure). Therefore iron-fertilizer is probably effective on yield increase and methane suppression in Southeast Asian paddy fields, especially original Fe and Si levels are low.

Key words: greenhouse gas, silicate fertilizer, steel making slag, rice yield, Takai theory

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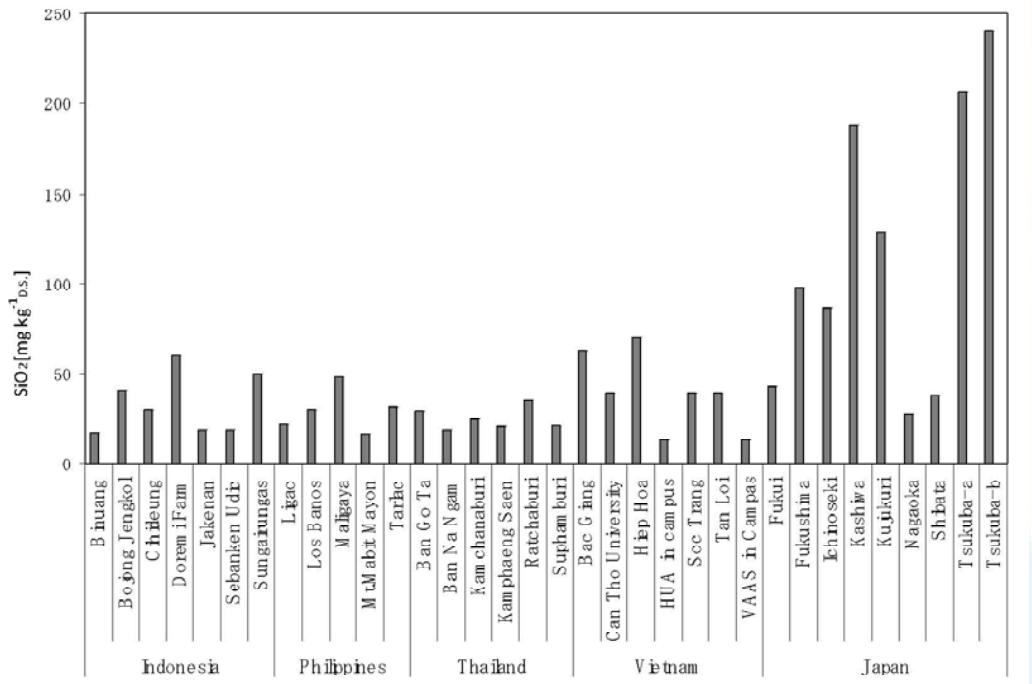

Figure. Available SiO_2 in soil samples.

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Short Oral

Silicification of *Cocos nucifera* and *Phoenix dactylifera*

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ABSTRACT

Silica deposition and its role have been studied intensively in many important crop species in the last years. The focus is mainly on cereals with high Si content (rice, sorghum, also maize and other). Interesting results were accumulated also about the positive role of Si in some other crops with lower Si content (tomato and several Cucurbitaceae). The deposition and role of Si in palms have been studied relatively rarely. The majority of published papers focus on silicification of stems and leaves. The data show deposition of Si in connection with vascular and mechanical tissues.

In the present study we have studied the deposition of Si mainly in two economically important species: coconut palm (*Cocos nucifera*) and date palm (*Phoenix dactylifera*) with the special focus on the roots. Anatomical structure of mature palm roots is specific by formation of thick hypodermal sclerified tissue and sclerenchyma fibres in the cortex. Endodermis matures in three ontogenetic stages: Casparian bands (stage I), suberin lamellae (stage II) and in stage III thick tertiary walls are deposited. Central cylinder of mature roots is also heavily lignified and sclerified. These characteristics are connected with their importance for mechanical strength of roots, which lack secondary thickening and must nevertheless anchor the tall plant in the soil. Mechanical strength of above ground plant parts – stems and leaves - are also very important in these large species. Deposition of Si in individual tissues was analysed by SEM coupled with X-ray microanalysis. Total Si concentration in roots and leaves was also analysed and compared. The data show considerable variation of Si deposition in individual organs, in some cases reaching almost 2 % of the dry weight.

Keywords: coconut palm; date palm; root; shoot; leaf; Si deposition; X-ray microanalysis

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The critical silicon dose in seedling root-dip method in acid soils dependent on rice cultivar and soil type

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ABSTRACT

Seedling root dip in soil:water slurry amended with nutrient element prior to transplantation of crops in main field is increasingly recognized as efficient rhizosphere based approach for management of plant nutrition in problematic acid soils for sustaining low input agriculture. Silicon (Si), the beneficial element of rice is quite expensive for soil application which is not affordable by the resource poor farmers practicing low-input agriculture in acid soil region. Therefore, seedling root-dip in silicon amended soil:water slurry before transplantation of rice seedlings on main field may be adopted for management on Si in rice crop. This study reported that the critical doses of Si in soil:water slurry for three rice types (Hybrid rice variety: Arize 6444, high yielding rice variety: Ranjit, and traditional rice cultivar: Mendri) in two common acid soils (i.e. sandy clay loam, pH 4.98 and clay loam, pH 4.52) prevalent in the northeastern region of India from an incubation experiment. In this incubation experiment, the graded dose of Si (applied as $Na_2O_3Si.9H_2O$) in soil:water slurry was ranged from 0 to 400 mg kg^{-1} soil at an interval of 50 ppm. The incubation duration for seedling root dip was 10 h. After incubation, the Si content and uptake in rice seedling biomass were determined and derived the relative Si uptake for determining the critical Si dose using Cate and Nelson approach (1965). The critical doses of Si in Si amended soil:water slurry were 225 mg kg^{-1} soil for traditional and HYV rice and 275 mg kg^{-1} for Hybrid rice in sandy clay loam and 175, 225 and 325 mg kg^{-1} soil for traditional, HYV and Hybrid rice, respectively in clay loam. The content and uptake of Si in seedling biomass (dry weight basis) upon root-dip was higher in clay loam than the sandy clay loam soil for HYV and Hybrid rice; whereas, it was reverse for traditional rice. The uptake of Si in seedling biomass (dry weight basis) was increased due to seedling root dip in Si amended soil:water slurry over no Si amendment and the increase of Si uptake was in the order Traditional rice (42.3 %) > Hybrid rice (30 %) > HYV rice (27.2 %) in sandy clay loam soil; whereas, in clay loam soil the uptake of Si in seedling biomass was increased in the order of Hybrid rice (57.9 %) > HYV rice (50.2 %) > Traditional rice (27.7 %). In conclusion, it was established that the critical doses of Si for amending soil:water slurry was dependent on rice cultivar type and soil type. The Si nutrition in rice may be improved through seedling root-dip method.

Keywords: Silicon nutrition; Relative Si uptake; Hybrid rice; High yielding rice; Traditional rice

Bioavailability of silicon by silicate solublizing micro-organisms for increasing yield and quality of Sugarcane

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ABSTRACT

Silicon (Si) is the second most abundant mineral element in soil and considered as functional element because it is presumably not essential for plant growth and developments. Plants absorb Si exclusively as monosilicic acid i.e. orthosilicic acid (H_2SiO_4) and is deposited in the form of silica gel or as amorphous $SiO_2 \cdot nH_2O$ in cell walls and intercellular spaces of root and leaf cell. Silicon is also found in the form of colloidal silicic acid or organo silicone compounds in plant tissues and under biotic and/or abiotic stresses in sugarcane. Silicon plays many functions like it increases resistance to lodging, drought and dry matter accumulation in crops. It plays a crucial role in Graminaceous crops like rice, barley, sugarcane etc. Silicon deficiency is observed due to unavailability of silicon to plant in readily available form. There are many micro-organisms having capacity of silicon solublization in soil in nature, but they differ in degree of solublization. Duff and Webley in 1959 reported that the transformation of silica into monomeric silica (Silicic acid) by *Proteus mirabilis*, *Bacillus caldolytics* and some *Pseudomonas*. Muralikannan (1996) reported that several silicon solublizing bacteria shifts the pH of the medium to alkalinity indicating that not only acids but also alkali production cause silicon solublization. In present studies it was observed that in Acid Alkali assay studies the results coincide with the results of previous work done by Muralikannan (1996). An attempt was made for isolation, identification and screening of bacteria having capacity of silicate solublization from different agro climatic zones. Soil incubation studies were carried out with and without different source of silicon and SSB for testing of efficiency. The common growth media for all isolated SSB strains were designed and formulated by using different cell growth boosters and cell protectants to increase its shelf life. The most efficient strains of bacteria were selected for development of consortium of liquid SSB bioinoculant. The Silicon Solubilizing Bacterial (SSB) bioinoculant was prepared as a unique agro-product for fulfilling the hidden hunger of silicon of crop plants. Further this bioinoculants was used for field level studies. A field study was carried out for three consecutive years. To study effect of application of silicate solublizing bacterial bioinoculant with different sources of silicon on cane and sugar yield It revealed that, application of silicon applied through bagasse ash along with silicate solublizing bacteria @ 2.5 lit /ha gave maximum cane yield 144.33 t/ha and sugar yield 21.17 t/ha with as compared to control. Thus application of enriched compost (@20 t/ha) coupled with bagasse ash (@1.5 t/ha) and consortium of Silicate Solublizing Bacterial (SSB) liquid bioinoculant @ 2.5 L/ha at the time of planting is recommended for higher cane and sugar yield.

Keywords: Sugarcane, Silicon, Silicon solublizing bacteria, Solublization

Si fertilizers impact on greenhouse gas emission

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ABSTRACT

Greenhouse gas (GHG) emissions pose a global weather problem. Agriculture is considered to be the world's second-largest emitter, after the energy sector. The reduction of GHG emissions has thus become one of the primary focuses of environmental programs in countries all over the world. Some politics and scientists suggest to reduce our overall consumption of animal products and reduce active plant cultivation (especially rice growing) by making more climate-friendly food choices. Their suggestions are based on the data, which shows that the intensive agricultural activity accelerates organic matter degradation in the soil, thus resulting in transferring carbon from soil to CO_2 in atmosphere, and that intensive application of the N fertilizers (urea, manure, etc.) provokes denitrification process, which accelerates the N_2O emission. However, such action will dramatically reduce the food safety in many countries. One of possible ways to mitigate the problem is silicon (Si) fertilization. Convincing scientific data is available which shows that application of the Si fertilizers could reduce both the methane and N_2O emissions. The methane and N_2O emissions from the soil are regulated by microbial population and a number of factors affect these processes: soil moisture, oxygen concentration, mineral N, available C, soil texture, pH and temperature, granulometric composition and others. Periodical flooding paddy soils activates N_2O emission. Literature data demonstrated that application of active forms of Si to flooded soil in the climatic chamber provide the N_2O emission reduction by 90 % for only 10 day. Optimization of the Si in the soil-plant-microbial system promotes more complete denitrification process resulting in reduction of nitrate to molecular nitrogen. Another effect of Si fertilization on the GHG emissions is carbon sequestration to soil proceeding due to Si-induced increase in the root system formation. Our and literary data has shown that the Si fertilizers can increase the root biomass by 20 to 100 %. The results of field tests conducted on rice evidence that Si fertilization could provide transferring additional 3 to 13 ton of CO_2 from atmosphere to soil. Some mechanisms of the Si effect on GHG emissions remain unclear and require further investigation.

