Silicon
in Agriculture Conference
SOUTH AFRICA 2008

4th International Conference
26-31 October 2008
Wild Coast Sun, Port Edward, KwaZulu-Natal, South Africa

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Silicon in Agriculture Conference SOUTH AFRICA 2008

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FOREWORD

Dear Colleague in Silicon,

Welcome to South Africa. Welcome to the 4th Silicon in Agriculture Conference and to the voluptuous environment of the Wild Coast.

The field of research that we meet to discuss has matured as a subject, with widespread recognition. After all, it is now nine years after the first Silicon in Agriculture Conference in Florida in 1999.

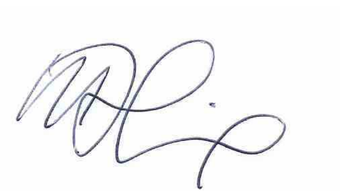
In my humble view, silicon as a plant nutrient, has made it into the consciousness of a broad agricultural public, especially in the Southern Hemisphere, where the problem is so widespread. We estimate that well over 40% of Africa's soils are deficient to severely deficient in plant available silicon. And the range and scale of papers now being published in global journals shows that its role in agriculture is being established, block by block, in many countries.

As a mature field, our concerns shift from a pioneer's issue of establishing the field, to one of consolidation and implementation. The paradigm has shifted, now we need to confirm the new paradigm.

The age profile of silicon researchers might be a concern, with many of the pioneers retiring in the near future. However, it is pleasing to see many young and middle-aged scientists and students registered at this conference.

So let the games begin. Let us hear about the next four year chapter in the dynamic field of silicon in agriculture!

Sawubonani.



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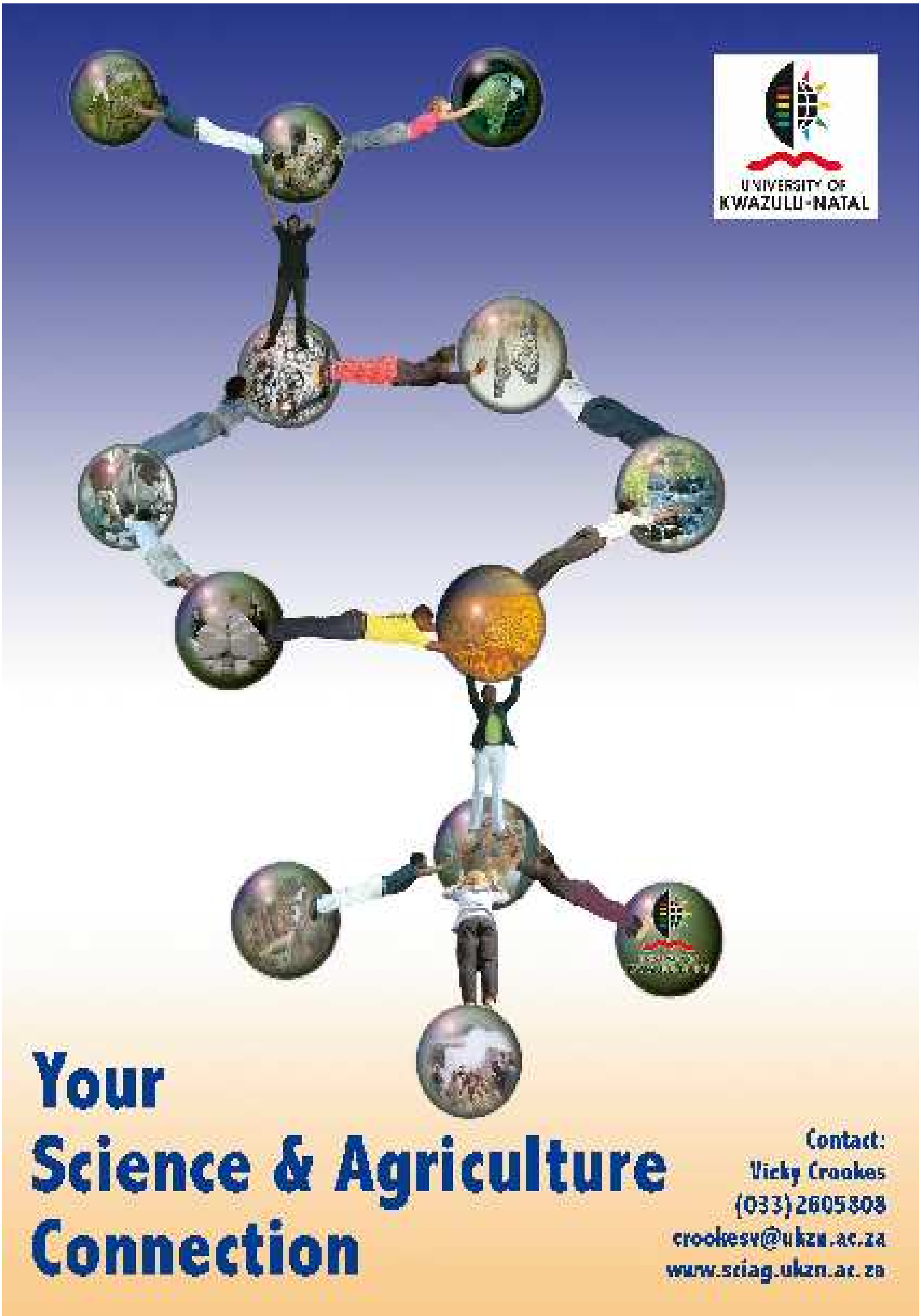
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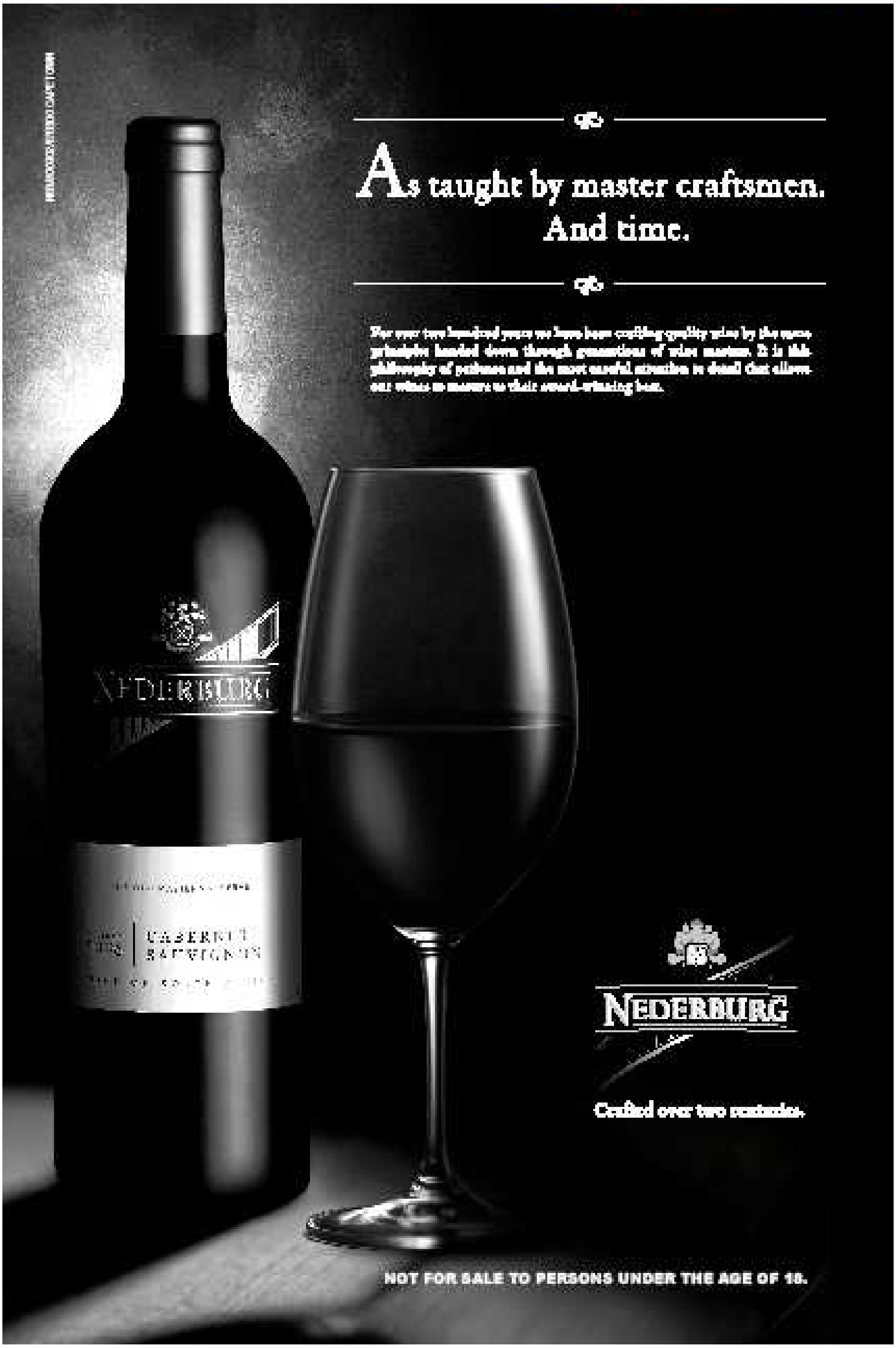
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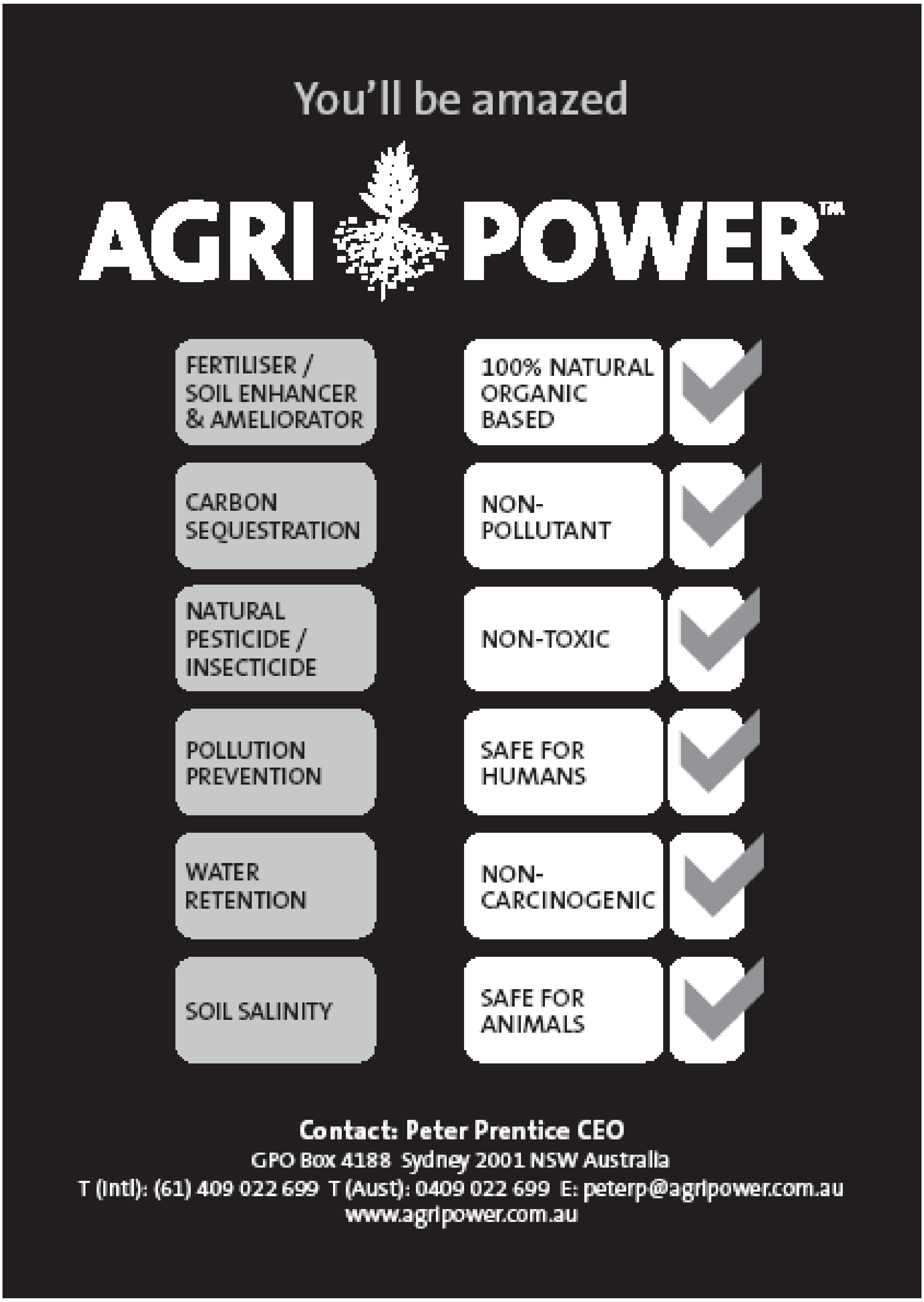
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ORAL PROGRAMME

IV Silicon in Agriculture Conference
Wild Coast Sun, KwaZulu-Natal, South Africa, 26 - 31 October 2008

Sunday 26 October 2008

Registration: 10:00 - 18:00
Ice Breaker: 18:00 - 20:00

Monday 27 October 2008

SESSION NO. 1 - SPONSORED BY PQ CORPORATION

Start time	Title	Author(s)	Presenter	Abstract Page No.
Opening Session Chair: Mark Laing				
8:30	Opening and Welcome		Mark Laing	
8:45	Climate change and the agriculture sector in South Africa: to stress or not to stress . . . that is the question	Schulze	Roland Schulze	72
9:30	Silicon: its manifold roles in plants	Epstein	Emanuel Epstein	18
10:15	Thank you to keynotes		Mark Laing	
10:30	**Coffee break & Poster Viewing**			

SESSION NO. 2 - SPONSORED BY THE UNIVERSITY OF KWAZULU-NATAL

Start time	Title	Author(s)	Presenter	Abstract Page No.
Chemistry of Silicon in Soils Chair: Jan Meyer				
11:00	Measuring soil, plant and fertilizer silicon availability	Korndorfer, Berthelsen	Gaspar Korndorfer	35
11:30	Silicon fractions in Histosols and Gleysols of a temperate grassland site	Höhn, Sommer, Schalitz, Breuer, Kaczorek	Axel Höhn	27
11:50	Soil classification on deficiency of active Si	Matichenkov	Vladimir Matichenkov	50
12:10	Calibration, categorization and status of plant available silicon in different rice soils of South India	Narayanaswamy, Chandrashekhar, Vinutha, Prakash	N.B. Prakash	61
12:30	Effects of soil type, source of silicon, and rate of silicon source on development of gray leaf spot of perennial ryegrass turf	Uddin, Nanayakkara, Datnoff	Wakar Uddin	83
12:50	**Lunch break**			

SESSION NO. 3 - SPONSORED BY THE NATIONAL RESEARCH FOUNDATION, SOUTH AFRICA

Start time	Title	Author(s)	Presenter	Abstract Page No.
Chemistry of Silicon in Soils (continued) Chair: Gaspar Korndorfer				
14:00	Some new perspectives for predicting the silicon supplying potential of soils in the South African sugar industry	Meyer, Keeping	Jan Meyer	53
14:30	The extractability of Cr(III) and Ni from soils of South Africa's Eastern Highveld as influenced by an external source of Silicon	Rossouw, De Jager, Claassens	P.S. Rossouw	71
14:50	Soil weathering degree of volcanic ash soils governs the silicon status of banana (*Musa* spp.)	Henriet, Opfergelt, Dorel, Delvaux	Bruno Delvaux	26
15:10	**Coffee break & Poster Viewing**			

SESSION NO. 4 - SPONSORED BY OMNIA NUTRIOLOGY

Start time	Title	Author(s)	Presenter	Abstract Page No.
Chemistry of Silicon in Soils (continued) Chair: Gaspar Korndorfer				
15:40	A comparison of soil extraction methods for predicting the silicon requirement of sugarcane in the South African sugar industry	Kanamugire, Meyer, Keeping	Andre Kanamugire	29
16:00	The effect of row spacing on silicon uptake in sugarcane	Smit, Meyer	Michiel Smit	78
16:20	Relationship between available silicon in soils of Mauritius, soil properties and plant silicon concentration	Lalljee	B. Lalljee	42
16:40	**Sessions concluded - Evening at leisure**			

Tuesday 28 October 2008

SESSION NO. 5 - SPONSORED BY AGRIPOWER

Start time	Title	Author(s)	Presenter	Abstract Page No.
	Silicon and Plant Stress **Chair: Richard Belanger**			
8:00	Effect of Si on growth and tolerance to stressful environments and plant diseases in higher plants including protein and oil-bearing crops	Liang	Yongchao Liang	43
8:30	Role of silicon in plant defensive system	Biel, Matichenkov, Fomina	Vladimir Matichenkov	9
8:50	Silicon application alleviated salinity stress in wheat (*Triticum aestivum* L.) grown in hydroponics and field conditions	Tahir, Aziz, Rahmatullah	Tariq Aziz	79
9:10	Alleviation of abiotic stress with silicon addition: a meta-analysis	Cooke, Leishman	Julia Cooke	15
9:10	Using Si fertilizers for reducing irrigation water application rate	Bocharnikova, Matichenkov	Vladimir Matichenkov	10
9:50	Silicon alleviates the toxicity of cadmium and zinc in maize (*Zea mays* L.) grown on a contaminated soil	Nascimento, Cunha, Silva	Clistenes Nascimento	62
10:10	Active silicon for increasing salt tolerance in plants	Kosobryukhov, Shabnova, Kreslavsky, Matichenkov	Vladimir Matichenkov	37
10:30	**Coffee Break & Poster Viewing**			

SESSION NO. 6 - SPONSORED BY PROTEIN RESEARCH FOUNDATION

	Silicon and Plant Stress (continued) **Chair: Yongchao Liang**			
11:00	Understanding the benefits of silicon feeding in plants through transcriptomic analyses	Belanger	Richard Belanger	6
11:30	Dynamic of monosilicic and polysilicic acids in the plant tissue under salt stress	Matichenkov, Biel, Bocharnikova	Vladimir Matichenkov	51
11:50	Influence of silicon on cadmium in wheat	Greger, Landberg	Maria Greger	25
12:10	Silicon improves growth and increases root cell wall extensibility of cadmium treated maize	Lux, Vaculik, Tanimoto, Luxova, Kulikova, Lichtscheidl	Alexander Lux	47
12:30	Alleviation of copper toxicity in *Arabidopsis thaliana* and *Zinnia* elegans by silicon addition	Li, Frantz, Leisner	Scott Leisner	46
13:10	**Lunch break**			

SESSION NO. 7 - SPONSORED BY THE USDA AGRICULTURAL RESEARCH SERVICE

	Silicon and Disease Management **Chair: Fabricio Rodrigues**			
14:10	Influence of insoluble and soluble silicon on leaf blast development in rice	Datnoff, Ma, Mitani	Lawrence Datnoff	17
14:40	Cold stress ameliorating effect of silicon and its impact on Fusarium wilt of banana	Kidane, Laing	Eyob Kidane	31
15:00	Movement of silicon through *Saccharum officinarum* (sugarcane) and its effect on *Puccinia melanocephala* (brown rust)	Naidoo, Caldwell, McFarlane	Prabashnie Naidoo	60
15:20	Preharvest or postharvest silicon treatment for the control of postharvest *Penicillium digitatum* of citrus fruit	Abraham, Laing, Bower, Clark	Abraha Abraham	1
15:40	**Coffee Break**			
16:10	**Poster Presentations - 1 minute each** **Chair: Shaun Berry** **SPONSORED BY PISTORIUS**			
17:00	**Sessions concluded**			
18:00	**Braai**			

SESSION NO. 10 - SPONSORED BY DISTELL

Silicon in Plants Chair: Olivia Kvedaras				
14:00	The case for organosilicate chemistry in-planta	Kinrade	Stephen Kinrade	34
14:30	Silicon transporters in rice	Yamaji, Mitani, Ma	Naoki Yamaji	89
14:50	Silicon transporters in maize and barley - comparison of silicon transporters in different plants species	Mitani, Chiba, Yamaji, Ma	Namiki Mitani	56
15:10	Silicon and germanium uptake and transport by plants using Ge/Si ratio and Si isotopes	Opfergelt, Delvigne, Cardinal, Delvaux, André	Sophie Opfergelt	65
15:30	**Coffee Break & Poster Viewing**			

SESSION NO. 11 - SPONSORED BY FLORATINE BIOSCIENCES, INC.

Silicon in Plants (continued) Chair: Olivia Kvedaras				
16:00	Forest tree species impacts the plant uptake of silicon	Cornélis, Ranger, Delvaux	Jean-Thomas Cornelis	16
16:20	Evaluating silicon uptake in floriculture crops grown in the U.S.	Frantz, Locke	Jonathan Frantz	21
16:30	Effect of silicon and nitrogen rates on N and Si absorption and rice yield (*Oryza sativa* L.) in two water management systems in the north of Iran	Ghanbari Malidarh, Kashani , Nourmohammadi, Mobasser, Alavi, Fallah	Abbas Ghanbari Malidarh	23
17:00	**Sessions concluded**			
18:00	**Wine Tasting (WINE SPONSORED BY DISTELL)**		**Rasvan Macici & Dirk Bosman (Distell)**	
19:00	**Gala Dinner & Awards Presentation (WINE SPONSORED BY DISTELL)**		**Mark Laing & Olivia Kvedaras**	

Friday 31 October 2008

SESSION NO. 12 - SPONSORED BY ARYSTA LIFESCIENCE

Start time	Title	Author(s)	Presenter	Abstract Page No.
Silicon in Plants (continued) Chair: Graham Kingston				
8:00	Silicon in dicotyledonous plants	Laing, Kidane	Mark Laing	41
8:30	Uptake and distribution of silicon on *Zucchini* and *Zinnia* and its Interaction with other elements	Tesfagiorgis, Laing, Morris	Habtom Tesfagiorgis	82
8:50	Effect of oligomeric silicon and low dose boron as foliar application on wet land rice	Prakash , Chandrashekhar, Mahendra, Thippeshappa, Patil , Laane	N.B. Prakash	67
9:10	Effects of silicon application to nitrogen rate and splitting on agronomic characteristics rice (*Oryza sativa* L.)	Mobasser, Ghanbari Malidarh, Sedghi	Hamid Reza Mobasser	57
9:30	Calcium silicate as silicon source and its interaction with nitrogen in aerobic rice	Shashidhar, Chandrashekhar, Narayanaswamy, Mahendra, Prakash	H.E. Shashidhar	74
9:50	Steel slag as a silicon source for sugarcane: evaluation of Si availability and plant accumulation	Ferreira, Nascimento, Silva, Costa	Clistenes Nascimento	20
10:10	Response of rice and sugarcane to Mg silicate in different soils of Colombia, South America	Bernal	Javier Bernal	7
10:30	**Coffee Break & Poster Viewing**			

SESSION NO. 13 - SPONSORED BY SA LIME & GYPSUM

Silicon in Plants (continued) Chair: Malcolm Keeping				
11:00	Silicon fertilisers - requirements and field experiences	Kingston	Graham Kingston	33
11:30	Silicates in contemporary Australian Farming: A 20 year review	Lynch	Mel Lynch	49
11:50	Silicon for humans: beneficial or essential?	Laane	Henk-Maarten Laane	40
12:10	**Closing Ceremony: Presentation on next Silicon in Agriculture Conference, China Closing remarks & fairwell**		Mark Laing Yongchao Liang Mark Laing	
13:00	**Lunch**			

POSTER PROGRAMME

IV Silicon in Agriculture Conference
Wild Coast Sun, KwaZulu-Natal, South Africa, 26 - 31 October 2008

Monday 27 October 2008

SESSION NO. 1

Title	Author(s)	Presenter	Poster No.	Abstract Page No.
Chemistry of Silicon in Soils Silicon and Plant Stress				
Correlation between two methods for silicon extraction in natural and undisturbed tropical savanna soils of Brazil	Lima Filho, Silva	Oscar Fontão de Lima Filho	1	45
Silicon-mediated responses of soybean to UV-B radiation stress	Shen, Li, Li, Duan, Wang, Eneji	A. Egrinya Eneji	2	75
Silicon status and its relationship with major physico-chemical properties of soils in the northern highlands of Ethiopia	Yimamu	Fassil Kebede Yimamu	3	90
Response of sugarcane to silicon levels and sources in medium deep black soils	Phonde, Pawar, Yadav, Ghodake	D.B. Phonde	4	66
Alleviation of abiotic stress with silicon addition: a meta-analysis	Cooke, Leishman	Julia Cooke	5	15
Effects of silica gel supply on leaf silica concentration, other traits and covariations within six tropical fodder grass species grown in humid conditions	Kindomihou, Ma, Mitani, Kazunori, Sinsin, Matsumae, Meerts	Valentin Kindomihou	6	32
Silicon-mediated alleviation of salt stress effects in sugarcane genotypes differing in salinity tolerance	Ashraf	Muhammad Ashraf	7	3
Status of silicon in soils of Middle Egypt	Morsy	Mahmoud Morsy	8	58
Physiological changes with silicon application to improve salt tolerance in wheat genotypes under salt stress	Mukaram, Rahmatullah	Rai Mukaram	9	59

Tuesday 28 October 2008

SESSION NO. 2

Silicon and Disease Management				
Effect of silicon and nitrogen rates on leaf and neck blast, chlorophyll content and yield of rice (*Oryza sativa* L.) in two water management systems (flooding and deficit irrigation) in the north of Iran	Ghanbari Malidarh, Mobasser, Alavi	Abbas Ghanbari Malidarh	10	24
Assessing the effectiveness of silicon content materials against blast disease of rice	Quazi, Mohammed	Shireen Quazi	11	68
A new Silicon technology for powdery mildew protection in IPM strategies.	Botta, Sierras, Marín, Carrion, Piñol	Anna Botta	12	11
The in vitro and in vivo effect of silicon on *Fusarium* wilt on potatoes	Nxumalo, Wairuri, van der Waals	Nokukhanya Nxumalo	13	63
Greenhouse evaluation of effect of silicon soil applications for control of *Verticillium* wilt of potatoes	Millard, van der Waals, van der Waals	Cornel Millard	14	54
The effect of silicon-amended soil on the phenolic content of potato tubers infected with *Pectobacterium carotovorum* subsp. *brasiliensis*	Van der Merwe, Van der Waals, Van der Waals	Jacquie van der Waals	15	84
Control of eucalyptus seedlings dumping off by silicon	Coelho, Silva, Duarte, Moura	Lísias Coelho	16	14
Inhibitory effects of foliar applied Si on powdery mildew in greenhouse cucumber	Wolff, Rohloff, Karoliussen	Kenneth Day	17	87
Impact of silicon on the susceptibility of banana plants (Musa acuminata) to black Sigatoka disease	Kablan, Delvaux, Legreve	Lucie Kablan	18	28

Thursday 30 October 2008

SESSION NO. 3

Silicon and Plants - 1				
Characterization of silicon transporters from rice and maize	Mitani, Yamaji, Ma	Namiki Mitani	19	55
A transporter regulating silicon distribution in rice shoots	Yamaji, Mitani, Ma	Naoki Yamaji	20	88
Mobility and deposition of silicon in rice and bean plants using the stable isotope 30Si	Carneiro, Oliveira, Bendassolli, Abreu Jr, Rossete	Josiane Carneiro	21	13
Transcriptome analysis of the silicon-*Magnaporthe* grisea interaction	Brunings, Datnoff, Ma, Mitani, Nagamura, Rathinasabapathi	Lawrence Datnoff	22	12
Differential uptake of silicon in two cultivars of pumpkin	Ago, Mitani, Yamaji, Iwasaki, Ma	Yukiko Ago	23	2
Study of silicon effects on wheat cultivars under drought stress	Tale Ahmad, Haddad	Sara Tale Ahmad	24	80
Dynamic of the uptake and accumulation of silicon in wheat, rice, soybean and bean in nutrient solution	Oliveira, Carneiro, Bendassolli, Abreu Jr.	Lilian Oliveira	25	64
Production of foliar phenolics and condensed tannins in pigeon pea and leucaena supplemented with silicon	Lima Filho, Abdalla	Oscar Fontão	26	44

Friday 31 October 2008

SESSION NO. 4

Silicon and Plants - 2				
Potato production as influenced by soil applications of silicon	Seome, van der Waals, van der Waals, Marais	Daphney G. Seome	27	73
The effect of silicate on potatoes in Minas Gerais, Brazil	Luz, Rodrigues, Gonçalves, Coelho	Lísias Coelho	28	48
Effect of the foliar application of soluble oligomeric silicic acid and low dose boric acid on papaya trees	Realpe, Laane	Henk-Maarten Laane	29	69
New generation of silicon fertilizers	Matichenkov, Bocharnikova	Vladimir Matichenkov	30	52
Study of the effect of silicon on lodging parameters in rice plants under hydroponics culture in a greenhouse experiment	Fallah	Abbas Ghanbari Malidarh	31	19
Effect of silicon application on rice productivity in a rice-wheat cropping sequence	Singh, Singh, Singh	R.K.Singh	32	77

PREHARVEST OR POSTHARVEST SILICON TREATMENT FOR THE CONTROL OF POSTHARVEST *PENICILLIUM DIGITATUM* OF CITRUS FRUIT

Abraham, AO[1], Laing, MD[1], Bower, JP[2] and Clark, C[1]

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Postharvest application of silicon potassium silicate (Ksil) reduced disease lesion diameter caused by *Penicillium digitatum* in lemon fruit at 22±1°C. The inhibition or delayed fruit decay was correlated with Ksil concentrations. Potassium silicate concentration at 100,000 mg L^{-1} provided the lowest lesion diameter when applied as preventative treatment (3 h before potassium silicate inoculation with *P. digitatum*) or a curative treatment (inoculated with *P. digitatum* 3 h before treatment). Based on results with scanning electron microscopy, germination and growth of *P. digitatum* was inhibited or germination of spores delayed up to 10 d by Ksil in the wounds of lemon fruit, compared with a water-treated control. Application of potassium silicate as root drench application in the field three months before harvest did not significantly reduce the incidence of *P. digitatum* on navel or Valencia fruit stored at 22±1°C or 7±1°C. However, continued application of KSil to the same orchard trees for a full season resulted in significant reduction in the incidence of *P. digitatum* on both fruit. The best control was achieved at 1000 mg L^{-1}. Some fruit from field potassium silicate treatment were further treated with a yeast isolate B13 (*Candida fermentati*) as postharvest and decay was completely controlled. Therefore potassium silicate has shown great potential in controlling postharvest green mould of citrus fruits when applied pre or postharvest or both. It also provided synergistic effects with yeast isolate B13, a biocontrol agent, to provide a high level of control of *P. digitatum* fruit disease.