Studies on soil silicon status in vertisols and silicon nutrient management in Sugarcane

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ABSTRACT

Sugarcane is a silicon accumulator crop and considering the beneficial role of silicon in crop growth, this study was undertaken to assess silicon availability in soils, its requirement, uptake and management with Si sources and silicate solubilizing bacterial culture for sustainable productivity. The plant available silicon (PA-Si) was determined using 0.5 M ammonium acetate, 0.5 M acetic acid and 0.1 M calcium chloride extractants. The extraction pool of PA-Si was the highest by 0.5 M acetic acid followed by 0.5 M ammonium acetate and least by 0.01 M calcium chloride. The relationship with soil properties revealed that available Si content increased with pH, clay %, exchangeable cations and cation exchange capacity of the soil. Phosphate availability appeared more in higher PA-Si containing soils. The fields monitored for leaf Si content at 120 days after sugarcane plantation, cane and sugar yield showed positive strong correlation with 0.5 M acetic acid extractable PA-Si compared to 0.5 M ammonium acetate indicating more suitable extractant to measure plant available silicon. Response of sugarcane was examined to the levels and sources of Si and silicate solublizing bacterial culture (SSB) in field experiments. The cane yield significantly increased with Si @ 400 kg ha^{-1} (142.8 t ha^{-1}) over the control (124.5 t ha^{-1}) and found cost effective. The optimum level of Si @ 400 kg ha^{-1} was tried with silicon sources viz. thermal power station fly ash, pond ash and bagasse ash which were found equally beneficial as calcium silicate. Locally available bagasse ash from sugar mills followed by calcium silicate in conjunction with consortia of SSB culture @ 5.0 lit ha^{-1} showed significant role for increasing soil available Si, sheath moisture, Si uptake, cane yield, sugar yield and found cost effective.

Response of Banana to Silicon Nutrition in Typic Ustifluvent Soil

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ABSTRACT

Farmers are intensifying land use without proper nutrient management practices, which resulted to depletion of nutrients from soil causing yield decline. Silicon removed from world arable soil is estimated to the tune of 200-224 million tonnes annually. The need for proper silicon management to increase yield and sustain crop production appears to be necessary in temperate and tropical countries. In addition, the silicon diminution in the soil can occur in intensive agriculture with continuous monoculture of high yielding cultivar. Banana owing to its large size and rapid growth rate require relatively larger amount of nutrients for high yields of quality fruits. Little is known of silicon in banana. Field experiment was conducted to study the response of tissue cultured banana Var Grand naine, through soil and foliar application of potassium silicate. The treatment details is T_1- NPK (RDF), T_2 - NPK + potassium silicate (FS) – 0.25 %, T_3- NPK + Potassium silicate (FS) – 0.5 %,T_4- NPK + Potassium silicate (FS) – 1 %, T_5- NPK + Potassium silicate (FS) – 0.25 %, T_6- NPK + Potassium silicate (FS) – 0.5 %, T_7- NPK + Potassium silicate (FS) – 1 %, T_8- NPK + Potassium silicate (SA) – 50 kg SiO_2 ha^{-1}, T_9- NPK + Potassium silicate (SA) – 100 kg SiO_2 ha^{-1}, T_{10}- NPK + Potassium silicate (SA) – 150 kg SiO_2 ha^{-1} (FS – Foliar spray, SA – Soil application). The treatments T_2 to T_4 (two sprays at 3 and 5th month) and T_5 to T_7 (three sprays at 3, 5 and 7th month). The results revealed that soil application of silicon recorded higher growth and yield characters and yield compared to foliar application Pseudostem height, Pseudostem girth, LAI, chlorophyll, sucker production and leaf dry matter were highest with soil application of 50 kg Si ha^{-1} and declined with Si levels. Similarly, foliar application of silicon at 1 % applied at 3rd and 5th month recorded the highest morphological characters compared to 0.25 and 0.5 % Si. Foliar spray at 0.25 and 0.5 % when sprayed at 3rd, 5th, and 7th month recorded higher growth characters compared to foliar spray at same concentration when applied at 3rd and 5th month. However, when sprayed at 1 % Si it declined. Soil application of silicon recorded higher fruit characters and yield compared to foliar application. Soil application of 50 kg Si ha^{-1} registered the highest bunch weight and length, number of hands/bunch, number of fingers/hand, total number of fingers/bunch, finger weight, length and girth. All the fruit characters declined with Si levels. Foliar spray at 1% Si applied at 3rd and 5th recorded the highest fruit characters followed by 0.5 % Si sprayed at 3rd, 5th and 7th month. The percent increase in fruit yield due to various silicon treatments ranged from 3.34 to 14.42 over control. Similarly, the yield response also ranged from 3.8 to 12.1 t ha^{-1}. The highest fruit yield was noticed with 50 kg Si ha^{-1} (96.0 t ha^{-1}) and it reduced with Si levels. Among foliar treatments, fruit yield increased with silicon concentrations (0.25 to 1 %). The highest fruit yield was observed with 1 % Si applied at 3rd and 5th month (92.7 t ha^{-1}).

Key words: Silicon; banana; growth; yield; potassium silicate

Beneficial effects of silicon on the growth and biotic stress of melon (*Cucumis melo* L.) var. Glamour Sakata

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ABSTRACT

Production of melon var. Glamour Sakata (commercial netted melon) increased gradually through increasing cultivation area in Malaysia to support high demand from the consumer. Most of the farms using fertigation systems and some small scale farming could reach 4 tonnes yield of two thousands melon plants. However, pests and diseases such as powdery mildew could cause a considerable yield losses. Therefore, our work to determine the effect of silicon nutrient application on melon (*Cucumis melo* L.) var. Glamour Sakata especially their growth and when plant under biotic stress. Silicon (Si) nutrient (concentrated blend of bioavailable silicic acid and microelements) was applied once a week as root applications at the concentration of 0.15 % Si nutrient (v/v), 0.25 % Si nutrient (v/v), 0.35 % Si nutrient (v/v), 1.5 % Si nutrient (v/v), 2.5 % Si nutrient (v/v) and 3.5 % Si nutrient (v/v) along with the grower's conventional fertilizer applications. The control plants were untreated without any Si nutrient. The experimental plot was conducted in a complete randomized block design (CRBD) scheme with fifteen replicates per treatment. There were positive results from experiment trials on melon var. Glamour Sakata, which were the plants treated with Si nutrient showed an earlier anthesis compare to the untreated plants. The earlier anthesis could give earlier pollination and harvesting less than 60 days compare to the usual timing of 75 days after transplanting. Results showed that the average vein length of treated plants (1.5 % Si nutrient (v/v)) was 3m where as the average vein length of the untreated plants was 2.3 m. There was a significant difference ($P< 0.05$) of average root weight between treated plants (27 kg) and untreated plants (20 kg). There were considerable increase of fresh and dry weight of melon plants treated with Si nutrient. The average biomass of plants treated with Si nutrient was 27.2 kg and the average of untreated was 23.4 kg. Fresh fruit weight in the range 2.2 to 2.5 kg harvested from plant treated with the concentration of 0.15 % Si nutrient (v/v), 0.25 % Si nutrient (v/v), 0.35 % Si nutrient (v/v), 1.5 % Si nutrient (v/v) and 2.5 % Si nutrient (v/v) whereas average of 0.8 kg from 3.5 % Si (v/v). Fruits harvested from the untreated plants were mostly less than 2 kg. There were several internal quality of fruits were obtained such as fruit firmness, fruit sweetnest and acidity. Results showed that produce from plant being treated with 0.25 % Si nutrient (v/v), 0.35 % Si nutrient (v/v), 1.5 % Si nutrient (v/v) were significantly firmer than the untreated plants. The average°Brix of ripe fruits were significantly ($P< 0.05$) increased with the treatment of 1.5% Si nutrient(v/v) compare to the untreated. There were no significant differences in acidity of fruits between treated and untreated samples and pH range 6-7. There is a potential role of Si nutrient in delaying the development of melon var. Glamour Sakata powdery mildew which the results showed that the reduction of severity of the powdery mildew compare to the untreated. Results showed that the disease severity index (DSI) was below 2.5 (6 % - 25 % infection) for melon plants were treated with 0.15 % Si nutrient (v/v), 0.25 % Si nutrient (v/v), 0.35 % Si nutrient (v/v) and 1.5 % Si nutrient (v/v), DSI<1 (less than 5 % infection) for melon plants were treated with 2.5 % Si (v/v) and 3.5 % Si (v/v). The delay of the epidemic development could give more time to manage disease outbreaks and reduce the amount of fungicides useage. We believe that the application of Si nutrient enhanced the

growth of melon plants var. Glamour Sakata and also reduced the damage caused by powdery mildew. The role of Si nutrient in increasing chlorophyll content and leaves cuticle thickness are also reported. Therefore, these results showed that Si nutrient could act as a preventive role for plants.

Keywords: Silicon nutrient, silicic acid, *Cucumis melo*L., var. Glamour Sakata, powdery mildew, growth, fruit quality

Fig.: Powdery mildew on upper surface of leaves of untreated melon plant (*Cucumismelo*L.) var. Glamour Sakata with DSI 4 (51-75 % infection).

The tropical fodder silicification as influenced by burning: Cases of *Andropogon schirensis*, *Brachiaria falcifera* and *Hyparrhenia subplumosa* from Guinean Benin

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ABSTRACT

Although silicon is beneficial for promoting plant growth and yield, a high content may affect palatability and digestibility of fodder grasses. Where the economy is agricultural dependent, preoccupation is to reduce forage leaves silica concentration to improve nutrient value for animals. Fire as a key driver of grassland structure and biological functioning, might promote increased silicon storage in above ground biomass. We evaluated the burning effect on silicification of 3 main forage grasses (*Brachiaria falcifera, Andropogon schirensis* and *Hyparrhenia subplumosa*) of native pasture from Samiondji Cattle Breeding Ranch in Guinean Benin.