Keywords: citrus, silicon, yeast, biological control

DIFFERENTIAL UPTAKE OF SILICON IN TWO CULTIVARS OF PUMPKIN

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

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The accumulation of silicon (Si) in plant shoots differs widely between species, ranging from 0.1 to 10% dry weight. Gramineae and Cyperaceae show high Si accumulation, while Cucurbitaceae, Urticaceae and Commelinaceae show intermediate accumulation, and most other plant species show low Si accumulation. On the other hand, there are genotypic differences in Si accumulation, with the mechanisms underlying these differences being unknown. Physiological studies were conducted to compare the uptake and translocation of Si in two pumpkin cultivars. Shintosa (ST) and Super Unryu (SU) were used as rootstock to produce blooming and bloomless plants, respectively. Since blooms contain Si, the difference in bloom production may result from the ability of the roots to take up Si. Accumulation of Si in the two cultivars was compared by growing them in soil under the same conditions. The Si concentration in SU shoots was 0.06%, whereas that of ST was 0.96% dry weight. To understand the mechanisms underlying the different Si accumulation, the Si uptake by the whole root system was compared in the two cultivars. A time-course experiment up to 24 h showed that Si uptake by ST was much higher than that by SU. A kinetic study showed that Si uptake increased with increasing external Si concentrations in both cultivars, and Si uptake by ST was significantly higher than that by SU at both Si concentrations. To further confirm these results, the Si uptake per single root was compared between cultivars by using a transport compartmentation box. The results showed that, similar to the results from the whole root systems, Si uptake by ST was much higher than that by SU. These results indicate that the difference in Si accumulation depends on the ability of the roots to take up Si. Also compared were Si concentrations in the root symplast and xylem between the two cultivars. The concentration of Si in the symplast was two-fold higher in ST than in SU at the root tip (0-15 mm) and mature zone (15-30 mm). The Si concentration in the xylem sap was 15-fold higher in ST than in SU. Furthermore, the Si concentration in the xylem of ST was higher than that in the external solution, whereas that of SU was lower than that in the external solution. Taken together, results suggest that ST has an active transport system for Si from the external solution to root-cell symplast and xylem. Work on transporters involved in Si uptake is currently being undertaken.

Keywords: pumpkin, silicon

SILICON-MEDIATED ALLEVIATION OF SALT STRESS EFFECTS IN SUGARCANE GENOTYPES DIFFERING IN SALINITY TOLERANCE

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Soil salinity is a major abiotic stress which adversely affects crop yield and quality. However, adequate regulation of silicon (Si) may ameliorate the deleterious effects of salinity and help to sustain crop productivity under salt stress. Salt sensitive (SPF 213) and salt tolerant (HSF 240) sugarcane genotypes were grown in gravel at 0 and 100 mM NaCl by supplying 0, 3, 4.5 and 6 mM Si as calcium silicate. Results revealed that plants treated with NaCl alone showed reductions of 48% in dry matter, 27% in chlorophyll content, 32% in photosynthetic rate, 39% in shoot K concentration, 43% in cane yield and 30% in sugar recovery in the salt sensitive genotype compared to the control. The salt tolerant genotype showed relatively less reduction at 28% in dry matter, 22% in chlorophyll contents, 19% in photosynthetic rate, 26% in shoot K concentration, 27% in cane yield and 25% in sugar recovery. Addition of calcium silicate significantly (p=0.05) reduced the uptake and translocation of Na^+, but increased K^+ concentrations in roots and shoots of both sugarcane genotypes with a resultant increase in the K^+:Na^+ ratio, a good indicator for assessing salt tolerance. Chlorophyll contents and photosynthetic rate were also significantly (p=0.05) improved by added silicate. Cane yield and yield attributes such as cane height, cane girth, internode length and number of tillers per plant were significantly (p=0.05) higher where silicate was added. Juice quality characteristics such as Brix (% soluble solids in juice), Pol (% sucrose in juice), commercial cane sugar (CCS) and sugar recovery were significantly (p=0.05) improved in both the salt sensitive and salt tolerant sugarcane genotypes with the supplementation of silicate. Concentrations of Si in shoots were positively correlated with corresponding shoot dry matter in both genotypes. The results suggested that Si interacted with Na^+, reduced its uptake and transport to shoots and consequently improved cane yield and juice quality in salt sensitive and salt tolerant sugarcane genotypes under salt stress.

Keywords: sugarcane, silicon, salt stress, salinity

EFFICACY OF WATER SOLUBLE POTASSIUM SILICATE AGAINST PHYTOPHTHORA ROOT ROT (*PHYTOPHTHORA CINNAMOMI*) OF AVOCADO (*PERSEA AMERICANA* MILL.)

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Avocado root rot caused by *Phytophtora cinnamomi* Rands. is a serious disease of avocados worldwide. *In vitro* dose responses to soluble potassium silicate (20.7% silicon dioxide) were determined. Inhibition of mycelial growth was dose-related, with 100% inhibition at all concentrations tested. Potassium silicate applied as a soil drench to *P. cinnamomi* inoculated avocado trees in the greenhouse effectively suppressed root rot, stimulated regeneration of new roots and resulted in significantly higher root mass compared to the untreated *P. cinnamomi* inoculated controls. Disease suppression with a single application of silicon was similar to that of potassium phosphonate application. Field trials were also conducted in a 13-year old ‘Hass’ on ‘Duke 7’ avocado orchard naturally infested with *P. cinnamomi*. Three soil drench applications of potassium silicate per season resulted in significantly higher root densities of avocado trees than the untreated control and potassium phosphonate treatments. Furthermore, tree canopy condition, which is an indication of tree health, was significantly improved by three soil drench treatments of potassium silicate when compared to untreated control trees. These findings confirm that potassium silicate applied as a soil drench to *P. cinnamomi* infected trees, is a viable control measure for avocado root rot and may be considered as an alternative to the conventional fungicide treatment currently being used against the disease.

Keywords: avocado, silicon, avocado root rot, potassium silicate, phosphite, phosphorous acid, silicic acid

ACCUMULATION OF SOLUBLE AND WALL-BOUND PHENOLIC POLYMERS IN AVOCADO (*PERSEA AMERICANA*) ROOTS EXPOSED TO *PHYTOPHTHORA CINNAMOMI* RANDS. AFTER SILICON APPLICATION

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Root rot of avocado trees, caused by *Phytophtora cinnamomi* Rands. is the most serious disease of avocados worldwide. Application of potassium silicate as a soil drench has shown positive results as a potential alternative treatment effective against avocado root rot, and the current study focuses on the role that phenols play in this process. Soluble and wall-bound phenolics and phenolic polymer accumulation in *Persea americana* Mill. roots from thirteen year-old 'Hass' on 'Edranol' trees exposed to the pathogen *Phytophthora cinnamomi* Rands., and treated with water soluble potassium silicate was investigated. The root tissue was found to respond strongly towards the applied potassium silicate through the increased synthesis of phenolic compounds compared to the untreated control. Following elicitation, conjugated and non-conjugated phenolic metabolites present in the induced root tissue were extracted and quantified. Three applications of soluble potassium silicate per season resulted in significantly higher concentrations of crude phenolic compounds in the roots compared to the untreated control. Upon extraction of phenolic fractions it was clear that three potassium silicate applications per season led to a significant increase in glucoside bound phenolic acid concentration compared to the untreated control over a period of 18 months. Significantly lower cell wall-bound phenolic acid concentrations were found in potassium silicate treated trees compared to the control treatment over the same period. High performance liquid chromatography (HPLC) separation of hydrolysed phenolic acids extracted from roots revealed all non-conjugated phenolic acid hydrolysed samples to contain 3,4-hydroxibenzoic acid. The glucoside-bound samples of both the potassium phosphonate and the untreated control treatments contained 3,4-hydroxibenzoic acid and vanillic acid, while the control also contained syringic acid in the hydrolysed glucoside-bound extract. Although potassium silicate treatment of avocado trees resulted in fewer identifiable phenols in avocado roots compared to the untreated control treatment, these results indicate that potassium silicate application to avocado trees under *P. cinnamomi* infectious conditions increase total phenolic content of avocado root tissue.

Keywords: avocado, silicon, phenols, potassium silicate, *Phytophthora cinnamomi*, root rot

UNDERSTANDING THE BENEFITS OF SILICON FEEDING IN PLANTS THROUGH TRANSCRIPTOMIC ANALYSES

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There is accumulating evidence, based on recent scientific findings, that silicon (Si) feeding will provide benefits to plants by alleviating stress caused by abiotic and biotic factors. However, this evidence is tainted by conflicting reports on how benefits are affected by the source of Si, the mode of application, the concentration used, the plant species, the mode of action, the abiotic factor involved and the plant pathogen studied. To better understand the intrinsic properties of Si, transcriptomic analyses now offer unprecedented opportunities to look into the most subtle changes in plants in response to Si feeding. For instance, in a recent work, more than 30,000 genes were analyzed simultaneously in Arabidopsis plants grown under conditions of pathogen stress or not. The results revealed that unstressed plants appeared to be unaffected by Si feeding as only two genes were up-regulated. This observation somewhat contradicts previous reports claiming that Si feeding increases photosynthesis, chlorophyll content and other activities linked to the primary metabolism. On the other hand, in stressed plants (infected with powdery mildew), Si-treated plants responded much better to the infection by up-regulating a number of defense-related genes and by displaying an overall better physiological activity than non-treated plants. This would indicate that the benefits of Si feeding are manifest primarily, if not exclusively, under conditions of stress. While these results have been generated through the Arabidopis model system, recent advances in genomics have made it possible to contemplate using agricultural plants, such as rice and wheat, that have been better documented in terms of response to Si. Indeed, in the case of rice and wheat, their genome has been fully sequenced, many genes annotated and commercial chips developed. This now makes it possible not only to study the complete transcriptomic responses of different plant species fed with Si under a variety of conditions, but also to compare this response among plants with different abilities to absorb Si. This powerful approach should thus find many applications in the effort to optimize the use of Si in agriculture.

Keywords: arabidopsis, silicon, transcriptomics, powdery mildew, disease resistance

RESPONSE OF RICE AND SUGARCANE TO MAGNESIUM SILICATE IN DIFFERENT SOILS OF COLOMBIA, SOUTH AMERICA

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Magnesium silicate is a natural product found in Colombia, South America, and is being used extensively as a soil conditioner and source of soluble Mg and Si for different crops. Magnesium silicate contains 31% MgO and 32% SiO_2. Applied at low rates of 100 to 300 kg/ha to acid or basic soils, it increases yields of different crops such as sugarcane and rice by between 5 and 20%. It can be applied as dust or pellets, alone or mixed with other conditioners or fertilizers.

Several trials have been conducted in the rice and sugarcane growing zones of the country. A summary of some results obtained in Cauca valley with sugarcane are reported in the present paper. Rice trials were also conducted in the eastern planes, Magdalena valley and the Atlantic coast, the three main rice producing areas of the country. Determinations basically included cane and sugar production for sugarcane, and yield of grain (green paddy) for rice.

Results obtained indicate a positive response in yield and other parameters determined with the application of increasing rates of Mg silicate to agricultural soils of Colombia, mainly those with low pH and high soluble Al and Fe and a high P-fixing capacity. Yield of sugarcane increased by 17.37 tons/ha (14.63%) and sugar production increased by 20.5% in relation to the control with an application of 200 kg/ha of Mg silicate. Rice production increased between 21 and 33% with rates of application ranging between 100 and 200 kg/ha, in relation to the control treatment.

Keywords: sugarcane, rice, silicon, magnesium silicate, Colombia

SILICON AND PLANT PARASITIC NEMATODES IN SUGARCANE

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Plant parasitic nematodes are a constraint to sugarcane production, particularly on the sandy soils of South Africa. Research into reducing the impact of nematodes on sugarcane productivity has been ongoing for the past 30 years. At present, nematode management is achieved through the use of chemical nematicides and the choice of resistant varieties. The former option is the most widely adopted. However, the negative environmental impact and gradual withdrawal of many nematicides has resulted in the need to find alternative solutions. Because of its beneficial impact on sugarcane, silicon (Si) has been gaining in popularity in recent years. Much research conducted within the South African sugar industry has shown the effectiveness of Si against the main stem borer insect, *Eldana saccharina* Walker (Lepidoptera: Pyralidae).

In 2002, a silicon x variety trial was established to study the effect of different rates of Si and different varieties on reducing the impact of *E. saccharina*. It was decided to use this trial to also assess the impact of Si on plant parasitic nematode populations, a study that had never been done before. Initial results were encouraging, and led to further investigation of the effect of Si on these organisms under more controlled conditions. Two pot trials were thus established in 2003 and 2006 for this purpose. Two different Si sources were used: Thompson slag for trial 1 and Calmasil for trial 2, both applied at two rates (5 t ha^{-1} and 10 t ha^{-1}). These were compared to untreated control pots in a split-plot design.

Results showed that the amount of Si in the roots correlated with that in the leaves. In addition, even though no Si had been added to the control pots, the average Si in the control roots (1.2%) was relatively high compared to other crops and not significantly different to that of the treated pots (1.6%). Si also had an impact on the nematode community: there was no effect on the total number of plant parasitic nematodes, but rather an effect on different genera. The ectoparasitic nematodes were the most affected, with significant reductions in numbers of *Helicotylenchus dihystera*, *Paratrichodorus minor* and *Xiphinema elongatum* for variety N27, and significant reductions in numbers of *X. elongatum* for variety N12. Both varieties exhibited significant decreases in the free-living (non-plant parasitic) nematodes.

Future challenges in Si research are to understand its mode of action, how it affects the different components of the nematode community and what effect this has on sugarcane growth and yield.

Keywords: sugarcane, silicon, nematodes

ROLE OF SILICON IN PLANT DEFENSIVE SYSTEM

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It is well known that optimization of plant silicon (Si) nutrition reinforces plant resistance against biotic and abiotic stresses. Traditionally, it is suggested that an accumulation of Si in the epidermal tissue of the plant is the main mechanism which provides defense against insect and fungal attacks. The chemical properties of monosilicic acid maintain plant protection against the effects of heavy metal contamination. However, phenomenons associated with Si fertilization, such as increased plant resistance to drought, frost and viral attacks, were not explained. New data obtained from greenhouse, laboratory and field experiments, as well as from literature sources, allowed a new hypothesis to be formed with regard to reinforcement of the plant's defense system by active Si. The role of Si in the plant defense system will be presented, and the participation of Si in stress tolerance promotion in organisms will be discussed. According to the hypothesis, plants, as well as every other living organism (humans, animals and microorganisms) have unique protective mechanisms which involve in part the mobile Si compounds (mostly monosilicic acid and polysilicic acids). It is speculated that the function of the Si constituent can provide additional synthesis of stress protection molecules, and this synthesis is carried out under genetic control but without “physical” participation of the genetic apparatus. The assumption is based on indirect experiments, and on a basis of subordination of two constituencies: (a) response of genetic apparatus to stress, ensuring synthesis of stress protection compounds such as antioxidant enzymes, stress proteins, glutathione, phenols and others antioxidants, and (b) on additional non-enzymatic formation of the same protection compounds on the matrixes of polysilicic acids. The active forms of Si within plants are being considered as a matrix-depot for the formation of compounds which assist the organism(s) to maintain positive homeostasis under stressful conditions. This hypothesis provides the possibility of elaborating new ways to protect cultivated plants against unfavourable conditions and biotic stresses.

Keywords: plants, silicon, active silicon, stress tolerance

USING SILICON FERTILIZERS FOR REDUCING IRRIGATION WATER APPLICATION RATE

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Water is a limiting factor for plant growth in the dry and semi-dry regions. Unfortunately, traditional irrigation technology does not prevent high losses (about 60-70%) of plant-available water due to leaching, evaporation, and transpiration through plants. The drip irrigation system allows a reduction in fresh water withdrawals by reducing water leaching, but does not affect evaporation and transpiration levels. New technology for reducing irrigation water application rate was elaborated and tested in laboratory and field experiments. The technology is based on the use of Si fertilizer with a high content of active Si. Plants adsorb Si in an amount exceeding that of other nutrients. Optimization of Si nutrition results in increased weight and volume of roots by 20 to 200% and in enhanced drought and salt resistance in cultivated plants. Active Si compounds are shown to be extremely important for formation of soil fertility. These compounds have a direct effect on soil texture and increase soil water holding capacity by 20 to 30% and exchange capacity by 10 to 25%. Barley, wheat and grass were used in the greenhouse experiments and sorghum was used in the field trial, which were conducted on sandy soils. The active Si benefits were demonstrated to include improved soil adsorption capacity (increased by 20 to 40%) and soil water holding capacity (increased by 10 to 30%) as well as enhanced plant resistance to water deficiency and salt toxicity. The greenhouse tests with different water regimes and salt concentrations in irrigation water allowed determination of the most effective sources of solid and liquid Si fertilizers which could be used on commercial fields. The technology allows reducing irrigation water application rate by 10 to 40% without negative influence on crop productivity and quality. The field demonstration showed that the application of commercial Si fertilizer ensured the survival of the sorghum crop in the treated plot, while in the control plot all plants withered. The elaborated technology can be adapted for any soil climatic conditions and quality of irrigation water. This preliminary analysis of the use of active Si in agriculture relative to crop production, water discharge and environmental benefits was conducted in the dry and semi-dry regions of different countries.

Keywords: silicon, water stress, irrigation, silicon fertilizer, technology

A NEW SILICON TECHNOLOGY FOR POWDERY MILDEW PROTECTION IN IPM STRATEGIES

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Powdery mildew type fungi are among the most persistent and common diseases limiting production of a wide range of crops worldwide. In addition to direct damage caused by the pathogen, fungal disease also weakens the plant's resistance to any biotic or abiotic stress factor. With this in mind, the R&D Department of Bioiberica, SA, focused on plant stress management to develop a new foliar spray product containing amino acids plus soluble active silicon (Si). This approach combines the well-known beneficial properties of both components: the biostimulant effect of amino acids, which helps plants to rapidly overcome physiological stress, and the effect of Si on the plant's resistance to fungal infections. Two modes of action have been reported to elucidate the Si effect: a structural reinforcement function due to its deposition underneath the plant cell wall and, more recently, the role of soluble Si as an inducer of plant defense responses. Regardless of these mechanisms acting in an independent or complementary way, alternative plant disease protection treatments have recently aroused more interest due to limitations on the use of pesticides and environmental concerns. This study sums up the results of several new product trials in different plant-pathogen systems. Findings confirm a synergic effect of amino acids plus Si on a reduction in the incidence and severity of powdery mildew in different plant species of agricultural interest, such as fruit trees and horticultural crops. The use of this new double-action product permits a reduction in the number of fungicide applications while improving health and yield parameters in sustainable crop management.

Keywords: silicon, biostimulant, stress, powdery mildew

TRANSCRIPTOME ANALYSIS OF THE SILICON-*MAGNAPORTHE GRISEA* INTERACTION

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Silicon (Si) is known to increase resistance to the rice blast pathogen *Magnaporthe grisea*. To investigate the extent to which the transcription profile of rice is altered in plants amended with Si in response to *M. grisea*, a microarray study with a 44 kb genechip was conducted to assess the global activation/repression of rice genes using the rice cultivar Monko-to and *M. grisea* 86-137. Plant gene expression was analyzed by comparing plants amended with Si to untreated control plants (Si/c), plants inoculated with the pathogen compared to those untreated (P/c), plants amended with Si and inoculated with the pathogen compared to plants amended with Si (SiP/Si), and plants amended with Si and inoculated with the pathogen compared to plants inoculated with the pathogen (SiP/P). The Si/c comparison yielded 281 differentially regulated genes, including metabolic and plant defense response genes. Not surprisingly, 486 genes were differentially regulated in the P/c comparison. Most interestingly, 432 genes were differentially regulated in the SiP/P comparison, of which 231 were unique to this comparison. In the SiP/P comparison, 491 transcripts were differentially regulated, of which 167 were unique. In addition to known pathogenicity response genes, a number of genes encoding transcription factors, and proteins with protein-protein interaction domains, were identified as unique to the response of Si-amended rice to the blast pathogen. The data suggest that Si-mediated resistance involves multiple pathways, changing the plant response to rice blast infection. Si amendment clearly results in altered plant defense signaling, rendering the plant more resistant to infection by *M. grisea*.

Keywords: rice, silicon, *Oryza sativa* L.

MOBILITY AND DEPOSITION OF SILICON IN RICE AND BEAN PLANTS USING THE STABLE ISOTOPE ^{30}SI

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Silicon (Si) is an important element for plant development, and its presence has been related to increased plant resistance. Si accumulation differs greatly between plant species. Rice has a gene encoding an Si uptake transporter, the low silicon rice 1 (*Lsi1*) gene, which controls Si accumulation. According to literature, Si absorbed by the roots in the form of monosilicic acid (H_4SiO_4) is carried through the plant and deposited in the leaves, but its mobility within the plant after accumulation in plant tissue is unknown. Stable Si isotopes can be used to trace the biochemical pathways of Si as it moves from its source to different parts of the plant system, thereby providing new knowledge on the role and behavior of Si in plants. In this work, the mobility and deposition of Si were studied in rice (Si accumulator) and bean (Si non-accumulator) plants grown in nutritive solution labeled with the stable isotope ^{30}Si. The Si isotopic composition was determined by mass spectrometry using the method based on SiF_4 formation. According to results, rice and bean differed widely in uptake capacity for Si. The absorption level was ±85% for rice and 42% for bean. The Si concentration exhibited a significant gradient with a progressive increase from lower to upper organ in both cultures, and approximately 75% of the total Si was distributed in the leaf tissues. It was found that transportation of Si from the nutritive solution to the leaf tissue is mediated in both species, and up to 94% of the Si taken up by plants was transported rapidly to the leaves. That the Si accumulation is much higher in rice than in bean plants might be explained by a defect in or the absence of a Si transporter in bean plants. The cumulative amounts taken up by rice and bean grown at 25 mg L^{-1} Si were 17 and 8.5 mg per plant, respectively. The absence of Si in the new leaves showed that when Si is accumulated in the older leaf tissues it is not redistributed to the new leaves. This is possibly due to Si polymerization as SiO_2 in the tissues of the older leaves.

Keywords: rice, bean, silicon, stable isotope, mobility, deposition

CONTROL OF EUCALYPTUS SEEDLINGS DUMPING OFF BY SILICON

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Seedling production is the most critical phase for forming quality forests due to the high seedling density, their susceptibility to abiotic and biotic stresses, and because environmental conditions are favourable for disease development. Silicon (Si), a beneficial micronutrient for plants, has been reported as capable of mitigating both abiotic and biotic stresses. Among the biotic stresses are diseases, such as dumping off, caused by several fungi, and leaf spot. This study analyzed Si accumulation in eucalyptus seedlings and its effect on leaf disease control. The best leaf for Si accumulation analysis was determined by collecting leaves from three positions (upper, intermediate and lower third) of the seedlings in a commercial nursery located at Itumbiara, GO. Material from another nursery, at Belo Oriente, MG, was used to evaluate the fertigation systems: (i) drip irrigation in a sand substrate and (ii) the nutrient film technique in stainless steel trays. The material collected in this nursery had been previously evaluated for resistance to the major diseases, and these data were used to correlate Si accumulation with disease severity. The evaluation of Si applied to the root system, on the severity of leaf spot caused by *Cylindrocladium* sp. in eucalyptus was done in nutrient solution (0, 25, 50, 75, 100 mg Si L^{-1}). Also, the direct effect of Si on *Cylindrocladium* sp. and *Botrytis cinerea* mycelial growth was evaluated in potato-dextrose-agar (PDA). The results obtained indicated that the oldest and the youngest leaves accumulated more Si than the intermediate leaves. Eucalyptus seedlings grown in stainless steel trays showed greater Si absorption than seedlings grown in sand substrate. There was no direct correlation between Si accumulated by the seedling and disease severity in the commercial nursery. There was no significant difference between Si doses, or leaf age, on *Cylindrocladium* sp. severity. Colloidal Si was not capable of inhibiting mycelial growth of either *B. cinerea* or *Cylindrocladium* sp. However, there was growth inhibition by potassium silicate and potassium hydroxide. This effect could be due to potassium, or increased pH in the growth medium.

Keywords: Eucalyptus, silicon, dumping off, silicate

ALLEVIATION OF ABIOTIC STRESS WITH SILICON ADDITION: A META-ANALYSIS

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Silicon plays an important role in agricultural and natural environments in the alleviation of a broad range of plant stresses. The role of silicon addition in stress alleviation has been explored through factorial experiments in a large number of studies for a range of abiotic stresses. In general, experiments have tested the effect of silicon addition on stressed and unstressed plants of single or few species. Response variables measured include biomass, growth rate, plant element content, photosynthetic parameters, water relation parameters, leaf traits, enzyme activity and yield. The results of these experiments were combined in a meta-analysis in order to discern trends not obvious in individual studies. A literature search (BIOSIS Previews) was designed and conducted to identify papers containing results from relevant studies. The data in these were then collated into a database and the effect size or response ratio of each response measure was calculated, allowing unbiased statistical comparisons between studies. The following questions were addressed: (1) Do stressed plants take up more silicon than plants that are not stressed? (2) Are root and shoot responses consistent across species and stresses? (3) Is the magnitude of the alleviation related to the severity of the stress? It is believed that identifying similarities and differences between responses will contribute to understanding the mechanisms behind silicon-induced stress alleviation.

Keywords: silicon, meta-analysis, abiotic stress

FOREST TREE SPECIES IMPACTS THE PLANT UPTAKE OF SILICON

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Plants take up dissolved silica in the soil, then form and return biogenic opal-A particles (phytoliths) to the topsoil within organic residues. They thus exert a strong imprint on the soil-plant cycle of silicon (Si), which is important in terms of hydrological output of Si and beneficial effects for plants. In forest ecosystems, the impact of tree species on the uptake and restitution of Si is poorly known, because studies in identical soil and climate conditions are lacking.

This study quantifies the stocks and annual uptake of Si in five monospecific forest stands (European beech, oak, Norway spruce, Douglas fir and Black pine) grown on an acid brown soil within a unique 32-year old planting site under a humid temperate climate (Morvan Plateau, France). Si concentrations were measured in living and dead organic pools. Phytoliths were quantitatively extracted from leaf/needle, humus and soil horizons. Allometric relationships between tree circumference (C_{130}) and biomass were used to evaluate Si stocks and uptake. Leaves and needles accumulated the largest quantities of Si relative to other tree parts, thus making Si largely mobile in the soil-tree cycle through litter fall and decomposition. Leaf/needle Si content significantly decreased in the sequence European beech (0.74%) > oak (0.55%) > Douglas fir (0.53%) > Norway spruce (0.46%) >> Black pine (0.02%). The morphology of phytolith particles differed largely between tree species. The minimum values of the annual Si uptake by oak and European beech stands were 18.5 and 23.3 kg ha^{-1} yr^{-1}, respectively. Black pine had a low annual Si uptake (2.3 kg ha^{-1} yr^{-1}) compared to Douglas fir (30.6 kg ha^{-1} yr^{-1}) and Norway spruce (43.5 kg ha^{-1} yr^{-1}). Si uptake was the lowest within the pine ecosystem as evidenced by the highest residence time of amorphous silica in the soil and the increased levels of Si leached out of the soil.

Forest tree species thus play an important role in the continental Si cycle, since they strongly influence the biological cycle of Si and the morphology of phytoliths, which influences the solubility of phytolith particles and thus the mobility of Si in the soil-plant system.

Keywords: temperate forest, silicon, silicon cycle, phytolith

INFLUENCE OF INSOLUBLE AND SOLUBLE SILICON ON LEAF BLAST DEVELOPMENT IN RICE

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A mechanical barrier (insoluble silicon) or plant mediated defense response (soluble silicon) are two of the potential mechanisms hypothesized as to how silicon (Si) nutrition suppresses plant disease development. A Si nutrient culture method with rice inoculated with *Magnaporthe grisea* was used to test these hypotheses. Rice plants of cultivar Monko-to were grown with 2 mM Si (+Si) and without (-Si). Twenty-four hours before inoculating rice with *M. grisea*, half of the plants grown in +Si +Si were changed to -Si and half of the plants grown in -Si -Si were changed to +Si. The final four treatments were +Si +Si (insoluble and soluble Si), +Si -Si (insoluble Si), -Si +Si (soluble Si), and -Si -Si (control). Two hours before inoculation, soluble Si was measured in the xylem sap. Plants in the +Si +Si and -Si +Si treatments had concentrations of 13 and 14 mM, respectively, while plants in the +Si -Si and -Si -Si had less than 2 mM. Twenty-four hours after inoculation, % insoluble shoot Si was 7.9, 6.6, 3.5 and 1.0 for +Si +Si, +Si -Si, -Si +Si and -Si -Si, respectively. Symptoms of leaf blast appeared about 60 hours after inoculation, and disease development was evaluated based on percentage area of the leaf surface infected. Final rice blast disease severities were 2%, 6%, 8% and 20% for +Si +Si, + Si - Si, -Si + Si and -Si -Si, respectively. All treatments with +Si were significantly lower in blast development in comparison to the control. Significant differences were not detected between +Si -Si (insoluble Si) and -Si +Si (soluble Si), while the +Si +Si was significantly different from all the treatments. These preliminary findings suggest that both insoluble and soluble silicon confer leaf blast resistance, and that both are important in maximizing disease suppression in rice.

Keywords: rice, silicon, *Magnaporthe grisea*, *Oryza sativa* L.

SILICON: ITS MANIFOLD ROLES IN PLANTS

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The title of this paper implies that silicon (Si) does indeed have roles in plants, and all participants in this conference know that that is so. This knowledge, however, is not shared by the general community of plant biologists, who largely ignore the element. The baffling contrast is based on two sets of experiences. First, higher plants can grow to maturity in nutrient solutions formulated without Si. This has led to the conventional wisdom that Si is not an essential element, or nutrient, and thus can be disregarded. Second, the world's plants, however, do not grow in the benign environment of solution culture in plant biological research establishments. They grow in the field, under many conditions that are often anything but benign. It is there, in the real world, with its manifold stressful features, that the Si status of plants can make a huge difference in their performance. The stresses that are alleviated by Si range all the way from biotic, such as diseases and pests, to abiotic, such as gravity and metal toxicities. Si performs its functions in two ways: (i) by the polymerization of silicic acid leading to the formation of amorphous, hydrated silica, and (ii) by being instrumental in the formation of organic defense compounds through alterations of gene expression often affected by Si. The Si nutrition of plants is not only scientifically intriguing, but important in a world where more food will have to be wrung from a finite area of land, for that will put crops under stress.

Keywords: silicon, stress, defense

STUDY OF THE EFFECT OF SILICON ON LODGING PARAMETERS IN RICE PLANTS UNDER HYDROPONICS CULTURE IN A GREENHOUSE EXPERIMENT

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Lodging is a major constraint in rice production. In order to study the effect of silicon (Si) on lodging parameters in the rice plant, a pot experiment using a nutrient solution was conducted in 2007 at the Yoshida Rice Research Institute of Iran (Amol). Treatments were arranged in a factorial randomized complete design with four replicates. Ammonium nitrate at 40 and 80 ppm was added to the sodium silicate solution (27% SiO_2). In this study, Nemat (Iranian high yielding rice variety) was used. Fifteen-day old seedlings were transplanted into 4-liter nutrient solution pots. The culture solution was renewed once a week. The water deficiency in each pot was made up by adding distilled water. The pH of the culture solution was adjusted every two days to 5.0-5.5 using a pH meter model HI9025. The plant height, internode lengths, fresh weight, bending moment, breaking resistance and lodging index were measured at physiological maturity. The Si and nitrogen (N) concentrations in roots, stems, leaves and panicles were measured as well. The results showed that Si concentrations in roots, stems, leaves and panicles increased with the use of Si; however, an increase in N in the nutrient solution decreased the Si concentration in the rice plant parts. Si improved plant height, internode length, fresh weight, bending moment and breaking resistance. In addition, the lodging index, which is the ratio of bending moment to breaking resistance, was increased. An increase in Si concentration in rice plant parts, and deposits of Si in the form of silica gel, are expected to stiffen the stems. Therefore, using Si fertilizer will increase the lodging resistance of rice plants.