Productivity plots sized 10 m x 10 m were delimited. Treatment consisted in 3 burning dates setout of 4 to 7: 25/01/2003; 25/02/2003; 5/04/2003. Globally, 27 observations (*3 species x 3 burning dates x 3 replicates*) were compared to controls. Leaf blades were harvested after 13 weeks vegetation. Apart from morphometric and structural traits, samples collected respectively in 2002, 2003, 2004 were 48 h oven dried and analyzed for SiO_2 and dry Ashes gravimetrically, Nitrogen by Kjeldahl, and others (Ca, K, Mg, P) using Inductively Coupled Plasma Atomic Emission Spectrometry (Varian Vista MPX;Brussels). Log transformation restored normality before a Repeated Measures ANOVA and Pearson correlations at 5 % were performed using Statistica 10. As no significant effect of year appeared, only data for 2003 were considered in this report.

As results, (a) Both species are quite rich in silica as well as in macro nutrients; (b) Factors such as "Species", "Burning" and "Species * Burning" highly influenced SiO_2 and nutrients concentrations. *B. falcifera* showed the highest value for SiO_2 (11.57 – 13.82 % DM i.e. 3 to 4 fold the controls) followed by *A. schirensis* (8.24 – 9.84 % DM i.e. 2 to 2.3 fold the controls) and *H. smithiana* the lowest (6.44 – 9.26 % DM i.e. 1.8 to 2.8 fold the controls); (c) Species are silica accumulators (SiO_2>1 % DM; $[SiO_2]/[Ca]$ (14,2-52,32) >1); (d) Covariations analyses showed SiO_2 positively related to Ashes ($R_{SiO2/Ashes}$= 0.95; p<0.001) while negatively with proteins ($R_{SiO2/Protein}$= -0.65; p<0.001), Calcium ($R_{SiO2/Ca}$= -0.38; p<0.05) and Magnesium ($R_{SiO2/Mg}$=-0.35; p<0.05). Additionally, Ca and Mg positively related (R= 0.72; p<0.001). (e) Even under burning, SiO_2 concentration tended to decrease with significant increase in Proteins, Ca and Mg. These results suggested that silica could be reduced with significant increase in important nutrients. In pooled treatments, SiO_2 and soluble Ashes concentrations largely differed between species; but positive relationship suggested similar accumulation pattern for silica and soluble ashes.

While high ashes concentration is desirable for grasses nutritive value, high silica concentration is undesirable for reducing palatability. Despite prescribed burning ability to increase grass SiO_2, it could serve as tool for managing silicification as well as nutritional status for higher animal productivity. However, mechanisms for this complex SiO_2 accumulation process are not well known. Ecological interactions with molecular and chemical techniques will help in controlling silicification and filling knowledge gap on the role of fire in the production and storage of silicon in tropical plants.

Key words: Fodder grass; Silicification; Nutritional value; Burning; Tropics

Poster Presentation

Diatomaceous earth as source of silicon in tomato crop

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ABSTRACT

A field experiment was carried out at College of Horticulture, Hiriyur to study the effect of Diatomaceous earth as a source of silicon in tomato crop, during Kharif 2013-14. Experiment was carried out with nine treatment and three replication and soils were alkaline in reaction, medium in salt and organic matter. The tomato growth parameters of Arka Ananya was significantly influenced by an application of DE as a source of silicon. Among the different levels of DE with POP, application of T6: POP + DE @ 750 kg/ha gave significantly higher leaves and branches over rest of the POP treatments and was at par with the treatments of POP+DE (500). In case of treatment, ½ POP + DE @ 750 kg/ha also significantly increased the number of leaves and branches over POP (T2). The observations on growth attributes of plant height was not recorded significant increase in plant height. The tomato fruit yield of Arka Ananya was significantly influenced by an application of DE as a source of silicon. Among the different levels of DE with POP, application of T6: POP + DE @ 750 kg/ ha gave significantly higher yield over rest of the POP treatments and was at par with the treatments of POP+DE (500). In case of treatment, ½ POP + DE @ 750 kg/ha also significantly increased the tomato fruit yield over POP (T2) which reduced 50 % of POP which will help in cost reduction in terms of chemical fertilizer and soil pollution too and get higher economic return. Application of varied levels of Diatomaceous Earth (DE) along with graded levels of POP increased the nutrients content after harvest of tomato crop. Significantly higher N, P, K, S and Si was observed with the application of 100 % POP + DE @ 500 kg ha^{-1} compared to absolute control. With respect to pH, EC and OC there was no significant difference. But, there was a significant difference with respect to available K_2O, exchangeable Ca & Mg, available Si and DTPA extractable Fe, Mn, Zn & Cu. Application of varied levels of Diatomaceous Earth (DE) along with graded levels of POP increased the leaf and fruit nutrient concentration over the absolute control. Significantly higher potassium, calcium and silica content were observed with the application of 100 % POP + DE @ 500 kg ha^{-1} compared to absolute control in leaf samples. The fruit nutrient concentration were no significant in NPK and Ca, Mg, S, where as silica content was significant. Application of varied levels of Diatomaceous Earth (DE) along with graded levels of POP increased the leaf and fruit nutrient uptake over the absolute control. Significantly higher silicon uptake in leaf and fruit were observed with the application of 100 % POP + DE @ 250 kg ha^{-1} compared to absolute control.

Keywords: Diatomaceous earth, package of practices, organic matter and diethyl triaminepenta acetic acid

Applying silicate fertilizer increases both yield and quality of table grape (*Vitis vinifera* L.) grown on calcareous grey desert soil

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ABSTRACT

Silicon (Si), as a beneficial element for a number of crops, can significantly improve the growth and yield of crops partly through silicon-enhanced resistance to biotic and/or abiotic stress. However, the mechanisms of Si-improved growth and fruit quality of horticultural crops, in particular, remain poorly understood. In the present study, two-year field experiments were conducted aimed at testing the effects of different sources of silicate fertilizers applied on table grape yield, fruit quality and fruit commercial characteristics during storage period. For this, two table grape cultivars were tested with treatments including: (1) no silicate fertilizer (control), (2) steel slag fertilizer and (3) water-cooling slag fertilizer. The application rate of silicate fertilizer was 60 kg SiO_2 ha^{-1}. Fruit yield, cluster weight, berry weight, berry size (*i.e.* length and width) were significantly increased by application of silicon fertilizers ($P < 0.05$) in both cultivars. Table grape fruit yield was 13.5 % higher in the treatment with either water-cooling slag fertilizer or steel-slag fertilizer than in the control across the two years tested. Silicon fertilization significantly improved fruit total soluble solid, the ratio of total soluble solid to titratable acidity (TSS/TA) and fruit firmness. Applying silicate fertilizer significantly extended the fruit shelf-life by decreasing fruit respiratory intensity, decay incidence and weight loss ($P < 0.05$). Water-cooling slag fertilizer did not show a significant difference from steel slag fertilizer in grape yield and fruit quality. Our findings suggest that silicate fertilizer could prolong fruit shelf-life and increase the yield and quality of grape in a calcareous grey desert soil.

Key words: Silicate fertilizer; Table grape; Fruit yield; Fruit quality; Fruit shelf-life

Silicon and phosphorus fertilization in aerobic rice-wheat system

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ABSTRACT

The productivity of rice and wheat is increasingly threatened due to different biotic and abiotic stresses. Among abiotic stresses water scarcity and lodging are the main constrains to achieve higher productivity in aerobic rice-wheat system. Aerobic rice is a good alternateto cope up with water scarcity which can save about 50 % water and enhanced water productivity by 60 % over transplanted rice. Application of both Si and phosphorus may be helpful to overcome these problems. Silicon imparts leaf erectness, minimizes transpiration losses and reduces lodging besides imparts resistance to diseases and pest in cereals. Aerobic rice is more exposed to water stress compared to transplanted rice. Si has a great potential of to cop-up with the water stress in aerobic rice and enhance its productivity. Role of Phosphorus is more in aerobic rice as compared to lowland rice for root growth and development. Till date, less attention has been given to explore positive interactions between silicon and phosphorus in rice. Therefore, the study was initiated during 2016-17 to observe the effect of silicon and phosphorus under aerobic rice condition withfour levelseach of silicon (0, 40, 80, 120 kg Si/ha through calcium silicate) and phosphorus (0, 30, 60, 90 kg/ha through DAP) in rice (Pusa1612)- wheat (HD 3086) system. Grain yield of rice 5.33 and 5.26 t/ha was recorded from 90 and 60 kg phosphorus/ha, respectively and it was statistically similar but higher than the remaining treatments. Similarly, application of Si 120 kg/ha produced maximum grain yield (5.22 t/ha) and it was at par with 80 kg Si/ha (5.08 t/ha). The highest effective tillers (291.3), panicle length (27.63cm), grains panicle^{-1} (141.1), panicle weight (2.43 g), and 1000–grain weight (24.65 g) were recorded with 90 kg phosphorus/ha and it was at par 60 kg phosphorus/ha except for panicle length. Effective tillers, panicle length and weight were highest with 120 kg Si/ha but at par with 90 kg Si/ha. Highest wheat grain yield (6.45 t/ha), effective tillers, spike length, grains spike $^{-1}$, panicle weight and 1000–grain weight were obtained with 90 kg phosphorus/ha and it was at par with 60 kg phosphorus/ha. Similarly, application of Si 120 kg/ha recorded highest wheat grain yield (6.24 t/ha) and all the yield attributes but it was found at par with 80 kg Si/ha. There were no lodging (lodging score 0) when Si and phosphorus were applied at 120 & 90 or 90 & 60 kg/ha,respectively, but highest lodging score (9.2) was recorded without phosphorus and silicon in wheat. Thus, it is concluded that application of 90 kg Si/ha and 60 kg phosphorus/ha in aerobic rice has potential to reduce lodging and enhance the productivity of rice and succeeding wheat.