Keywords: rice, silicon, lodging

STEEL SLAG AS A SILICON SOURCE FOR SUGARCANE: EVALUATION OF SILICON AVAILABILITY AND PLANT ACCUMULATION

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In northeast Brazil, sugarcane is extensively cultivated on soils that are prone to silicon (Si) deficiency, owing to the low levels of available Si present in these soils. However, studies that evaluate sugarcane response to Si application as well as the best extractant for predicting Si availability in such soils are scarce. Research was carried out to investigate sugarcane response to a steel slag (EAF - electric arc furance) applied to soil. Additionally, Si availability in the slag-amended soil by different extractants was examined. The experiment was conducted under greenhouse conditions utilizing 10 dm^3 pots filled with Ultisol soil collected from a sugarcane plantation. The pots received five doses of the steel slag (0, 0.25, 0.5, 1.0, and 2.0 g kg^{-1}) and were kept incubated for 15 days. After that, the soil was cultivated with sugarcane for 60 days. The shoots and roots were collected and analyzed for biomass and Si concentration. The available Si content in the soil was estimated using three extractants: calcium chloride, water and acetic acid. The results showed that the steel slag applied to soil increased the sugarcane biomass and Si accumulation. Shoots showed up to 15% increase in dry matter production after application of the slag. Water was the extractant best correlated (0.89^*) with Si concentration in plants. However, acetic acid (0.76^*) and calcium chloride (0.75^*) were also efficient in predicting Si concentration in sugarcane shoots. The steel slag tested showed potential as a source of available Si to sugarcane. Experiments under field conditions are being conducting to confirm such effectiveness and to indicate the dosage required for maximizing sugarcane production.

Keywords: sugarcane, silicon, silicon uptake, silicon availability, silicon sources

EVALUATING SILICON UPTAKE IN FLORICULTURE CROPS GROWN IN THE USA

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The inclusion of silicon (Si) in fertilizer solutions is not a typical crop management practice in floriculture in the USA, despite the growing body of literature showing a clear, beneficial effect on plant growth. Most floriculture crops have not been critically tested for their ability to take up Si when it is applied in a fertilizer solution. At the previous Silicon in Agriculture meeting held in Uberlandia, a report was presented on the ability of 11 floriculture crops to take up and accumulate Si in their leaves in various concentrations. This research has continued, and to date about 40 crops have been investigated. After hydroponically growing each crop for about four weeks in Si-containing solution, Si content and localization was determined by a combination of scanning electron microscopy, energy dispersive X-ray analysis, and inductively coupled plasma optical emission spectroscopy (ICP-OES) analysis. General patterns of Si deposition in leaf trichomes or along the leaf margins remained the same in the wide variety of species tested. Therefore, subsequent efforts focused solely on quantifying Si uptake in leaves, stems and roots using ICP-OES. Roughly 25% of the species tested so far have Si concentrations higher than 0.15% dry weight in the leaf tissue. There is minimal Si in stem or root sections. Six *Zinnia elegans* cultivars were tested for potential cultivar differences; no differences in leaf Si concentrations were detected and all contained over 1% dry weight of Si. This information has served in identifying species of floriculture crops that may benefit from supplied Si during production and could result in higher quality bedding plants with fewer agrochemical inputs.

Keywords: floriculture, silicon, ICP, greenhouse production, hydroponics

USE OF SILICON TO ENHANCE *BEAUVERIA BASSIANA* EFFICACY FOR THE CONTROL OF TWO SPOTTED SPIDER MITE (*TETRANYCHUS URTICAE* KOCH) ON EGGPLANT

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A possible synergy between the biological control agent, *Beauveria bassiana* (Bals.) Vuillemin and the element silicon (Si) for the control of two spotted spider mite (TSSM), *Tetranychus urticae* (Koch), was investigated on eggplant (*Solanum melongena* L.). *B. bassiana* is an entomopathogenic fungus with potential use in TSSM control, while the uptake of soluble Si is reported to increase host plant resistance to pest damage. Silicon, in the form of potassium silicate, was constantly available at concentrations of 0, 20, 40, 80 and 160 mg L^{-1} in hydroponic nutrient solution from transplanting to the end of the experiment. The *B. bassiana* conidia (Isolate R444), suspended in Break-thru®+water solution (0.01% v/v) were sprayed onto plants seven days after TSSM inoculation at concentrations of 0 and 1 g conidia L^{-1}. Results showed that the leaf damage index means were significantly different between the different levels of Si treatments. Application of Si increased the efficacy of *B. bassiana* and reduced the leaf damage by 59.1 and 55.5% compared to the untreated control, respectively, at the concentrations of 80 and 160 mg L^{-1}. However, single application of Si did not increase the death of adult mites ($p=0.07$). High mortality of adult TSSM was caused significantly by the application of *B. bassiana* ($p<0.001$) and this was more efficient when it was combined with Si. The combination of Si and *B. bassiana* also gave better control of TSSM juvenile population compared to single application of *B. bassiana*. Results in this study indicated that application of Si in fertilization of eggplant enhanced the efficacy of *B. bassiana* and the effect was additive or synergistic. Thus, this element can be used in the management of *T. urticae* with *B. bassiana*. Further investigations on the appropriate concentrations of Si to be applied are, however, needed.

Keywords: eggplant, silicon, *Beauveria bassiana*, *Tetranychus urticae*, soluble silicon, synergy

EFFECT OF SILICON AND NITROGEN RATES ON N AND SI ABSORPTION AND RICE YIELD (*ORYZA SATIVA* L.) IN TWO WATER MANAGEMENT SYSTEMS IN THE NORTH OF IRAN

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Silicon (Si) is the major element in soil, and is essential for maximum growth and yield of a number of plants, including rice. In 2007, a field experiment was conducted at Mazandaran, Iran, as a split-split plot arranged in a randomized block design with four replications. There were three factors: (i) two irrigation systems (continuous flooding and deficit irrigation) as main plots, (ii) nitrogen at four rates (0, 46, 92 and 138 kg N/ha) as sub-plots, and (iii) two rates of Si (0 and 500 kg Si/ha) as sub-sub plots. Measurements studied were grain, biological and straw yields and harvest index, and N and Si absorption in grain and straw. There were significant differences in biological and straw yields and harvest index between irrigation systems, N rates and interaction effects. Although there were no significant differences in grain yield between irrigation systems, there were significant differences between N and Si rates and interaction effects. Flooding and deficit irrigation produced maximum and minimum biological yields with 11 874 and 10 538 kg/ha, and straw yields with 6929 and 5922 kg/ha, respectively. Flooding produced the minimum harvest index (40.75) and deficit irrigation the maximum (42.75). N rates of 138 and 0 kg/ha produced maximum and minimum grain yields (5726 and 3329 kg/ha), biological yields (13 926 and 8219 kg/ha) and straw yields (8200 and 4890 kg/ha), respectively. Minimum (40) and maximum (43.5) harvest index was produced by 0 and 92 kg N/ha, respectively. There were no significant differences in biological and straw yields between Si rates. Grain yield and harvest index showed significant differences between Si and N rates and interaction effects. Biological and straw yields showed significant differences between N rates. Si at 500 and 0 kg/ha produced maximum and minimum biological yields with 11 874 and 10 538 kg/ha, and straw yields with 6529 and 6322 kg/ha, respectively. Minimum (40) and maximum (45) harvest index was obtained with 0 and 500 kg Si/ha. Grain yield increased by as much as 22% with Si applied at 500 kg/ha. Si absorption was better than N absorption in straw and grain. N application increased and Si application decreased straw and grain N. Si at 0 and 500 kg/ha produced maximum and minimum grain N with 1.93 and 1.91%, and straw N with 1.02 and 0.92%, respectively. Si absorption was minimal with flooding and 138 kg N/ha and maximal with deficit irrigation and 0 kg N/ha. There was a negative correlation between absorption of N and Si in rice.

Keywords: rice, silicon, nitrogen, grain, irrigation

EFFECT OF SILICON AND NITROGEN RATES ON LEAF AND NECK BLAST, CHLOROPHYLL CONTENT AND YIELD OF RICE (*ORYZA SATIVA* L.) IN TWO WATER MANAGEMENT SYSTEMS (FLOODING AND DEFICIT IRRIGATION) IN THE NORTH OF IRAN

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In 2007, research was conducted at Mazandaran, Iran, to investigate the effects of silicon (Si) and nitrogen (N) rates on rice production and disease incidence under two irrigation systems. A field experiment was conducted as a split-split plot arrangement in a randomized complete block design with four replications. There were three factors: continuous flooding and deficit irrigation as main plots, N application at 0, 46, 92 and 138 kg/ha as sub-plots, and Si application at 0 and 500 kg/ha as sub-sub plots. Grain yield, leaf and neck blast disease incidence and chlorophyll content were measured. Results showed that there were significant differences in grain yield, chlorophyll content, and leaf and neck blast disease incidence between N and Si rates and interaction effects. Although grain yield showed no significant difference between irrigation systems, there was a significant difference between N and Si rates. Nitrogen at 138 and 0 kg/ha had maximum and minimum grain yields at 5726 and 3329 kg/ha. Leaf and neck blast disease in a partially susceptible cultivar was reduced by increasing Si application. In general, a high rate of Si increased resistance to leaf and neck blast disease. Grain yield was increased by as much as 22% by Si applied at 500 kg/ha. Si at 500 and 0 kg/ha had maximum and minimum grain yields at 5874 and 4581 kg/ha, respectively. Results showed that Si concentrations of between 3 and 5% may be the minimum tissue levels needed for disease resistance and increased yields in rice.

Keywords: rice, silicon, nitrogen, chlorophyll, neck blast

INFLUENCE OF SILICON ON CADMIUM IN WHEAT

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Cadmium (Cd) concentration in wheat grains is a problem for cultivation of wheat flour used for bread and pasta. Wheat accumulates Cd in the grains and those cultivars with high protein content usually also have high Cd content in the grains. Since 43% of the Cd intake among Swedish people originates from wheat products, it is necessary to decrease the Cd level in the grains. Wheat is a grass and it needs silica. The objective was therefore to investigate whether silica could influence the Cd content in wheat grains. Wheat of *Triticum durum* was investigated on uptake and effects of 0-500 μM Cd by 100 and 500 μM K_2SiO_4 and several cultivars of *T. aestivum*, *T. durum* and *T. spelta* were grown until maturity in the presence of 0.034 μM 109 Cd ± 500 μM K_2SiO_4. Plants were then harvested and analysed for biomass, Cd and Si content as well as tolerance, using Weibull parameters. In addition, the relation of Cd concentration to soil available concentration of Si was analysed. Si increased the biomass of all plant parts up to 19% in all cultivars. The Si uptake differed between cultivars. The tendency was that the higher the total Si uptake, the lower the Cd accumulation in grains. The Cd content in grains decreased by up to 50% with Si treatment, depending on the wheat cultivar and type. In addition, there were indications that the magnitude of silica effect depends on the external Cd concentration and on the propensity of the cultivar to accumulate Cd in the grains. Silica slightly increased the Cd tolerance of the plant. It was concluded that Si can decrease Cd content in wheat grains and thereby in wheat products.

Keywords: wheat, silicon, cadmium

SOIL WEATHERING DEGREE OF VOLCANIC ASH SOILS GOVERNS THE SILICON STATUS OF BANANA (MUSA SPP)

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Plant species absorb silicon (Si), which is taken up by roots as monosilicic acid in soil solution. The Si concentration in soil solution is governed by silicate dissolution and formation. This study assesses the Si status of banana plants cultivated on soils developed on similar volcanic ash, but differing in weathering stage and mineralogical constitution. Two approaches with combined: (i) a field topsoil-foliar survey involving 600 mature banana plants, and (ii) an experimental study of Si soil-to-plant transfer in greenhouse conditions involving banana plantlets. The reserve of primary minerals mainly consisted of glassy and crystalline ferromagnesian and plagioclase minerals. With increasing weathering, the content of primary minerals decreased, whereas clay content increased and secondary minerals were increasingly dominant: gibbsite, Fe oxide, allophane, halloysite and kaolinite. From the field study, the average leaf Si concentration ranged from 2.7 to 3.9 g kg^{-1} for bananas cropped in the most weathered soils rich in secondary oxides, and from 7.7 to 9.6 g kg^{-1} in the least weathered soils. The leaf Si concentration was positively correlated with soil $CaCl_2$-extractable Si content, soil Si content and total reserve in weatherable minerals. The experimental greenhouse study showed that the reserve of weatherable primary minerals directly governed the soil-to-plant transfer of Si and the stock of soil biogenic Si (BSi). The largest contents of BSi in plant (6.9 to 7.0 g kg^{-1}) and soil (50 to 58 g kg^{-1}) occurred in the least weathered soils. The lowest contents of BSi in plant (2.8 to 4.3 g kg^{-1}) and soil (8 to 31 g kg^{-1}) occurred in the most weathered desilicated soils. This data thus imply that soil weathering stage directly governed the soil-to-plant transfer of Si, and thereby the stock of biogenic Si in a soil-plant system involving an Si-accumulating plant.

Keywords: banana, silicon, Guadeloupe, weathering, volcanic soil, Musa spp

SILICON FRACTIONS IN HISTOSOLS AND GLEYSOLS OF A TEMPERATE GRASSLAND SITE

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The importance of silicon (Si) in nutrition is currently being recognized for its beneficial effects on many crops. Therefore it is important to determine the soil Si status and to examine different extractants for testing plant available Si. Little information is available about the Si status of Histosols and Corg-rich Gleysols in temperate climates. This study was undertaken (i) to characterize different Si-pools in Corg-rich groundwater soils of an experiment site, and (ii) to test different extraction methods for the determination of plant available Si. The experiment site is situated about 60 km Northwest of Berlin (Northeast Germany). Soil types are Sapric Histosols to Haplic Gleysols, with groundwater levels from 40 to 80 cm. The thickness of the Corg-rich topsoil (mean Corg: 205 g kg^{-1}) ranges between 4 and 5 dm. The average Si content of the underlying fine sandy fluvial sediments (14.8 mol kg^{-1}) is twice as high as that of the topsoil. For the characterization of the different Si-pools, four extractants were evaluated: “plant available” Si-pool, 0.01 M calcium chloride and 0.5 M acetic acid, “organic/amorphous” Si-pool, 0.1 M sodium-pyrophosphate and 0.1 M Tiron ($C_6H_4Na_2O_8S_2$). Further total element content was determined with ICP following HNO_3/HF digestion. Calcium chloride soluble Si showed no difference between the organic rich topsoil and the underlying sand. Only in the top 10 cm of soil was a slight enrichment found which would be important for the Si nutrition of grassland plants. The Si fraction extracted with acetic acid displayed relations to the organic carbon content of the soil and a weak correlation to calcium chloride soluble Si, indicating that both solutions extract overlapping but not the same fractions. Based on published data, the soils investigated could be classified as Si deficient. Pyrophosphate soluble Si showed a negative relationship to Corg, indicating a closer relation of this Si fraction to mineral matter than to organic carbon. The Tiron solution extracted the most Si of all the extractants evaluated; however, this amounted to only 1% of the total Si content. It can be concluded from the high amounts of Tiron extractable Si in the organic-rich topsoils, that this extractant is able to dissolve amorphous forms of Si (phytoliths).