Key words: Aerobic rice, biotic and abiotic stress, Lodging score, Phosphorus, Silicon

Diatomaceous earth as silicon nutrition to onion

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ABSTRACT

The field experiment on silicon nutrition was conducted at Research Farm of Micronutrient Research Scheme, Mahatma Phule Krishi Vidyapeeth, Rahuri (MS) during *kharif* 2013. The onion was test crop (*cv*. Baswant-780). The soils of experimental field was moderately alkaline (pH 8.0) with low salt content (0.14 dSm^{-1}). The available nitrogen, phosphorus and potassium was low, moderate and very high respectively. Calcium chloride-silicon content was moderately high (50.12 mg kg^{-1}). The treatment consist of absolute control, GRDF 100:50:50 kg ha^{-1} N, P_2O_5 and K_2O + 10 t ha^{-1} FYM (full POP), half GRDF 50:25:25 kg ha^{-1} N, P_2O_5 and K_2O + 5 t ha^{-1} FYM (half POP), DE @ 200 kg ha^{-1} + full POP, DE @ 400 kg ha^{-1} + full POP, DE @ 600 kg ha^{-1} + full POP, DE @ 200 kg ha^{-1} + half POP, DE @ 400 kg ha^{-1} + half POP, DE @ 600 kg ha^{-1} + half POP and only DE @ 400 kg ha^{-1}. The highest significant chlorophyll content (1.70 mg g^{-1}), plant height (56 cm), polar diameter (59.02 mm), equatorial diameter (59.9 mm) and wt. of bulb (90 g) were recorded in the treatment where DE application @ 600 kg ha^{-1} + full POP. The highest bulb yield (18.68 t ha^{-1}), straw yield (38.32 q ha^{-1}), macro and micronutrient uptake was recorded in the similar treatment. However higher uptake of silicon by onion crop was significantly higher (13.48 kg ha^{-1}) was observed in the treatment with DE application @ 600 kg ha^{-1} + half POP. The application of DE did not showed distinguish variation in respect of soil pH, EC and organic carbon content in soil. However, soil fertility at harvest was maintained due to application of DE with full POP and half POP. The residual $CaCl_2$-Si content of soil was increased the treatment where diatomaceous earth was applied.

Thus, the addition of diatomaceous earth as a source of silicon to onion @ 600 kg ha^{-1} with full POP to produce higher onion bulb yield.

Key words : Bulb yield, nutrient uptake, package of practice (POP), diatomaceous earth

Effect of orthosilicic acid formulations on growth and yield of maize in different soils

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ABSTRACT

Silicon is the second most abundant element in the earth's surface and plays a significant role in imparting biotic, abiotic stress resistance and enhancing crop productivity. Plants absorb silicon from the soil solution in the form of monosilicic acid, also called orthosilicic acid. This molecule is highly unstable and readily becomes into non available form. Unstable nature of this molecule is not in many products which are available in the market. Therefore, Field experiments were conducted in two different soils *viz.,* clay loam soil at Experimental Farm, Annamalai University and sandy loam soil at Farmers field, Dharmapuri District during 2016 – 2017 to study the effect of orthosilicic acid formulations on growth and yield of maize. The experiment consisted of each three levels of silixol granules (25, 50 and 100 kg ha^{-1}) and silixol plus (1, 2 and 3 ml $litre^{-1}$ on 20, 40 & 60 DAS) and their interactions along with recommended dose of fertilizers and as control. The experiments were laid out in Randomized Block Design with three replications.

The results of the experiments revealed that the combination of soil and foliar application recorded highest values compared to individual application. Among the soil application, RDF + Silixol granules @ 100 kg ha^{-1} recorded highest plant height, LAI, DMP, cob length, cob diameter, number of grains per cob, test weight and grain and stover yield of 6240, 6345 kg ha^{-1} and 8072, 8145 kg ha^{-1} in clay and sandy loam soils respectively. However, it was statistically on par with silixol granules @ 50 and 25 kg ha^{-1} .With respect of foliar application, RDF + spraying of Silixol plus @ 3ml $litre^{-1}$ recorded highest plant height, LAI, DMP, cob length, cob diameter, number of grains per cob, test weight and grain and stover yield of 5939, 6043 kg ha^{-1} and 7968, 8041 kg ha^{-1} in clay and sandy loam soils respectively which was on par with its lower levels. Among the treatments tried, combination of soil and foliar application of RDF + silixol granules @ 100 kg ha^{-1} + silixol plus @ 3 ml $litre^{-1}$ recorded highest values for plant height, LAI, DMP, cob length, cob diameter, number of grains per cob, test weight and grain and stover yield of 6737, 6842 kg ha^{-1} and 8231, 8304 kg ha^{-1} in clay and sandy loam soils respectively. Among the two different soils, sandy loam soil was found best than clay loam soil. In respect of economics of maize, RDF + silixol granules @ 25 kg ha^{-1} + silixol plus @ 1 ml $litre^{-1}$ recorded highest net return of Rs.54270 and Rs.55881 and return $rupee^{-1}$ invested of 2.19 and 2.23 in both the soils respectively. Thus conjoint application of RDF + silixol granules @ 25 kg ha^{-1} + silixol plus @ 1 ml $litre^{-1}$ can potentially contribute to overall maize productivity.

Key words: orthosilicic acid, maize, growth, yield

Impact of silicates on the growth of coconut seedlings grown in a tropical Entisol

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ABSTRACT

Silicon is considered as one among the beneficial elements required for crop nutrition particularly that of a monocotyledonous crop like coconut. In order to study the effect of different silicate sources on the growth of coconut seedlings, a pot culture study was conducted with coconut variety West Coast Tall in the Completely Randomized Design during the period 2013 - 2015. The treatments were T_1 (absolute control), T_2 (Sodium silicate @ 200 ppm per kg soil), T_3 (Sodium silicate @ 400 ppm per kg soil), T_4 (Calcium silicate @ 200 ppm per kg soil), T_5 (Calcium silicate @ 400 ppm per kg soil), T_6 (Potassium silicate @ 200 ppm per kg soil), T_7 (Potassium silicate @ 400 ppm per kg soil). Biometric observations such as height and number of split leaves were recorded. The increase in leaf thickness was monitored by recording the micrometric observations. Observations recorded before the application of treatments as well as one year after planting of the seedlings were compared in the present paper. It was observed that the highest percentage increase in plant height was recorded by the treatment which received potassium silicate @ 400 ppm per kg soil (87.63) followed by calcium silicate @ 400 ppm per kg soil (78.68). The later treatment also recorded the highest number of split leaves (8 nos.) In our study, the highest percentage increase in leaf thickness (19.81) was recorded by the treatment which received potassium silicate @ 200 ppm per kg soil followed by sodium silicate @ 400 ppm per kg soil (18.51). Silicates can impart resistance to the attack of pest and diseases. Those silicon which is being absorbed by the plants from the various silicates applied in soil are deposited as amorphous silica in the cell walls and upon interaction with the pectins and poly phenols can enhance the rigidity and thickness of the leaf tissues. Silicon can also reinforce the cell wall and is being reflected as the improvement in leaf thickness. Thus it can be observed that application of silicates have positive impact on the growth as well as the improvement in leaf thickness of coconut seedlings.

Keywords: Silicates; Entisol; Coconut

Research progress in the positive influence of silicon fertilizer on the quality of crops

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ABSTRACT

This article summarizes the positive influence of silicon fertilizer on the quality of 30 kinds of crops including cereal, fruit and vegetable on the basis of 12 times experiments during 20 years and references. The study indicate that silicon can increase the output rate of brown rice and white rice, and decrease rice gel consistency. As a result, the mouth-feel and taste are better. To varying degrees, the content of crude protein, lysine, starch and soluble sugar in waxy corn can be raised by the use of silicon fertilizers. Therefore, quality and taste of waxy corntrend to be improved. Silicon fertilizers can improve potassium content, Shmuk value, ratio of purity degree, protein, nitrogen, total sugar, total volatile nitrogen and ratio of sugar to nicotine in tobacco and makes the quality higher. Silicon fertilizers can improve the sugar content in sugarcane, apple, nanguo pear, nectarine, grape, watermelon, pomegranate, watermelon, strawberry and melon and enhance the resistance to extrusion of apple, grape and tomato. Silicon fertilizers can increase the vitamin C content in strawberry, eggplant, greenhouse celery, celery cabbage, green Chinese onion, garlic and ginger, and also the soluble solid in the petiole of strawberry, eggplant and greenhouse celery. In addition, silicon can decrease the nitrate content in greenhouse celery, tomato, bitter gourd and grape. Silicon fertilizers can increase protein content in soybean and peanut and decrease fat content. Silicon fertilizers can improve quality of tea.

This article explains the mechanism of improving the quality of crops in the aspects of soil improvement, mineral fertilizer absorption, advancing photosynthesis, promoting organ development and crop resistance. It describes an aspiration of crops improvement with silicon fertilizer and popularity of silicon fertilizer.

Keywords: silicon; crop; quality

Bio-active silicon for improving phosphorus uptake and reduction in fixation in soils by mineralization

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ABSTRACT

In an agrarian country like India, where agricultural productivity is key to improving incomes and livelihoods, low-cost and scalable solutions to boost crop yields and quality without disturbing the soil health are of paramount importance. Therefore, there was a need to sensitize the farming community for the importance of a component which can add to the crop yield alongwith the improved soil health & micro flora. Considering the importance of phosphorus in crop yield & productivity, there was a need to search for the organic material that can have a good result on crop yield & soil health. The efficient use of phosphorus is a necessity in a world with finite phosphorus reserves but it is still common in agricultural systems for phosphorus to be applied at levels far exceeding produce exports.

Agricultural Development Trust's Krishi Vigyan Kendra, Baramati (Pune, India) in collaboration with Aadi Agro, Latur (M.S.) carried out the assessment trials for the pomegranate & sugarcane crops.

The trials were conducted in laboratory as well as open fields of 10 pomegranate growers and 10 sugarcane growers across the villages in Baramati & Indapur tehsils of Maharashtra. In the laboratory tests, soil less medium coir pith with a pH value of 7 was used. DAP was used 50 gram per kg of coir pith, whereas 50 gram of Bio Active Silica with Plant Available phosphorus P_2O_5. The content of this fused combination Bio Active Silica in H_4SiO_4 form is 10 % of total mass and Phosphorus as P_2O_5 form 5 % of the total mass of the product. In the open field, 100 Kg DAP was applied in the control plot, whereas 100 Kg of the combination of Bio Active Silica with Plant Available Phosphorus. The phosphorus percentage in DAP is 46 % while the Phosphorus content in the combination product is 5 % along with 10 % Bio Active Silica.

Our study demonstrated the increase in Phosphorus uptake immediately with less fixation in soils and more utilization by the longer period of availability in plant available form by fusing Bio Active Silica with Rock phosphate through a biological process. The work presented here studied physiological responses of Sugarcane and Pomegranate in the presence of fused Phosphorus in P_2O_5 form and Phosphorus in chemical form such as DAP and 10:26:26. It was noticed that the combination product increased the mass of the plant and overall growth parameters such as leaf size, stem girth and the length of internodes were increased considerably.

Keywords: Silicon; Agriculture; Phosphate Uptake; Pomegranate; Sugarcane

Effect of diatomite as a silicon source on growth, yield and quality of potato

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ABSTRACT

The application of Silicon (Si), a beneficial element, has proven to perform well in terms of yield, protection from fungal diseases and improved uptake of other essential nutrients. Although, information on the effect of soil and foliar application of silicon on potato are available, use of diatomite as a silicon source in potato is of primary importance as the material is a naturally occurring sedimentary rock and a rich source of Si. Hence, a study was taken up to determine the effect of different levels of AgriPower diatomite (*Melosiragranulata* species) on potato production and quality.

Field experiments were conducted at College of Agriculture, Hassan, Karnataka, South India for two seasons during *Kharif* 2012-13 and 2013-14 to study the effect of Diatomite as a Si source for improving yield and quality of potato. The experiments were laid out in a Randomised Block Design with nine treatments and three replications with potato variety *KufriJyoti*. The Diatomite was tested at 150, 300 and 600 kg ha^{-1} with 50 and 100 % of Package of Practice (POP).The Recommended Doze of Fertilizer (125: 100:125 kg of N:P: K ha^{-1}) + 25 t ha^{-1} of Farm Yard Manure was used as control besides an absolute control (without any fertilizers) in the field experiment. The observations on growth, yield and quality parameters of potato as well as potato late blight disease incidence were taken periodically during the crop growth period.

The tuber and halum yields of potato were significantly influenced by an application of Diatomite in both the seasons. The pooled data indicated that Diatomite application @ 150 kg ha^{-1}+ 50 % POP recorded significantly higher potato tuber yield (24.28 tha^{-1}) than control (17.51 tha^{-1}) and 100 % POP (21.51 t ha^{-1}) which is 12.87 % increase over the 100 % POP alone treatment. Application of Diatomite at different levels with 100 % POP gave lower yield compared to different levels of Diatomite with 50% POP. This may be due to higher late blight disease incidence recorded with 100 % POP compared to 50% POP. Application of Diatomite significantly reduced the incidence of late blight of potato disease to the extent from 37.72 % (100 % POP alone) to 9.41 % (50 % POP + Diatomite @ 600 kg ha^{-1}). Application of Diatomite has influenced significantly tuber size and the tubers of grade >75 g has increased (64 numbers/plot) with application of Diatomite @ 600 kg/ha compared to 100% POP alone (34 numbers/plot). Application of Diatomite created a favourable soil environment with an optimum soil nutrient content, higher Si uptake and reduction in disease incidence which ultimately resulted in higher dry matter production and the yield.

Keywords: Diatomite; Silicon; potato tuber yield; tuber grades; late blight disease.

Impact of ortho silicic Acid formulation on yield and disease incidence of potatoes

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ABSTRACT

The potato (*Solanum tuberosum* L.) serves as a staple food worldwide and is capable of reducing the world's food shortages. Survey studies to identify the potential crops to play a key role in alleviation of food crises have highlighted the major role of root and tuber crops. The crop is grown globally but is challenged due to high susceptibility to numerous pests and pathogenic organisms coupled with abiotic stresses (temperature fluctuation and water status). In the recent past, studies have highlighted that Silicon (Si), non essential nutrient, is beneficial to plants in terms of yield, protection from fungal diseases and improved uptake of nutrients mainly, phosphorus and calcium.

Studies were conducted at Central Potato Research Institute (CPRI) campus Modipuram farms since 2013 to 2017, to understand the role of Silixol Potato (Ortho Silicic Acid based formulation of M/S Privi Life Sciences Pvt Ltd., Mumbai, Maharashtra) on potato yield and other attributes. Three popular varieties of potato (Kufri Khyati, Kufri Bahar and Kufri Garima) were used. Experiments were conducted with different modes of treatment of potatoes with Silixol Potato as tuber dipping prior to sowing or foliar sprays or combination of two. All experiments plots were laid with RBD having three replications. Observations on various growth parameters and yield attributes were recorded along with the disease incidence and quality parameters

Potato crop raised without the addition of recommended dose fertilizer (RDF) exhibited a significant yield increment following application of Silixol Potato. Only dipping of tuber in Silixol Potato @ 1ml/ l prior to planting had increased the yield of tuber upto 15 %. While, only foliar application of Silixol Potato, exhibited a dose dependent increment in the yield upto 50 % when used @ 4 ml/l. This clearly indicates that the yield increment following application of Silixol Potato was due toincreased the uptake of the soil available nutrients. When the full RDF was applied to plots, no significant difference in yield was recorded in terms of yield with respect to tuber dipping application. However, foliar application contributed towards significant yield increment upto 20 %, when used @ 4 ml/l. The yield increment has been attributed to improvement in physiological parameters like chlorophyll content, leaf size and increased nutrient uptake. Interestingly, it has been observed that percent yield increment following the foliar application of Silixol Potato is more if fertilizers are not applied to the fields compared to well fertilized plot, thereby has a role in improving the utilization of nutrients.

In addition to yield increment, the quality of tubers (w.r.t growth cracks and hollow heart) was better following the use of Silixol Potato. Treated plots exhibited a lower incidence of leaf blight compared to untreated control. The impact of OSA formulation on the reduced incidence of biotic stress could be attributed due to the reinforcement of OSA into biogenic silica layer within leaf tissue. The cost benefit ratio for the farmer is coming around 1:6 (approx), when used @ 4ml/l of Silixol Potato. In addition to the yield increment, indirect benefits due to better tuber quality, reduced incidence of disease and pest are also beneficial for potato growers.

Bioavailability and budgeting of different sources of silicon and their effect on growth and yield of rice in acidic, neutral and alkaline soils of Karnataka, South India

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ABSTRACT

Effect of three different sources of silicon (Si) on growth, yield and Si bioavailability for rice crop was studied in three contrasting soils of Karnataka in a pot experiment. Acidic, neutral and alkaline soils collected from different locations were used for the study. Calcium silicate, diatomite and rice husk biochar was applied at 250 and 500 kg Si ha^{-1} and experiment was conducted in presence and absence of rice crop by maintaining the control under submerged condition. Soil solution sampler (Rhizon) was placed horizontally at 10cm depth of the pot to collect the water samples at different intervals.Elemental Si budget was estimated for each treatments as the difference between the inputs (irrigation water and fertilizer) and outputs (straw and grain Si uptake, plant available Si stock in soil after completion of the experiment). There was a significant increase in the yield parameters such as panicle number pot^{-1}, panicle length pot^{-1}, straw dry weight pot^{-1} and grain weight pot^{-1} in acidic and neutral soil whereas only straw dry weight pot^{-1} in alkaline soil with the application of Si sources over control. Higher nutrient content and uptake was noticed in neutral soil followed by acidic and alkaline soil. Although the application rate of different Si sources was 250 and 500 kg Si ha^{-1}, there was a significant difference in the nutrient content and uptake by rice among the Si sources. Significant difference in plant available silicon status of the soil was noticed with the application of different Si sources over control in all three studied soils. Plant available Si in soil decreased in the presence crop in acidic and neutral soil while increased in alkaline soil. The results of present investigation revealed that there was negative Si budget in control and extent was higher in the presence of crop in all three studied soils. About 16 to 28 per cent of Si in acidic and neutral soil and 10 to 19 per cent Si in alkaline soil was accounted by irrigation water. Crop Si uptake was found to be higher in neutral soil followed by acidic and alkaline soil. Effectiveness of the different sources of Si varied based on the type of soil, calcium silicate followed by RHB in acidic and neutral soil and RHB in alkaline soil performed better which can be due to variation in the reactivity of material based on the type of soil. Application of calcium silicate increased the plant available Si stock in soil as extracted by acetic acid in all soil which may be due to extraction of part of the Si adsorbed into the soil which might be useful for the succeeding crop. In the present investigation, there was negative Si budget in control treatments for the acidic and neutral soil and values were lower in the presence of crop in all three soils which emphasise the need of Si fertilization.

Keywords: Silicon; rice; bioavailability; yield; types of soil; budgeting; diatomite; calcium silicate; rice husk biochar

Silica content, anatomical traits and herbivory damage in leaves with different age and solar radiation exposition of invasive tree *Ligustrum lucidum*

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ABSTRACT

Ligustrum lucidum (Aiton) is an invasive tree out of its native distribution range (China). In Argentina, many areas have been invaded by this species, resulting in significant changes in the dynamics and functionality of the ecosystems. Previous studies have detected the herbivory preference in individuals developed in different environments. In addition, there are antecedents about the presence of amorphous silica biomineralizations in this species.However, little is known about howsilica accumulation occurs and if it content have effect in the leaves palatability. Considering the scarce information about silicification process in *Ligustrum lucidum*, and its possible influence in its susceptibility to herbivory damage, we carried on this work. The aims were 1) to analyze the silica content in leaves with different size (age) and solar exposition, and 2) to relate this silica content with anatomical features and herbivory damage, in tress from forests from SE Pampean region, Argentina. We selected 5 individuals with similar height. In each plant, 5 sun-exposed and 5 shadow leaves with 3 different age or size (new/small, media/median and old/big) were collected. Leaves were scanned, dried at 60 C for ve days and weighted in order to estimate specific leaf area. Damage produced by herbivores in the eld per leaf was measured by the proportion of leaf surface eaten calculated using Image J version 1.42d (National Institute of Health, Bethesda, Md, USA). Silica content was quantified through a calcination technique (Labouriau, 1983) and through a dissolution technique with Na_2CO_3 digestion. Some samples were subjected to histological techniques (cross sectioning, clearing and staining). Data was subjected to Kruskal-Wallis or ANOVA tests. Silica content ranged between 0.7-4 % (calculated as % dry weight), and was higher in older leaves ($F=30.55$, $p< 0.01$). Shadow leaves have higher silica content, higher SLA, and, in general, a lower herbivory damage in comparison to sun leaves. A higher SLA in shadow leaves is related to anatomical characteristics, such as a thinner parenchyma. These results showed that silica content increase with age, due to the continuous silica accumulation along the life of the organs. A higher accumulation of silica in shadow leaves could be related to a long life span of this type of leaves. Finally, the higher accumulation of silica in shadow leaves, along with a lower disponibility of biomass (due to thinner leaves) could account to a lower herbivory damage.