Keywords: grassland, silicon, Histosols, Gleysols, extraction methods

IMPACT OF SILICON ON THE SUSCEPTIBILITY OF BANANA PLANTS (*MUSA ACUMINATA*) TO BLACK SIGATOKA DISEASE

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Silicon (Si) is known to have positive impact on plant disease. In this study, the effect of Si on black Sigatoka disease of banana was studied under a hydroponic culture system. *In vitro* multiplied plants (*Musa acuminata* (AAA), cv Grande Naine) were grown in pots containing 2500 ml of nutrient solution supplied or not with 1.66 mM Si. After four months, the five last fully unfolded leaves were inoculated with *Mycosphaerella fijiensis* Morelet by spraying 10^4 conidia or by brushing 0.3 mg of mycelial fragments on 9 cm diameter areas. From 19 to 34 days after inoculation, the development of symptoms was assessed on each inoculated area on a severity scale from 0 to 5. Symptoms progressed more rapidly on non-Si supplied (-Si) than on Si supplied (+Si) plants, and disease severity was higher in -Si plants than in +Si plants 22, 24, 27 and 30 days after inoculation. The corresponding areas under disease progress curves (AUDPC) were significantly different ($P<0.05$). The disease severity index was significantly ($P<0.05$) higher on leaf areas inoculated with mycelial fragments than on areas inoculated with conidia. Thirty-four days after inoculation, the quantification of disease, using the image analysis software “Assess”, confirmed that infection was higher on leaves from -Si plants, compared to leaves from +Si plants. These results suggest that silicon supply reduces this susceptibility to banana plants to black Sigatoka disease.

Keywords: banana, silicon, black Sigatoka disease, *Mycosphaerella fijiensis*

A COMPARISON OF SOIL EXTRACTION METHODS FOR PREDICTING THE SILICON REQUIREMENT OF SUGARCANE IN THE SOUTH AFRICAN SUGAR INDUSTRY

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Crop and sucrose loss from damage caused by the stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) ranks as one of the most important factors limiting productivity in the South African sugar industry. Recent studies at the South African Sugarcane Research Institute (SASRI) have emphasized the important role of applied silicon (Si) in improving the resistance of sugarcane to *E. saccharina* infestation, especially in more susceptible varieties such as N26 and N30. To ensure that the risk of damage from *E. saccharina* due to a potential lack of Si is minimized, a reliable soil test procedure for diagnosing the Si status of soil is crucial in determining the need for applying a silicate carrier such as calcium silicate to soils, as well as the optimum amount of the carrier to apply. This study was initiated (i) to assess Si availability in a range of soils, (ii) to establish the confidence level on the ability of the candidate sources to supply Si, (iii) to identify the soil extraction method that correlated best with Si uptake from the crop, and (iv) to define a provisional critical value at which a response to applied Si treatment is likely. For this purpose, glasshouse and laboratory studies were conducted with five acid soils (representing the most important agricultural soil groups used for sugarcane production in the South African sugar industry) treated with three candidate Si sources (Calmasil®, Slagment® and wollastonite), applied at rates equivalent to 0, 3 and 6 tons ha^{-1}, using a split-split plot design with four replications. Six different soil extractants for estimating plant available Si were evaluated. Sorghum and sugarcane were used as the indicator crops. The correlation between the soil Si extracted over the cropping period using the six extraction methods and the plant Si uptake varied between 0.55 and 0.72. The 0.025 M H_2SO_4 extraction method gave the highest correlation coefficient and was appreciably superior to other extractants for the five soils investigated. The three carriers showed no difference in their ability to supply Si to the soils. The results obtained also indicated that the Si critical value is positively correlated with soil clay content.

Keywords: sugarcane, silicon, soil extractants, soil pH, calcium silicate, *Eldana saccharina*

EPIDERMAL SILICON IN THE SUGARCANE STALK AND RESISTANCE TO THE STALK BORER *ELDANA SACCHARINA*

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Silicon (Si) absorption can appreciably increase resistance of plants to insect herbivory. In sugarcane, Si-mediated resistance to the lepidopteran stem borer *Eldana saccharina* involves reductions in survival, feeding efficiency and stalk penetration. This study examined (i) the effect of soil-applied Si on the concentration of amorphous epidermal Si at three positions on the sugarcane stalk where the borer may penetrate, and (ii) whether the concentration of epidermal Si at these positions in Si-treated and control cane plants varied between borer-resistant (N33) and borer-susceptible (N11) cultivars. The cultivars were grown in a pot trial in Si-deficient river sand with (Si+) and without (Si-) calcium silicate. Cross-sections of mature stalk were subjected to energy dispersive X-ray (EDX) microanalysis to localise and quantify Si deposits in the stem epidermis. Si-treated plants had increased silica in each epidermal tissue zone (leaf bud, internode, root band) in both cultivars, and X-ray mapping confirmed that Si accumulation was localized mostly in the epidermis of the internode and root band, but was sparse in the underlying tissues. It is argued that these patterns of Si deposition may account substantially for the enhanced resistance of Si+ sugarcane to penetration and feeding by *E. saccharina*, and are therefore consistent with an hypothesis based on increased mechanical hindrance to feeding. Epidermal Wt% of Si was significantly higher in all three tissue types of (Si+ and Si-) N33 plants compared with N11 plants, indicating that the higher total stalk Si for N33 compared with N11 was expressed to an appreciable degree at the epidermal level. Should amorphous Si increase mechanical resistance to stalk penetration, then the lower Si content of the bud scale epidermis compared with the internode and root band epidermis may partly explain the observation that the leaf bud is a preferred entry point into the stalk for *E. saccharina* larvae.

Keywords: sugarcane, silicon, plant resistance, stalk borer, X-ray microanalysis, epidermis

COLD STRESS AMELIORATING EFFECT OF SILICON AND ITS IMPACT ON FUSARIUM WILT OF BANANA

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Cold stress is a particularly important factor in the production of tropical plants, such as banana, grown in the subtropical region of the Earth. This factor, like other environmental factors such as drought and salinity, affects plant growth and crop production. Chill stress may result in damage or adaptation reactions from plants, depending on the level of stress. Such abiotic stress also aggravates the effect of biotic stress, caused by Fusarium wilt fungi. In this study, the ameliorating effect of silicon (Si) in banana plants to stresses resulting from biotic (Fusarium wilt) and abiotic (low temperature) factors and their combination was assessed visually, and some physiological responses of banana plants to such treatments were investigated. Tissue culture banana plantlets were treated with 0, 1000 or 2000 mg L^{-1} Si in the form of potassium silicate for six weeks. Half of these plants were treated with *Fusarium oxysporum* f.sp. *cubense* and were subjected to cold stress at 4°C for up to eight days. Cold damage and corm discoloration were significantly reduced by application of Si. Cold stressed plants showed higher levels of disease, and higher levels of cold damage were obtained on *F. oxysporum* f.sp. *cubense* inoculated plants. Si-treated plants showed significantly lower levels of lipid peroxidation, electrolyte leakage and membrane damage, and decreased production of proline. Plants commonly respond to stress by increasing the production of proline. Application of Si significantly increased sucrose and raffinose levels in the leaves and roots of banana plants. Reduced lipid peroxidation, electrolyte leakage and proline production are signs of reduced stress levels. Sugars such as sucrose and raffinose are believed to be cryoprotectants that increase plant tolerance to cold damage. The application of silicon protected banana plants from cold damage. Reduced cold stress means more vigorous plants and decreased susceptibility to Fusarium wilt. The results of this study indicate that the application of Si to tropical plants growing in marginal subtropical environments to protect them against frost or cold damage may have application for other crops as well.

Keywords: banana, silicon, cold, Fusarium

EFFECTS OF SILICA GEL SUPPLY ON LEAF SILICA CONCENTRATION, OTHER TRAITS AND COVARIATIONS WITHIN SIX TROPICAL FODDER GRASS SPECIES GROWN IN HUMID CONDITIONS

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Although silicon (Si) is beneficial for promoting plant growth and yield, a high content may affect palatability and digestibility of fodder grasses. In developing countries where the economy is dependent on agriculture, it is important to reduce Si concentration in grass leaves to improve palatability, digestibility and nutrient value for animals. This study examined Si supply effects on fodder plant silicification patterns. Six tropical grasses (*Andropogon gayanus* Bisquamulatus (Hochst.) Hack, *Brachiaria ruziziensis, Panicum maximum* Orstom C1*, P. maximum* T673*, P. maximum* T58 *and P. maximum* Jacq.) were selected for their high forage value and biomass provision. A complete randomized design used clay soil fractions from the Research Institute for Bioresources station of Kurashiki. Two-week old clumps were transplanted into pots containing 3.3 kg soil. Each pot contained three tillers per replication in three replications (i.e. 9 tillers per pot), irrigated each day with distilled water. Treatments were silica gel at 0 (-Si) and 100 g (+Si). Plants were grown in a greenhouse from 29 April to 29 May 2006, then transplanted and harvested three months later. Shoot biomass was measured. Si and P concentrations were analysed by colorimetric method using spectrophotometer (Jasco, Japan). Specific leaf mass (SLM) and leaf water content (LWC) were determined. Two-way ANOVA and Pearson correlations at 5% were performed using Statistica 7.0. Results showed significant species effects, except for shoot biomass and Si concentration. Shoot biomass increased by 6% in *P. maximum* T673 and 108% in *B. ruziziensis*. Si and P concentrations, LWC and SLM were also highly affected. Species responded differently in Si accumulation ($F_{(1,24)}=9.17$, $p<0.01$; $F_{(5,24)}=3.89$, $p<0.05$; $R^2=0.41$). *B. ruziziensis* showed the highest Si concentration (11.54% DM) and *P. maximum* T673 the lowest (4.17% DM). Si and P increased in *B. ruziziensis* by 77% and 29%, respectively, and decreased in *P. maximum* T673 by 37% and 1%, respectively. LWC decreased by 2% in *B. ruziziensis* and by 8% in *A. gayanus*. Si positively correlated with LWC (R=0.53; p<0.05). SLM increased from 13 to 21% but decreased with *B. ruziziensis* (4%). Mechanisms for this complex silicon accumulation process are not known. These results suggest a need to explore ecological interactions with molecular and chemical techniques for controlling tropical grass silicification.

Keywords: fodder grass, silicon, silica gel, functional traits, covariations, tropical

SILICON FERTILISERS - REQUIREMENTS AND FIELD EXPERIENCES

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Beneficial effects of silicon (Si) fertilisers for increasing yield of crops by relieving biotic and abiotic stress are well documented in the literature. Responses in Si accumulator field crops such as rice and sugarcane are associated with depleted capacity of the root zone to supply sufficient plant available Si. This capacity is diminished by weathering processes and export of Si in commercial biomass (210-224 million tonnes in world food crops in 1998). There is a clear sustainability issue for the rice industry and other production systems on weathered tropical soils. Soil and plant based criteria are available to determine the likelihood of economic responses in rice and sugarcane crops to application of silicate fertilisers. However, no similar criteria were identified for dicotyledons and non-Si accumulator crops, other than recommendations for use of potassium silicate in nutrient solutions for soil-less culture of curcurbits. Reduced incidence of foliar disease and stimulation of photosynthesis have been attributed to foliar applications of potassium silicate. It not clear that such responses are due to *in planta,* or merely topical effects, as similar responses occur with non-Si products. *In planta* Si responses are not usually reported and incorporation of foliar applied Si in leaf tissue is contrary to current understanding of Si uptake, transport and deposition. The first commercial Si fertilisers were derived from steel industry slags registered in 1955 in Japan. Subsequent fertiliser registrations followed in Korea and Brazil. By-product silicate fertilisers now include a range of slags derived from the steel and elemental phosphorus industries. These are applied at 1.5-2.0 t/ha/year in the rice industry and 4.0-7.5 t/ha every four to five years for sugarcane and rice/sugarcane cropping systems. Significant manufactured products include fused potassium and magnesium silicates and calcium meta-silicate. Significant liquid products include potassium silicate and the soluble Si in irrigation waters. Geological materials such as wollastonite, crushed rocks and diatomaceous earths are used as silicate fertilisers, but use is constrained by market availability of wollastonite and the high rates of application required for low solubility crushed rock and diatomaceous earth. Yield responses to silicate fertilisers of 1-30% were achieved in rice crops (depending on the disease pressure) and 7-45% in sugarcane, where response mechanisms are not clear, but may include greener leaves, resistance to stem borers and lower impact of aluminium and manganese on phosphorus nutrition. Silicate fertilisers also have a clear role in improving food quality by suppressing uptake of heavy metals such as cadmium. Knowledge of benefits of Si fertilisation must be translated into practical and economic strategies based on suitable products to underpin improvements in crop yield and quality while arresting degradation of the soil environment.

Keywords: rice, sugarcane, silicon, silicated amendments, calcium silicate, potassium silicate

THE CASE FOR ORGANOSILICATE CHEMISTRY IN-PLANTA

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Despite the well known benefits of silicon (Si) treatment on the growth and development of plants, definitive evidence of the underlying chemistry has proven highly elusive. Certain sugars and sugar-derivatives (e.g. ribose, sorbitol) remain the only biomolecules known to combine covalently with orthosilicic acid, yielding monomeric *bis*- and *tris*-ligand complexes in which the Si centre is, respectively, penta- and hexa-coordinated. The stability constants at pH 7 are generally small, however, and, to date, no organosilicate complexes have been detected in a bulk biofluid (such as xylem exudates from wheat and rice). A transient hexa-coordinated Si complex has nevertheless been identified in colonies of the diatom *Navicula pelliculosa*. As well, Si has been shown to bind *in vitro* with the pectic polysaccharide rhamnogallacturonan-II and, coincidentally, to reduce the thickness of cell walls in wheat. Recent work has therefore focused primarily on the intracellular environment. Preliminary findings show that the formation of organosilicates is enhanced by: (a) the highly structured (low mobility) nature of intracellular water; (b) the presence of electron-withdrawing functional groups on Si-binding ligands; and (c) the co-complexation of key bio-metals such as Ca^{2+}. Moreover, it has been discovered that Si binds to a wider array of polyhydroxy ligands than was originally appreciated, albeit in most cases with marginal affinity. Lastly, work carried out with methyl-substituted derivatives of orthosilicic acid, $(CH_3)_nSi(OH)_{4-n}$ (n=1-3), has revealed the phytotoxic character of these ubiquitous silicon degradation intermediates.

Keywords: silicon, organosilicates, sugars, biochemistry

MEASURING SOIL, PLANT AND FERTILIZER SILICON AVAILABILITY

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The analysis of silicon (Si) in soils, plants and fertilizers is not well developed and standardized and doubts persist, particularly when determining plant availability from Si present in soils and fertilizer materials. While several extractants are used for determining available Si, most are often restricted to limited groups of soils or fertilizers with specific characteristics. Since Si fertilizer sources differ in Si solubility, analytical methods need to be developed that can predict their ability to provide plant-available Si. Greenhouse and field evaluation is essential for making decisions on the appropriate extractant to use. To develop recommendations for field applications of silicate materials, knowledge of the soil Si status and the availability of Si in the amendment are essential. To determine a crop's response to Si applications requires calibration of soil Si status and plant uptake. While a method for determining plant Si levels using the autoclave induced digestion procedure is well established, the challenge for routine testing of soils and amendment materials is the development of simple, dependable and robust methods that correlate well with changes in soil Si status and corresponding plant tissue levels. The total Si content of soils can have little relationship to the concentration of soluble Si in soils, which is the component important for plant growth. The concentration of soluble Si is dynamic, and although leaching of Si from the soil and plant uptake are important processes determining Si concentrations, the equilibrium concentration is largely controlled by adsorption/desorption reactions. Consequently, when Si is added to soil, it can react rapidly with amorphous surfaces, and presence of other anions. This paper examines a number of chemical extraction procedures that have been developed to determine "plant available" soil Si status, and a range of these are compared when used on different soil types.