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Keywords: Leaf silica; Sun leaves; Shadow leaves; Oleaceae; Leaf anatomy; Herbivory

Comparison of different sources of silica on the yield and quality of "Alphonso" mango in Kokan Region of Maharashtra

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ABSTRACT

Mango, known a "king of fruits" is third largest fruit cultivated throughout the tropics and subtropics. The productivity and quality of mango is highly constrained by major factor like nutrient deficiency disease and pest incidence. Proper nutrition is pre-requisite for a tree to sustain the normal crop load to maturity. Higher rates of nutrient utilization by developing fruits, lead to a competition for survival of fruits on a tree. Soluble silicon ranges from 2 to 375 ppm in various soils. Silicon though not considered as beneficial nutrient, has well documented beneficiary role in nutrient uptake and mitigation of abiotic and biotic stresses by plants. Keeping this in view, investigation was carried out to assess the impact if application of silicon sources along with chemical fertilizer can improve on yield, quality of fruits and leaf nutrient content of mango (*Mangifera indica* L.) in Lateritic soil of Konkan region".

The present study is a part of doctoral research, conducted on the 25-year old mango orchard at Dapoli, located at 17°45', North latitude and 73°12', East longitude at an elevation of 280 meters above Mean Sea Level. The climate of Dapoli is warm and humid with the mean annual rainfall 3000 mm during June-September. According to the Agro-climatic zone of Maharashtra, the soil comes under high rainfall with lateritic soil type. The soil was moderately acidic in reaction, pH 4.96 with 0.043 dSm^{-1} electrical conductivity. The status of organic carbon 8.9 g kg^{-1}, available nitrogen 326 kg ha^{-1}, available phosphorous 6.8 kg ha^{-1}, available potassium 384 kg per ha. To assess the impact of various silicon sources both soil applications (calcium silicate and rice husk ash) and foliar applications (potassium silicate and stabilized silicic acid (Silixol, a commercial product)) were used. Soil applications were done twice in year (July and September), while foliar applications were done on pre flowering stage, peanut stage, marble stage fruit and three weeks before harvest. For foliar applications approximately 30 liters of water was sprayed per tree.

A significant increase in number of fruits per tree was recorded in all treatments of silicon sources when used at the lowest concentration. Among the two soil application sources, calcium silicate was better than rice husk ash resulting in yield increment more than 90 %, while among the two foliar sources, Silixol had attributed to more than three-fold increment in yield. This observed was supported by the better nutrient status of leaves and fruits done at various stages. For horticultural crops including mangoes, sugar content is a key quality attribute. Sugar content measured as TSS, increased substantially following the application of silicon sources as silicon has a well-documented role in sugar accumulation pathways. Shelf life of fruits had also increased by 5 days following the application of Silixol, compared to other silicon sources. To conclude, present study reveals that silicon sources plays a distinctive role in improving the yield and quality of Alphonso mangoes of Konkan region and the foliar application of Silixol has a potential of increasing the profitability of mango growers substantially.

Effect of sources and levels of silicon on soil properties, uptake, yield and quality of *Kharif* Onion

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Not Presented

ABSTRACT

An investigation was carried out by conducting a field experiment on *kharif* onion with the 15 treatment combinations of three Si sources (Diatomaceous earth, calcium silicate and bagasse ash) and five graded Si levels (0, 50, 100, 150, 200 kg ha^{-1}). DE recorded significant increase in soil pH, EC and OC (8.40, 0.49 dS m^{-1} and 0.58 %) respectively. The source S_3 (BA) recorded significant increase in available N and K (164.09 and 223.32 $kgha^{-1}$ respectively). However, S_1 (DE) recorded significant increase in Mn, Si and Cu (0.61, 73.6[illegible]nd 1.72 [illegible]g kg^{-1}) respecti[illegible]ely at harvest. The level Si 200 kg ha^{-1} recorded significant increase in ava[illegible]ity of [illegible], Si a[illegible] Zn (171.90, 93.23 kg ha^{-1} 4.52, 8.36 and 0.66 mg kg^{-1}) respectively over [illegible] ot[illegible] le[illegible]ls. [illegible]hile, [illegible]10[illegible] kg ha^{-1} recorded significantly highest available P (22.47 kg ha^{-1}) in soil. In [illegible]se o[illegible] act[illegible]n (S_2L_5) [illegible]e[illegible]rded significant increase in available N (180.00 kg ha^{-1}) over all other in[illegible]eractio[illegible] The [illegible]ource [illegible]$_3$ ([illegible]A) recorded significantly superior in polar diameter, neck thickness and total yield [illegible] onion ([illegible].27, 0.81 and 299.94 q ha^{-1} respectively). The average weight of onion, neck thickness, polar diameter, equatorial diameter and total and marketable yield of onion (92.40 g $bulb^{-1}$, 0.81 cm, 5.36 cm, 5.56 cm, 328 q ha^{-1}, 280 q ha^{-1}) respectively shown significantly superior at the level Si (200 kg ha^{-1}) over all other levels. The total yield of onion bulbs (343.80 q [illegible]ecorded significantly superior Si 200 kg ha^{-1} kg th[illegible]ough bagasse ash ove[illegible] all other interactio[illegible]. The so[illegible] (DE) was significantly increased in uptak[illegible] of Si (6.66 kg ha^{-1}) ov[illegible]r all the sources. T[illegible] ([illegible]CS) re[illegible]orded [illegible]ificant[illegible] highe[illegible]al up[illegible]ke of N [illegible] and [illegible]3.51, [illegible].33 and 99.63 kg [illegible]) respect[illegible]ely. T[illegible]$_5$ ([illegible]) recorde[illegible] si[illegible]ifi[illegible]e in to[illegible] uptake of N, P, K a[illegible] Si (130.4[illegible] 31.32 [illegible]113.0[illegible]d 8.5[illegible] ha^{-1}) r[illegible]ectivel[illegible] ov[illegible] all [illegible]her le[illegible] The i[illegible]eraction (S_3L_5) was recorded significant increase in N,P and Si (134.51, 11[illegible].30 and 11.[illegible] kg [illegible]) respectively over all other interactions. Thus, it is concluded that application of 200 kg ha^{-1} Si through bagaste ash @ 538 kg ha^{-1} with recommended dose of fertilizer to *kharif* onion found beneficial for increase in yield and yield contributing characters, total uptake of macro and micronutrient and residual fertility of soil.

Key words: *Aliium cepa*, silicon sources, marketable yield

Effect of varied levels of diatomite on growth and yield of sugarcane in Karnataka

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ABSTRACT

Silicon is reported to be beneficial and found to improve sugarcane productivity. Information on Diatomite as a source of silicon, its application rates and effects on growth and yield of sugarcane is lacking. Hence a study was under taken toknow the effect of varied levels of Diatomite (*MelosiraGranulat*a species) on growth and yield of sugarcane.Field experimentswas conducted at Kathalagere, Karnataka of South India in sandy loam soils with Co 86032 cultivar, during rabi-2013. The experiments consisted of nine treatments (T_1 : Control, T_2 :100 % Package of practice (POP), T_3:50 % POP, T_4:T_2+ Diatomite @ 250 kg ha^{-1}, T_5:T_2+ Diatomite @ 500 kg ha^{-1}, T_6:T_2+ Diatomite @ 750 kg ha^{-1}, T_7:T_3+ DE @ 250 kg ha^{-1}, T_8:T_3 +DE @ 500 kg ha^{-1} and T_9:T_3+ DE @ 750 kg ha^{-1}) laid out in RCBD design with three replications. The post harvest soils were subjected to chemical analysis. The plant samples were subjected to nutrient content and uptake and also for quality analysis.

Application of varied levels of Diatomite increased the yield and yield components of sugarcane over thePackage of Practice. Significantly higher cane yieldswas recorded to an extent of 164.96 t ha^{-1} with the application of 50 % POP + Diatomite @ 500 kg ha^{-1} as compared to 50% POP alone and 100% POP alone. Similar trend wasalsoobserved in top yield. The brix % and non reducingsugarsdid not differsignificantlywith the application of variedlevels of Diatomite. The millable cane height (cm), number of internodes per cane and inter-nodal girth significantly differed with the application of Diatomite. The $CaCl_2$extractable silicon of post harvest soil samples was higher in the plots with the application of graded levels of Diatomite over initial silicon content. Similarly the cane and biomass silicon content and uptake was increased with the application of DE along with the POP over 100 % or 50 % POP alone. The total P and K uptake differ significantly with the application of DE. Application of 50 % POP with the variedlevels of Diatomite(250, 500 & 750 kg ha^{-1})was on par with the cane yield of sugarcane obtained by the application of 100 % POP alone and significantlyhigherthanthat of 50% POP alone, whichindicates effective utilisation of applied nutrients without compromising yield.

Agronomic performances and chemical responses of rice to silicon nutrition through diatomaceous earth in two different soils

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ABSTRACT

Silicon is an important micronutrient for healthy and competitive growth of all cereals including rice. The applied silicate interacts positively with applied N, P, K improving their agronomic performance and efficiency with respect to yield and responses. Potassium silicate, sodium silicate, calcium silicates and calcium meta silicate are some of the sources are in use. One of the newer sources is diatomaceous earth a high – grade diatomite- based Silica (Si) fertilizer.Field experiments were conducted in two locations which were texturally different to evaluate response of rice to diatomaceous earth with following treatments T_1 - ½ POP, T_2 - Package of practice (POP), T_3 - POP + DE @-150 kg ha^{-1}, T_4 - POP + DE @ 300 kg ha^{-1}, T_5 - POP + DE @ 600 kg ha^{-1}, T_6 - ½ POP + DE @150 kg ha^{-1},T_7 - ½ POP + DE @ 300 kg ha^{-1}, T_8 - ½ POP + DE @ 600 kg ha^{-1}. The results revealed that diatomaceous earth applied at different rates along with POP or ½ POP caused significant and positive effect on growth, yield, nutrient uptake and availability in rice in both years and in both locations. The number of productive tillers hill^{-1}, panicle length, number of filled grains panicle^{-1} and 1000 grain weight was significantly higher when DE was applied along with POP or ½ POP over control and DE alone and was highest when DE @ 600 kg ha^{-1} was applied along with POP in clay loam and POP + DE @ 300 kg ha^{-1} in sandy clay loam soils.During 2012-13, the per cent increase in grain yield due to silicon treatment showed 8.95 to 38.8 in sandy loam soil and 20.5 to 45.2 in clay loam soil and in 2013-14, the per cent increase in grain yield ranged from 7.4 to 53.3 in sandy loam soil and 11.0 to 67.0 in clay loam soil. The highestgrain (7.40, 6.19 t ha^{-1}) and straw yields (9.14, 7.76 t ha^{-1}) was noticed with POP + DE @ 600 kg ha^{-1} in clay loam soil during 2012-13 and 2013-14 respectively. Similarly the highest grain (6.10, 5.15 t ha^{-1}) and straw yield (7.65, 5.96 t ha^{-1}) was noticed with POP + DE @ 300 kg ha^{-1} in sandy clay loam soil during 2012-13 and 2013-14 respectively. Uptake and availability of major nutrients *viz*., N, P, K, and Si and micronutrients was significantly influenced by DE application either with POP or ½ POP. Uptake of N, P, K, and Si in grain and straw was highest with POP + DE @ 600 kg ha^{-1} in clay loam and in sandy clay loam soil, uptake of nutrients in grain and straw was higher with POP + DE @ 300 kg ha^{-1}. Addition of POP + DE @ 300 kg ha^{-1} caused highest $KMnO_4$ – N, while POP + DE @ 600 kg ha^{-1} caused highest Olsen – P and NH_4OAc– K. DTPA extractable micronutrients (Fe, Mn, Cu, Zn) was found to be highest in POP + DE @ 600 kg ha^{-1} in both soils.

Key words: Silicon, diatomaceous earth, rice, yield, nutrient uptake, availability

Effect of silicon and micronutrients on plant growth, yield and disease incidence in chilli (*Capsicum annuum* L)

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ABSTRACT

This study was conducted to investigate the effect of silicon application at different concentration (0.1 %, 0.2 % and 0.4 % Si) with zinc (0.2 %) and boron (0.1 %) on plant growth, nutrients uptake by plants, and yield and disease incidence in chilli cv. Arka Meghana at ICAR-Indian Institute of Horticultural Research, Bengaluru, India during the year 2015-16. Silicon as potassium silicate (18 % Si) was provided to foliage by spraying at 15 days intervals from 30 days after transplanting. Results indicate that the foliar application of silicon irrespective of doses recorded significantly higher plant height and biomass production both at 45 DAP and crop maturity. Significantly higher head yield (33.7 %) was obtained due to foliar application of 0.4 % silicon over the control. Nutrient contents were partitioned into leaves, shoot, roots and fruits and it was found that the uptake of nitrogen, potassium and zinc was substantially higher in plants sprayed with silicon compared to control. The highest nitrogen (4.76 %), potassium (3.59 %), silicon (1.68 %), magnesium (0.54 %) and zinc (49 mg kg^{-1}) content were recorded in plants with 0.4 % silicon spray. Further, the study also revealed that disease incidence significantly decreased in plants with silicon supplement as compared to the control. There was no incidence of leaf curl/mosaic virus in plants treated with 0.4 % silicon at 75 days after planting (DAP). Foliar treatment at 0.4 % silicon was the most effective against the resistance of powdery mildew (20 PDI) and leaf spot (60 PDI) and did not observe any die back symptoms in chilli plants at 75 DAP.

Keywords: Silicon, micronutrients, biomass production, nutrients uptake, yield, disease incidence

Influence of diatomaceous earth (as a source of silicon) on flowering, yield and quality of pomegranate Cv. Kesar

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ABSTRACT

Pomegranate is one of the important arid region fruit crop grown in marginal soils. It is highly nutritive andused as table fruit; for Preparation of juice, wine, jelly and syrup; for extraction of tanin and phenols; preparation of anarrab (pomegranate jam), anardana (seeds used as spice) and many industrial purpose. The production of pomegranate can be increased by balanced nutrition on the profitable basis even though it is growing in the arid condition. The growth, yield and quality of pomegranate can be increased by application of manures and fertilizers because it is well respond to application of fertilizers. Silicon is most commonly found in soils in the form of solution as silicic acid (H_4SiO_4) and is taken up directly as silicic acid (Ma *et al*., 2001). Being a dominant component of soil minerals it has many important functions in environment, although silicon is not considered as an essential plant nutrient because of its ubiquitous presence in the biosphere. The response of silicon on many crops on growth and yield are encouraging and beneficial. Hence an experiment was carried out to know the effect of soil application of Diatomaceous earth (as a source of silicon) on pomegranate Cv. Kesar during 2014. The experiment was laid out on red loamy soil and in an established orchard of 5 year old plants with spacing of 3.5 m x 3.5 m. The source of silicon used was Diatomaceous earth (DE), applied as basal dose to the respective treatment in this experiment. The dosage of DE used in this experiment was 300, 600 and 900 kg/ha and was applied after bahar treatment as whole basal application and recommended dose of fertilizer at the interval of 0, 45 and 90 days after bahar treatment. The inorganic nutrient *i.e.* nitrogen was applied in the form of urea (46 % N), phosphorous applied in the form of Diamonium phosphate (18 % N: 46 % P: 0 % K), and potassium applied in the form of muriate of potash (60 % K). These nutrients were applied to the respective treatment according to the package of practice (400:200:200 g NPK/Plant) of UHS, Bagalkot. The design adopted for the experiment was Randomised Block Design (RBD) with nine treatments and replicated thrice. The treatment T_9 (RDF+ DE @ 900 Kg/ha) recorded higher total number of flowers (708.20) per plant, number of fruits per plant (71.36), yield (21.33 kg per plant) and followed by T_8 (RDF + 600 kg/ha DE). With respect to quality parameters fruit weight (298.66 g), fruit volume (315.00 ml), fruit girth (82.69 mm) and fruit length (83.68 mm) was recorded higher in T_9 (RDF+ DE @ 900 Kg/ha). Application of silicon will influence the yield and quality of pomegranate by providing absorption and translocation of nutrients, reducing plant stress.

Key words: Pomegranate, Kesar, DE

Effect of foliar application of silicic acid on growth, yield and quality of soybean [*Glycine max.* (L)]

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ABSTRACT

A field experiment was conducted at University of Agricultural Sciences, GKVK, Bengaluru, during *kharif*-2016 to study the effect of foliar application of silicic acid on growth, yield and quality of soybean [*Glycine max.* (L)]. The soil of experimental site was acidic in pH (5.26) with normal EC (0.08 dS m^{-1}) and low, high and medium in N (156.80 kg ha^{-1}), P_2O_5 (463.63 kg ha^{-1}) and K_2O (185.47 kg ha^{-1}), respectively. The plant available Si content was low (AA Si - 29.12 mg kg^{-1} and CC Si - 25.92 mg kg^{-1}). The split plot design was adopted with two soybean varieties (MAUS-2 and KBS-23), seven treatments and three replications. Foliar silicic acid (2 % as soluble H_4SiO_4) and boric acid (0.8 % as H_3BO_3) were given at two different doses (2 ml L^{-1} and 4 ml L^{-1}) at two and/or three different interval (21, 36 and 51 DAS) to the field applied with RDF (Recommended Dose of Fertilizer) of 25:60:25 kg of N: P_2O_5:K_2O ha^{-1}. Soluble silicic acid also contains 0.8 per cent of boron as boric acid. To nullify the effect of boron, treatments with boric acid was considered. Hence, 0.8 per cent of boron as boric acid foliar spray @ 2 ml L^{-1} and 4 ml L^{-1} was also performed at three intervals. The results revealed that significant increase in plant height (34.46 cm), number of leaves $plant^{-1}$ (15.83), pod yield (3296.23 kg ha^{-1}), seed yield (2004.96 kg ha^{-1}), protein yield (672.18 kg ha^{-1}) and oil yield (370.53 kg ha^{-1}) was observed with the foliar application of silicic acid at 2 ml L^{-1} for three times. Application of foliar silicic acid at 4 ml L^{-1} three times significantly increased number of branches $plant^{-1}$ (2.07), number of pods $plant^{-1}$ (32.13), number of seeds $plant^{-1}$ (64.33) and stalk yield (1774.61 kg ha^{-1}) over other treatments. Irrespective of treatments, foliar silicic acid significantly increased growth parameter of MAUS-2 variety, while increased the stalk, pod and seed yield of KBS-23 variety. Application of boric acidalso enhanced the growth and yield of soybean over control. It can be concluded that foliar application of silicic acid at two different doses (2 ml L^{-1} and 4ml L^{-1}) two or three times significantly enhanced the crop growth and yield of soybean. In general, silicic acid spray at 2 ml L^{-1} for three times along with RDF was found to be effective in soybean.

Key words: Foliar application; Silicic acid; Boric acid; Growth; Yield; Quality: Soybean

Effect of foliar spray of stabilized orthosilicic acid (OSA) on the fruit quality and quantity of Kinnow mandarin

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ABSTRACT

Horticulture crops are perennial with high productivity. Optimum nutritional status of crops ensures sustainable production by mitigating abiotic and biotic stresses. Silicon though not recognized as the essential nutrient for plants but its beneficial impacts to plants have been documented in both field and horticultural crops.

"Kinnow" mandarin is widely cultivated in the northern regions of India, with major growing areas spreading across Punjab, Rajasthan and parts of Haryana. The quality and yield of Kinnowis greatly affected by fluctuating climatic conditions. Present study was aimed to assess the dose and number of sprays of foliar formulation of stabilized silicic acid (Silixol) when applied at two critical stages offruit development. Foliar application was done at pea stage (starting from April) and ripening stages (starting from October) at different doses 2ml/l and 4 ml/l. Number of applications varied from 1-3 with an interval of 30 days.

The applications done at pea stage have improved the size of fruit significantly compared to untreated control. Though the number of applications and the dose of the product were not significantly different, thus indicated that single application @ 2 ml/l at pea stage of fruit would contribute to a increase in fruit size upto 25 %. The increment in size of fruit could be correlated with better nutrient status of leaves and fruits. The leave area index also improved following foliar applications.

Second application was done at the ripening stage of fruit (when fruit changes colour from green to yellow) starting from October. Applications at this stage had contributed significantly for higher juice volume and more ionic content in juice. At this stage too, no significant difference was recorded with dose and number of applications. Foliar application @ 4 ml/l was found to be the best at this stage. The shelf life of Kinnow also increased by 2 days following the foliar application, due to the formation of biogenic silicon layers within the rind of fruit. Improved juice quality is attributed due to higher sugar content and better nutrient ionic status.

To conclude, the present study highlights the importance of foliar application both in terms of yield and quality of juice. From the present study it was calculated that use of the Silixol is beneficial for kinnow growers due to high return of interest in their favour.