Keywords: silicon, plant tissue, calcium silicate, potassium silicate, solubility

EFFECT OF SILICON ON THE DEVELOPMENT OF THE SPITTLEBUG *MAHANARVA FIMBRIOLATA* STAL (HEMIPTERA : CERCOPIDAE)

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With an increase in green cane harvesting, the population of insects changed due to changes in the agroecosystem. Pests that were considered secondary, such as the spittlebug *Mahanarva fimbriolata*, became important. Many studies have demonstrated the active role played by silicon in improving defense system of plants. The objective of this study was to verify the effects of silicon and cultivar on spittlebug development. Sugarcane plants were grown under greenhouse conditions and submitted to different treatments: with and without silicon fertilizer in two different soil types (sandy and clay soil). Four different cultivars were tested. Newly hatched nymphs were transferred to sugarcane roots and placed into boxes with lids, to keep a moistened and dark environment favouring *M. fimbriolata* growth and maintaining the root system, thus providing the developing nymphs with access to food. Results showed that silicon significantly increased nymph mortality and decreased adult longevity ($p<0.05$).

Keywords: sugarcane, silicon, spittlebug, plant resistance

ACTIVE SILICON FOR INCREASING SALT TOLERANCE IN PLANTS

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Salt toxicity is a worldwide agricultural problem. Numerous studies have demonstrated the benefits of silicon (Si) for higher plants, particularly for gramineous plants. The work presented here studied physiological responses of salt-stressed wheat plants (*Triticum aestivum* L.) in the presence and the absence of Si in soil under controlled conditions. The treatments in the experiment were: control, 0.5 g Si and 1 g amorphous Si per kg soil with NaCl in irrigation water. The growth parameters, photosynthesis, respiration and chlorophyll fluorescence were determined. Growing of plants under salt stress led to a decrease in photosynthetic rate. The addition of Si to the soil resulted in an increased rate of photosynthesis from 158 to 520%, depending on salt concentration in the soil. Chlorophyll fluorescence and analysis of model parameters of photosynthesis indicated that Si enhanced photochemical efficiency. Leaf and stem dry matter was depressed under salt stress; however, this negative effect was decreased by the addition of Si. Hence, Si is beneficial in improving the photosynthesis and growth of wheat plants under high soil salinity. Several hypotheses of the active Si impact on salt stress in plants were suggested: (i) improved photosynthetic activity, (ii) increased antioxidant enzyme activity, and (iii) increased concentration of soluble substances in the xylem, which resulted in reduced sodium adsorption by plants.

Keywords: wheat, silicon, salt toxicity, *Triticum aestivum*, chlorophyll, antioxidant enzyme activity

SILICON AND CROP PLANTS: INDUCED PLANT DEFENCE AND BIOLOGICAL CONTROL

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There is good reason to suspect that silicon (Si) may have yet to be recognized significance in induced plant defences and in mediating biological control of arthropod pests. Si supplemented plants naturally translocate silicic acid throughout their tissues and, when attacked, produce systemic stress signals such as salicylic acid and jasmonic acid, that are key to induced plant defences. Si has been postulated to play two important roles in plant chemical defence: (i) acting as a modulator of metabolic signalling events at the cellular level and (ii) the generation of metabolic signals that give a systemic response at the whole plant level. Jasmonic acid is particularly important because this compound triggers production of herbivore-induced plant volatiles (HIPVs) by the attacked plant. These are the chemical signals referred to above, that 'recruit' predators and parasitoids. Given evidence of a role for Si in plant defences, it is surprising that virtually all arthropod work to date has focused on two trophic level studies, i.e. plants and pests. This paper will present results from current studies of the effects of soil-applied Si on natural enemies in a model system comprising cucumber (*Cucumis sativus*) and a range of arthropod pests and natural enemies. Findings will be presented on the attraction and performance of parasitoids and predators in Y-tube olfactometer bioassays and free choice experiments comparing infested and uninfested plants with and without potassium silicate. Results will be discussed in relation to the scope for Si compounds to be used as biological control enhancing treatments.

Keywords: cucumber, silicon, jasmonic acid, salicylic acid, aphid, lacewing

SILICON-AUGMENTED RESISTANCE OF PLANTS TO HERBIVOROUS INSECTS: A REVIEW

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Silicon (Si) is one of the most abundant elements in the earth's crust, although its essentiality in plant growth is not clearly established. However, the importance of Si as a nutrient that is particularly beneficial for plants under a range of abiotic and biotic stresses, is now beyond doubt. This paper reviews progress in exploring the benefits at two and three trophic levels and the underlying mechanism/s of Si in enhancing resistance of host plants to herbivorous insects. Numerous studies have shown enhanced resistance of host plants to insect herbivores including folivores, borers, and phloem and xylem feeders, mostly at two trophic levels. There are two mechanisms by which Si is likely to increase resistance to herbivore feeding. Increased mechanical resistance has long been believed to be the major mechanism by which Si defends plants from insect herbivore feeding, including reduced digestibility and/or increased hardness and abrasiveness of plant tissues due to silica deposition, mainly as opaline phytoliths, in various tissues, including epidermal silica cells. However, there is increasing evidence that soluble Si is involved in induced chemical defenses to insect herbivore attack, although studies are largely confined to plant pathogen systems. Only one study, however, has tested for the effect of Si on an insect herbivore and the resultant attractancy of the insect's predators and parasitoids. That work showed no effect of Si on natural enemies, but it used non-choice conditions in which parasitoid wasps were restricted on a small scale to individual plants that were narrowly spaced. Work recently commenced in Australia is methodologically and conceptually more advanced and any effect of Si on the plants' ability to generate an induced response by acting at the tri-trophic level (i.e. by attracting predators or parasitoids) will be apparent. Si may act directly on insect herbivores leading to a reduction in insect performance and plant damage. Indirect effects may be caused, for example, by delaying feeding and thus increasing the chance of exposure to natural enemies, adverse weather events or control measures that target exposed herbivorous insects, such as chemical applications. Alternatively, Si may act indirectly by increasing tolerance of plants to abiotic stresses, notably water stress, which can in turn lead to a reduction in insect numbers and plant damage. Crucially, there also is evidence that applied Si can mitigate the negative effects of high levels of N in promoting insect herbivore performance and plant damage. In drought-stressed plants, Si may play a role in simultaneously alleviating both water stress and high N levels.

Keywords: silicon, insect-plant interactions, trophic interactions, resistance, mechanisms

SILICON FOR HUMANS: BENEFICIAL OR ESSENTIAL?

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Although human biology has not changed during the past 50 000 years, foods and food patterns have. One of the most the striking differences in nutrients is silicon (Si). Until the seventies, Si was believed to be inert for humans. The Joint FAO/WHO Expert Committee on Food Additives stated that “data on orally administered silica and silicates appear to substantiate the biological inertness of these compounds”. In 1973, Carlisle showed that a Si deficient diet in chickens induced skeletal deformities and joint abnormalities, while Schwartz showed the same results in rats. Si deficiency has not been observed in humans because there is no validated method of assessing Si status. On the other hand, ‘Si deficiency’ in humans can cause skin, hair and nail problems and osteopenia, which can be restored with extra (bioavailable) Si. The bioavailability of Si in humans is relatively low. Silicates as such are not bioavailable. The only bioavailable form is silicic acid, especially as ortho- and di-silicic acid, which is easily absorbed from the gastro-intestinal tract (55-80%). The human body contains about 7 g Si, more than many other micronutrients together. Silicic acid is widely distributed in the tissues. High levels are present in bone, nails, tendons and the walls of the aorta, with nails containing the highest levels. Substantial amounts are also present in the kidneys, liver and lungs. Moderate amounts are found in bone, skin, muscle, testes and spleen. Si is predominantly and rapidly excreted in the urine, with smaller amounts being eliminated in the faeces. Si has been reported to interact with a number of minerals including copper, zinc, boron and germanium. The interaction between Si and aluminum (Al) has been researched in more detail as a means of inhibiting Al toxicity. There is growing evidence that Si plays a role as a regulatory agent for other minerals, e.g. calcium. Si is involved in the formation of mesenchymal tissues such as bone and connective tissues. The precise mechanism is uncertain. However, there is sufficient evidence that Si is involved in the formation of glycosaminoglycan and collagen components. The conclusion? Si is not inert for humans, and there is growing evidence that Si is at the least beneficial, and may be essential, for humans. Si is important for mesenchymal tissues such as connective tissues, bone, cartilage and also skin, nails and hair. In addition, Si plays a regulatory role on other minerals and has a detoxifying effect on Al. A major problem is the (bio) availability of enough Si. The quantities of silicates in the western diet are (too) low and there is a coincidence with skin, hair and nail problems, osteoporosis and Alzheimer’s disease.

Keywords: humans, silicon, bioavailability, deficiency, diseases

SILICON IN DICOTYLEDONOUS PLANTS

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Monocotyledonous plants have received greater attention than dicots in silicon (Si) research in agriculture. This is possibly due to the ability of monocots to take up, accumulate and deposit far greater amounts of Si. However, dicots, despite their apparent lesser ability to accumulate Si, also enormously benefit from Si fertilization. There is a need to measure the concentrations present in the cytoplasm of both monocots and dicots, rather than total Si levels that include deposited phytoliths. In some cases, dicots such as zinnia can accumulate up to 2% of their biomass as Si. Such differences are inherent and could be the result of evolution influenced by the environment in which they originated. Application of soluble Si to dicots shows that many of these also benefit from the role of Si in enhancing their ability to overcome biotic and abiotic stresses, as is the case with monocots. However, the relative importance of soluble and deposited Si to overcome these stresses is not well understood. It is also not known whether the effect of Si on biotic and abiotic stresses increases with elevated levels of dissolved cytoplasmic Si. Understanding the genetics behind Si uptake, differential accumulation in different forms in different organs, and excretion, if any, would enable breeders to select for dicots with the genes to acquire high levels of Si. This paper documents some important studies and outcomes of research into the Si requirements of dicots, its role in alleviating biotic and abiotic stresses, and putative mechanisms of uptake in dicots, and presents an outlook and future research needs analysis.

Keywords: dicots, silicon

RELATIONSHIP BETWEEN AVAILABLE SILICON IN SOILS OF MAURITIUS, SOIL PROPERTIES AND PLANT SILICON CONCENTRATION

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The soils of the tropical island of Mauritius, located in the South West Indian ocean, are all of volcanic origin. Many of these, such as the Latosols and Gibbsiorthox, are old soils and have been depleted of their mineral content by weathering. Although silicon (Si) is not yet considered an essential element, there have been positive responses to Si applications. Earlier studies have shown that sugarcane, which occupies almost 80% of the arable area, responds positively to Si applied in various forms. Similar positive responses in sugarcane and other crops, e.g. rice, have been reported from South Africa and Brazil.

Three hundred topsoil samples (0-15 cm) were collected from five soil types of the island of Mauritius and analyzed for available Si by extraction with 0.05 M H_2SO_4 and estimated by the blue colour molybdenum method. These soil samples were also analyzed for texture, porosity, pH, EC, total and available N, available P, exchangeable K, Ca and Mg, available Cu, Zn, Fe and Mn, and organic C, by standard methods. Similarly, top visible dewlap (TVD) of sugarcane leaves from the same areas were analyzed for total Si and N, P, K, Ca, Mg, Cu, Zn and Mn. Results were subjected to multiple regression analyses and correlation matrices derived between soil parameters and also between plant nutrient concentrations. The available Si showed wide variation between the different soil types, ranging from 10 to 90 mg/kg. pH was found to be positively and strongly correlated with available Si. Similarly, the soil Si was also positively correlated with the textural index of the soil, as well as several soil parameters. Available soil Si was positively correlated with total Si in the TVD as well as with other plant nutrients.

Si influenced sugarcane pests, the tolerance of water stress and increased photosynthesis rates due to plant architectural changes. Si has been shown to accumulate in rice plants, thereby reducing transpiration rate and decreasing intake of water by the plants. Also shown was that soil and plant parameters were significantly affected by Si sources and rates.

Keywords: sugarcane, silicon, soil

EFFECT OF SILICON ON GROWTH AND TOLERANCE TO STRESSFUL ENVIRONMENTS AND PLANT DISEASES IN HIGHER PLANTS INCLUDING PROTEIN AND OIL-BEARING CROPS

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Silicon (Si) has not been considered an essential element for higher plants; however, Si is well known to be beneficial for healthy growth and development of many plant species. Si is known to effectively mitigate various forms of abiotic and biotic stress. However, the underlying mechanisms are not clear. Si has long been demonstrated to reduce water loss from transpiration and consequently improve water use efficiency in plants that are exposed to water-deficit stress. Considering that some recent reviews have dealt with current progress in roles of Si in mitigating metal toxicity and suppressing fungal diseases, and that drought, chilling (or freezing), and salinity stresses are all related to osmotic stress caused by water deficit, the present review paper focuses mainly on some most current research advances in possible roles of Si in enhancing plant resistance to drought, chilling (freezing), and salinity stress. The key mechanisms of Si-mediated alleviation of water-deficit stress in higher plants include: (1) enhancement of plant growth via improved leaf photosynthesis and root activity, (2) alleviation of osmosis stress via less transpiration and/or better water retention, (3) stimulation of antioxidant defense activity and reduction of lipid peroxidation, and (4) improvement of plasma membrane and tonoplast structure, integrity and functions. Future research needs for Si-mediated alleviation of water-deficit stress are also discussed.

Keywords: abiotic stress, drought, freezing, salinity stress, silicon, water-deficit stress

PRODUCTION OF FOLIAR PHENOLICS AND CONDENSED TANNINS IN PIGEON PEA AND LEUCAENA SUPPLEMENTED WITH SILICON

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The functions of phenolic compounds may be extensive or specialized, participating in ecological interactions of plants with animals and microorganisms. These substances can be produced to help in the mechanisms of defence against biotic stresses such as pathogens, insects, birds and herbivores. Exogenous factors such as abiotic seasonal effects, light, temperature and soil fertility are involved in the synthesis of phenolics and tannins. The objective of this work was to study the synthesis of total phenols and condensed tannins in leaves of leucaena (*Leucaena leucocephala*) and pigeon pea (*Cajanus cajan*) supplemented with silicon (Si). Leucaena and pigeon pea plants were grown in nutrient solution (i) without the addition of Si and (ii) supplemented with 3.57 mM of the element in the form of sodium metasilicate ($Na_2SiO_3.5H_2O$) in a randomized complete block design, with eight replications. Plants were harvested 88 and 102 days after sowing for pigeon pea and leucaena, respectively. The production of total phenols and condensed tannins in the leaves, the content of macro and micronutrients and dry matter of the shoots were evaluated. There was no statistical differences in dry weights of the shoots for both species, supplemented or not with Si. Plants of leucaena supplemented with Si absorbed and translocated to leaves about 72% more Si than the control treatment. In pigeon pea the increase was lower, reaching an average 30%. In this species, however, there was a significant decrease in levels of total phenols and tannins with the addition of Si. The same did not occur with leucaena. A probable cause for this decline was an increase of 24% in the uptake of nitrogen (N) induced by the addition of Si. The N fertilization can cause a decrease in the level of phenols and tannins. Supplementation with Si in leucaena also caused an increase in leaf N content of 11% on average, but was lower in pigeon pea. A possible increase in photosynthetic activity and, consequently, in carbon skeleton production, due to Si supplementation, increased the demand for N for the synthesis of amino acids and other N compounds. Under similar environmental conditions, pigeon pea plants supplemented with Si absorbed more N, producing less condensed tannins and phenolic compounds in the leaves.