Rate and application time of plant available silicon on winter wheat yield and quality

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ABSTRACT

Many studies throughout the world has shown that various crops have positively responded to silicon (Si) application in terms of plant health, nutrient uptake, yield and quality. Some of the noted silicon-related benefits include: i) improved plant nutrient uptake and utilization, increased nitrogen and phosphorus use efficiency, thus, lower rates of nitrogen (N), phosphorus (P), and potassium (K), in combination with Si, may result in higher yields and better quality, ii) improved tolerance to drought and disease, and pest pressure, iii) improved plant stand and straw strength. Although not considered an essential element for plant growth, Si has been recently recognized as a "beneficial substance" or "quasi-essential", due to its important role in plant nutrition, especially notable under stress. This study was established in the fall of 2015, at two locations at University of Idaho (UI) Parma Research & Extension Center to evaluate silicon (Si) effect on wheat growth and development, grain yield and grain quality. Winter wheat (var. Stephens) was planted at 155 kg ha^{-1} seeding rate. Following preplant soil test, all plots were treated at seeding with N, P, and K to achieve UI recommended levels for wheat. Research plots were treated with Si (0-0-5) by Montana Grow Inc. (Bonner, MT). Wheat was irrigated using sprinkler irrigation system throughout the season. Two application times - emergence and Feekes 5 - and three application rates - 560, 280, and 140 kg Si ha^{-1} - corresponding to 100, 50, and 25% of manufacturer-recommended rates. Following Si application, plant height was measured in each plot. Whole plant above ground biomass samples were collected immediately prior to and two weeks after Si application. Biomass samples were analyzed for N, P, K, and Si content. At maturity, the effect of Si application rate and time on wheat grain yield, test weight, protein, and Si content were evaluated.

Keywords: winter wheat, silicon application rate, silicon application time
Conference Theme: Chemistry and analysis of silicon in soils, plants, and fertilizers

Panel Discussion

FUTURE SCENARIO OF SILICON IN AGRICUTLURE

Why is silicon still not used routinely for managing plant health and enhancing plant growth under greenhouse and field conditions?

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ABSTRACT

Since 1999 when the first silicon in agriculture conference was held, at least five books, over 60 book chapters, numerous reviews and 100s of refereed articles have been published on silicon's effects on abiotic and biotic stress as well as overall plant growth and development. Clearly, the science for silicon is well-documented and comprehensive. However, even with this robust body of information, silicon is still not routinely used for alleviating plant stress and for promoting plant growth and development in many countries. What is holding producers and growers back from using silicon? There are several reasons and include the following: lack of consistent information on which soil orders are low or limiting in silicon, no current soil tests for gauging the amounts of plant available silicon have been calibrated for many agronomic or horticultural crops, most analytical laboratories do not routinely assay plant tissue for silicon and current standard tissue digestion procedures used would render silicon insoluble, many scientist still state that plants are either silicon accumulators or non-accumulators when in reality all plants accumulate some silicon in their plant tissues, silicon is not recognized as being necessary for plant development, lack of economic studies to show the benefits of applying silicon and lack of extension outreach to present the positive benefits of silicon to producers and growers. Many of these aforementioned issues will need to be resolved if silicon is to become a standard practice in the production of agronomic and horticultural crops.

Keywords: soil orders, soil tests, silicon accumulators vs non-accumulators, plant tissue analysis

Future scenarios of silicon in agriculture: An Australian perspective

Bruce Cairns, Peter Prentice and Regan Crooks, Agripower, Australia

Research, backed by commercial field trials continually demonstrates the benefits of applying silicon to crops. Despite these results, the use of silicon in crop production systems remains relatively low.

ABSTRACT

The adoption of all new farming practices must go through a development phase prior to being accepted by agronomists and farmers as standard practice that will provide consistent benefits and an adequate return on the investment made- silicon is no different.

However, there are some issues that need to be addressed for silicon to become a accepted part of a crop production system

1. A reliable method(s) for measuring available silicon in different soils types,which correlates to a crop response and gives agronomists confidence to recommend silicon is not available
2. Silicon removal rates from harvested crops are not well established. Nutrient budgeting is commonly used tool by agronomists to determine crop nutrient requirements.
3. Lack of agreement on how Silicon fertilisers should be characterised, is leading to poor product choice by farmers.
4. Silicon is marketed as having multiple modes of action, resulting in over selling the benefits and agronomists and farmers believing that “its too good to be true”.
5. Lack of regional research carried out by government and universities. These resources no longer existin Australia and as a result silicon is not being researched and field tested to the extent that is required
6. The specifics around timing of silicon fertilisers application particularly in tree crops has to be developed with specific attentionas to how silicon fits into the overall nutrient program.
7. High application rates of solid silicon fertilisers and incompatibilities of silicon liquid fertilisers with other liquid fertilisers is restricting wider adoption

If silicon is to be successfully marketed as a nutrient, it must provide farmers and their advisers guaranteed results, like all other applied nutrients.

Silicon in agriculture: The future

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ABSTRACT

In agriculture, there are several types of silicon(Si) amendments that include*indirect* Si sources such as Si-slags,'recycled' straw, diatomaceous products and *direct* Si-sources based solely on silicic acid. However, there is insufficient recognition of the importance of Si compounds in agriculture and these sources are not mentioned in the EU list of EC fertilizers. In fact, in many countries there is a disbelief and complete lack of knowledge about Si. This still occurs despite the many scientific publications from research conducted in France, Russia, Japan, China, and India showing positive yield responses and plant disease reduction by Si fertilizers. Based on ongoing results of trials of SAAT (silicic acid agro technology) since 2003,Si can be considered as a potential '*silver bullet*' for increasing yield and quality as well as mitigating biotic and abiotic stresses. In the past decade, ReXil Agro BV took seven years to obtain registration for our silicic acid based products. Recently, we noticed a slight change in attitude the past few years thanks to our explanation of all aspects on Si such as itseffectiveness,safety, eco-aspects and CB-ratio. Since there continues to be a growing demand for safe, effective and eco-friendly agricultural products,'*the silicon community*' will need to help spread Si knowledge to agricultural institutionsand the legislating authorities to move this technology forward for the future.

Keywords: Silicon fertilizers, biostimulants, legislation, efficacy, sustainable agriculture

Status and prospects of utilization of different silicon sources: An overview of the results from seven international conferences on silicon in agriculture and future thrust

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ABSTRACT

Unlike other nutrients, especially macro (N, P, K, Ca, Mg, S) and micro nutrients (Fe, Mn, Cu, Zn) , silicon (Si) cannot be supplied as independent source materials as it has not been yet recognised as essential element for growth of higher plants. However, any source to be handy as a Si fertilizer must possess attributes like high content of Si, high solubility, provide enormous amount of plant available Si, should be cost effective, have local availability, easy to handle, have a physical nature that facilitates storage and application, and environmental friendly. Various Si sources like calcium silicate slag, calcium silicate, potassium silicate, sodium silicate, quartz sand, rice hull ash (RHA), diatomaceous earth (DE), amorphous silica (ASi) and silicic acid, etc., satisfy the first criteria, perhaps very few meet all of these requirement together. Consequently, it is very difficult to know the effect of Si alone, when such materials are being used.

From the papers presented in silicon conferences, it has been noticed that most of the research was confined to crops belonging to Poaceae family followed by Solanaceae and Fabaceae. Crop residues (straw, husk and rice hull ash), slags (processed calcium silicates, Ca and Mg silicates, and other iron and steel industry by-products), soluble Si (potassium silicate, sodium silicate and silicic acid), natural sources (diatomite and clays) and silica gel were the most commonly used Si sources for experiments. Moreover, major emphasis has been given to basic and strategic researchleading to limited number of field experiments without emphasizing cost benefit effects.

It would be ideal to include measurement of plant available Si in soil in the soil testing programme especially for silicon accumulating crops. Although problems arise in procuring sales permission for Si products, there should be some sort of provision and regulation for selling the Si products in the market. There is strong necessity of collaborative research with government agencies and Si fertilizer industries under public private partnership mode to evaluate different sources and bring it to the notice of policy makers and farmers for its effective and successful acceptance.

Keywords: Silicon conferences, Si sources, policy, collaborative research

Proven performance, economic incentive, and consistent terminology required for long-term grower adoption

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ABSTRACT

The future of silicon in agriculture is extremely promising yet dependent upon key issues within the scientific, regulatory, and business communities. How we resolve these issues could affectwhether silicon, as a crop input, is widely received as a norm within the Ag community. Agriculture is eager for value-added products that address the need forcrops to withstand increasingly severe abiotic and biotic stressors while simultaneously improving quality and yield.Before retailers and end users move new products through the distribution channel and onto fields, proven performanceand a probable economic return must be demonstrated in order to change established grower behaviors.

Among the key issues that must be addressed are scientific validation and consistent terminology. Validating silicon's key functions within the soil and plant are critical to establishing its base-line value, addressing the criteria of proven performance and economic incentives.Identifying and advocating for consistent terminology in the market space builds a reliable platform on which to effectively communicate silicon's base-line value,buildingmuch needed trust in product messaging.

Silicon in Indian agriculture: Policy and promotional issues

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ABSTRACT

Recognizing the role of fertilisers in national food security, Government of India declared fertiliser as essential commodity in 1957 and enacted Fertiliser(Control) Order(FCO) to regulate the sale, price, and quality of fertilisers.Fertiliser is highly regulated commodity in the country. For any new substance/product to be manufactured, imported or sold as fertiliser, it has to be first included in FCO. Concerted efforts were made in India during last 5 years to get the silicon fertiliser included in the FCO. Consequent upon these efforts, two major developmentsnamely, i) amendment in the definition of the term 'Fertiliser' in FCO in February, 2017 to cover the beneficial elements (silicon), and ii) inclusion of a natural silicon fertiliser 'Diatomite Amorphous Silica' in FCO in May, 2017 took place in 2017, which brought the importance of silicon in Indian agriculture to the fore. In India, not much work has been done on the extent of silicon deficiency and crop response to applied silicon. Result is that it is an uphill task to convince the farmers to use silicon fertiliser. There is a need to initiate collaborative research projects to expose the workers to the benefits of silicon application. International silicon industry should come forward to have tie ups with major Indian fertiliser companies and conduct large scale demonstrations at farmers' fieldsas *seeing is believing* is the best extension method of convincing the farmers on the soundness of any technology. Coordinated and concerted efforts by all concerned stakeholders *i.e*., research institutes, central and state governments and fertiliser industry would be needed to promote the use of silicon in Indian agriculture.

Keywords: Fertiliser Regulations, Fertiliser (Control) Order,Recent Policy Developments, Promotional Strategy

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