Keywords: silicon, phenol, nitrogen, silicate, *Leucaena leucocephala*, *Cajanus cajan*

CORRELATION BETWEEN TWO METHODS FOR SILICON EXTRACTION IN NATURAL AND UNDISTURBED TROPICAL SAVANNA SOILS OF BRAZIL

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The content of total silicon (Si) in the soil has low correlation with the concentration of soluble Si, which is dynamic. Soil solution contains mainly monosilicic acid (H_4SiO_4 or $Si(OH)_4$), also known as ortosilicic acid or simply silicic acid, also occurring in fresh water and oceans. At pH near neutral, silicic acid has solubility of 2 mM. Above this concentration polycondensation occurs, producing oligomeric silicic acid and possibly colloidal particles of hydrated silica ($SiO_2.xH_2O$). Plants have several methods of extracting available Si. The amount of Si extracted from soil varies according to the solution extractor. Solutions of diluted salts, as $CaCl_2$ 0,01 mol L^{-1}, extract Si readily available in the soil solution, while the results obtained with acetic acid indicate the solubilization of simpler polymers, which are affected by changes in pH, CTC and the Si:Al ratio in the soil solution. Thus, the figures obtained with acetic acid are higher than in calcium chloride. The purpose of this work was to obtain a correlation between two extractor solutions in soils in the State of Mato Grosso do Sul, Brazil. Samples collected from 35 sites of natural and undisturbed tropical savanna soils at 0-0.20 m depth and corresponding to the main representative soil units were studied for Si content and correlated with their chemical composition and physical parameters. They were classified as Lixisol, Acrisol, Nitisol, Phaeozem, Gleysol, Ferralsol, Fluvisol, Histosol, Planosol, Plinthosol and Vertisol, located in the counties Amambai, Anastácio, Aparecida do Taboado, Aquidauana, Bodoquena, Camapuã, Chapadão do Sul, Dourados, Guia Lopes da Laguna, Iguatemi, Itaquiraí, Maracaju, Miranda, Mundo Novo, Nioaque, Paranaíba, Ponta Porã, Rio Negro, Santa Rita do Pardo, Selvíria, Tacuru and Três Lagoas. The available Si (mg kg^{-1}) was measured with a weak acid (acetic acid 0.5 mol L^{-1}) and a salt (calcium chloride 0.01 mol L^{-1}). The determination of Si was performed by colorimetry, with three replications. Levels of available Si ranged from 1.2 to 53 mg kg^{-1} in calcium chloride and 2.3 to 270 mg kg^{-1} in acetic acid. The correlation between the two methods, despite the acetic acid possibly overestimating the Si available for plants, was positive and significant. The equations obtained can estimate available Si in natural and undisturbed tropical savanna soils and in the laboratory. The quadratic equations are: Si acetic acid = 0.084 $(Si\ CaCl_2)_2$ + 0.87 $(Si\ CaCl_2)$ + 1.17 (r=0.95**) and Si $CaCl_2$ = 0.0008 (Si acetic acid)$_2$ + 0.37 (Si acetic acid) + 2.29 (r=0.96**).

Keywords: silicon, calcium chloride, acetic acid, methodology, undisturbed soil, extractor

ALLEVIATION OF COPPER TOXICITY IN *ARABIDOPSIS THALIANA* AND *ZINNIA ELEGANS* BY SILICON ADDITION

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While the role of silicon (Si) in plants has been studied for over 150 years, and this element can mitigate the effects of certain heavy metals, its role in copper (Cu) metabolism is unclear. Therefore, the role of Si in plant response to Cu stress was investigated in *Arabidopsis thaliana* L. (Heyn) and *Zinnia elegans* L. Si was found to mitigate Cu toxicity stress based on plant symptoms and reduced PAL (phenylalanine ammonia lyase, EC 4.3.1.5) activity, a stress-induced enzyme, in both arabidopsis and zinnia. However, the effects of silicon on Cu stress in zinnia were not as dramatic as those on arabidopsis. Real-time reverse transcriptase-PCR indicated that the RNA levels of two arabidopsis Cu transporter genes, *COPT1* (copper transporter 1) and *HMA5* (heavy metal ATPase subunit 5) were induced by high levels of Cu, but were significantly decreased when Si levels were also elevated. Taken together, these findings indicate that Si addition can improve the resistance of plants to Cu stress, and this improvement operates on multiple levels ranging from physiological changes to alterations of gene expression.

Keywords: floriculture, silicon, metal toxicity, HMA5, PAL, COPT1

SILICON IMPROVES GROWTH AND INCREASES ROOT CELL WALL EXTENSIBILITY OF CADMIUM TREATED MAIZE

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Zea mays L. cv. Jozefina plants were cultivated in hydroponics to the stage of the second fully developed leaves with and without the addition of silicon (Si) and/or cadmium (Cd). Si was added in the form of sodium silicate and Cd in the form of $Cd(NO_3)_2.4H_2O$. After two weeks the growth parameters were determined. The mechanical properties of root cell walls were investigated. The plasticity and elasticity of the cell walls of apical, actively growing root segments were measured by creep meter. The Cd content was determined by AAS. The development of suberin lamellae-apoplastic barrier in the root endodermal cells was observed by fluorescence microscopy.

Cd decreased the growth of maize roots and decreased total extensibility of the root cell walls. On the contrary, the growth of the roots of this maize cultivar increased about 15% by Si addition when compared with the control, and also the total extensibility of the root cell walls was significantly increased. In the presence of Cd+Si, the growth of the root was improved and the cell wall plasticity and elasticity were increased in comparison with the Cd treatment.

The contents of Cd in under- and above-ground plant parts were significantly higher in the plants treated with Cd+Si than in plants treated with Cd only. This may be correlated with the development of the endodermis.

Keywords: maize, silicon, cell-wall extensibility, cadmium, heavy metals, endodermis

THE EFFECT OF SILICATE ON POTATOES IN MINAS GERAIS, BRAZIL

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This study evaluated the effect of leaf application of K_2SiO_3 on plant architecture, chlorophyll and yield of potato cv. Atlantic. The experiment was done at Montesa farm, in the county of Serra do Salitre, Minas Gerais, Brazil, in a randomized block design with four replications. Six different dosages of K_2SiO_3 were applied in the tank mixture: 0, 0.2, 0.4, 0.6, 0.8 and 1%. The plots were sprayed weekly at a dose of 600 L ha^{-1}, with a total of 14 sprays before harvest. Measurements of leaf insertion angle, and contents of chlorophyll a, b and total and the relationship of chlorophyll a/b in the third, seventh and tenth leaves were done 30, 45 and 60 days after planting. The potatoes were harvested and classified at the end of the cycle. In general, there was a reduction in leaf insertion angle on all three evaluation dates, i.e. as the K_2SiO_3 dosage increased there was an improvement in leaf architecture in all parts of the plant canopy. The contents of chlorophyll a, b and total had an inverted quadratic adjustment with increasing K_2SiO_3 doses, whereafter the pigment levels decreased until dose 0.4%. The chlorophyll levels then started to increase and, at 1% K_2SiO_3, were greater than in the non-sprayed control. The a/b chlorophyll relationship did not show significant variations. Potato yield of the extra and commercial classes also presented an inverted quadratic adjustment, with increases of up to 22.4% at 1% K_2SiO_3, in comparison with the non-sprayed control. It can be concluded that there was an improvement in plant architecture, with increased contents of chlorophyll a, b and total and the yield of extra and commercial potatoes at 1% K_2SiO_3 in the spray mixture.

Keywords: potato, silicon, plant architecture, chlorophyll, yield, potassium silicate

SILICATES IN CONTEMPORARY AUSTRALIAN FARMING: A 20-YEAR REVIEW

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Silicates have been used in Australia in broadacre agriculture, horticulture, viticulture, and beef and dairy cattle for 20 years with outstanding results in yield, quality, soil health and sustainability. These results have been consistently realized in all types of climatic conditions, such as droughts, dry periods, waterlogged conditions, acid soils, saline soils irrespective of the soil type, soil texture and soil pH. In broadacre cereal production these silicates consistently outperformed high analysis fertilizer in increased protein levels, increased yields, decreased screenings, and increased grains/head. With rape/canola significant improvement and performance has been consistently noted in yields, oil content and reduced pesticide and fungicide applications. In viticulture for both table and wine grapes superior grapes were achieved, having superior skin quality, higher Brix values, uniform bunch size and virtual absence of fungal diseases. High levels of beneficial insects are observed. In horticulture there are a vast number of case histories showing that silicates increase quality of fruit and vegetables with reductions in disease incidence and pest pressure. Dramatically improved storage potential and increased shelf life is evident. The silicates here are the key for organic horticulture. Use of silicates resulted in increased pasture quality with higher palatability, increased nutritional value and digestibility. The water-soluble carbohydrate content is higher and pasture composition had improved with significantly decreased weed intensity. There are always recorded increased weight gains in beef cattle, increased milk production (L/hd/day) and quality (increased milk protein and butter fat) with improved herd health. Silicates have been widely used in Australia to replace lime for treating exchange acidity/soil pH in a cost-effective manner. The cost analysis shows outstanding cost benefits to farmers when using silicates over aglime in both actual liming and in more rapid release of locked-up nutrients. The cost to the environment is a further economic factor in favour of utilizing activated silicates in agriculture for the reduction of greenhouse gases (GHG). The use of activated silicate fertilizer does not produce GHG as does aglime. Aglime when applied to acidic soils releases 400 kg CO_2 per tonne of lime applied. With the average 2.5 t/ha of lime this means that 1 t/ha CO_2 is liberated. The fact that these silicates fertilise and correct soil acidity also represents a significant cost saving for the farmer. The review of case histories shows that with these silicates significant advances in sustainability, productivity and quality can be readily achieved in a cost-effective manner.

Keywords: silicon, sustainability, exchange acidity, nutrient release, activated silicates, soil biomass

SOIL CLASSIFICATION ON DEFICIENCY OF ACTIVE SILICON

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Simple, universal and informative methods for soil testing and classification with regard to deficiency in plant-available and active forms of silicon (Si) are necessary for the effective use of Si fertilizers worldwide. In the soil-plant system, there are several forms of soluble Si: monosilicic acid, low- and high-molecular polysilicic acids, oligomers and organo-silicon compounds, and numerous sources of soluble Si such as Si-rich colloids, amorphous silica, clay and coarse minerals. Moisture fluctuations, the processes of adsorption of monosilicic acid by plants and soil microorganisms result in the dissolving or precipitation of Si compounds, thus determining the Si status in the soil. Si transport by natural waters and as a result of agricultural activity and the application of Si fertilizers can change the soil Si status. Actual Si (soluble and weakly adsorbed forms) and potential Si (forms serving as a source of actual Si) are primary parameters used in the methods suggested for soil testing and soil classification for Si. A complex parameter for evaluating soil deficiency in plant-available Si was elaborated. The parameter includes the amount of plant-available Si (water-extractable from fresh soil) and biogeochemically active Si (0.1 N HCl-extractable from dry soil). This complex parameter was tested on various soils from the USA and other countries. It was found that a close relationship exists between the parameter and total Si in plants (r^2=0.96-0.98). Four grades of active Si deficiency in soils were proposed: (1) soils with no deficiency, (2) soils with low levels of deficiency, (3) soils with a deficiency, and (4) soils with a critical deficiency. Soil samples taken from various regions of Florida were analyzed for active Si, and the results were used to create a map showing the areas of Si deficiency in Florida. Determination of Si deficiency in soils and soil mapping should help to solve practical problems involving the need for Si fertilizers and Si soil amendments.

Keywords: silicon, soil classification, active silicon, method, monosilicic acid, potential silicon

DYNAMIC OF MONOSILICIC AND POLYSILICIC ACIDS IN PLANT TISSUE UNDER SALT STRESS

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Salt toxicity (salinity) is one of the major problems in modern agriculture. Plants can employ silicon as a protective agent against stresses. The mechanisms of this process remain unknown. Barley (*Hordeum vulgare)* and *Distichlis spicata* were used in this investigation. Both plants were grown in a media low in plant-available Si. Shoots with several leaves were cut and put into water or into salt-bearing solution. After 24 and 48 hours, the total Si content and concentrations of monosilicic and polysilicic acids in the plant tissue were measured. Si constituted 1.50% of above-ground biomass and 0.68% of below-ground biomass for *D. spicata*, and 1.21% and 0.49% for barley. Si content in the young leaf-blade parts ranged from 1.53 to 1.82% and from 0.95 to 1.44% for *D. spicata* and barley, respectively. In order to observe the effect of NaCl on Si distribution, shoots were placed in three different "silicon-free" solutions of NaCl (0, 10 and 32 g/L) for 20 hours. In the young nodes, the increase in Si content over the control was 217% for *D. spicata* and 320% for barley. Similarly, the young internodes exhibited increases in Si of 237% for *D. spicata* and 387% for barley. In all parts of the leaf-blades, the Si content diminished. These results demonstrate that *D. spicata* and barley can redistribute Si via a specific mechanism in response to internal salt stress. The dynamic of monosilicic and polysilicic acids in the plant tissue was tested for barley only. The content of monosilicic acid in the leaves was 100-140 mg Si/kg, while the content of polysilicic acid in the leaves was 800-1000 mg Si/kg. The initiation of the salt stress decreased the content of monosilicic acid during first 24 hours of stress, and dramatically increased (more than two-fold) the content of polysilicic acid in the stem and leaves. However, after 48 hours, the content of monosilicic acid increased more than two-fold, whereas the concentration of polysilicic acid decreased. This data suggests that salt stress initiated the re-activation and transport of additional Si in the plant tissue, in the form of polysilicic acid. Thereafter, part of the transported polysilicic acid was transformed to monosilicic acid.

Keywords: barley, silicon, *Distichlis spicata*, monosilicic acid, polysilicic acid, salinity

NEW GENERATION OF SILICON FERTILIZERS

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The development of any type of fertilizer usually proceeds from a simple material to a complex which is able to increase fertilizer efficiency, and from simple methods of application to specific application. Advances in Silicon (Si) fertilizer have proceeded in a similar manner. Instead of doses of 2-4 t/ha of low efficiency Si-rich materials applied by broadcasting, it became possible to use doses of 1-50 kg/ha of active Si substance with special handling such as seed treatment or foliar application. Several types of new generation Si fertilizers were tested. These fertilizers include other ingredients which have synergic effects on the active Si. Both liquid and solid forms of new Si fertilizers have extremely high contents of plant-available Si. A field test of the liquid complex Si fertilizer consisting of concentrated monosilicic acid and specific organic substances was conducted in wheat. The fertilizer was applied at the time of seed planting at a rate of 0.4 L concentrated fertilizer per hectare (dilution 1:1000). As a result of Si treatment, the yield increased from 2.9 to 4.6 t/ha, and the quality of the wheat improved as well. New solid Si fertilizers were tested in greenhouse trials on cucumbers, cauliflower and tomatoes. These Si fertilizers contain activated diatomaceous earth (high in plant-available Si), specific soil microbes and organic substances for microbe nutrition and activation of Si. One of the Si fertilizers was applied to the soil twice per season, during sowing and picking of cultivated plants. Another solid Si fertilizer was applied as a foliar treatment at the third leaf stage, and then once every two weeks. The cauliflower yield increased from 5.3 to 10.6 t/ha for the foliar treatment and from 11.6 to 14.4 t/ha for the combined treatment of soil and leaves. The tomato yield increased from 34.5 t/ha in the control to 42.8 t/ha for the foliar treatment and 43.0 t/ha for the combined treatment of soil and leaves. The cucumber yield increased from 21.3 to 39.6 t/ha for the foliar treatment and from 28.1 to 25.8 t/ha for the soil treatment. The dynamic of the cucumber maturation was determined as well, and showed that the application of Si fertilizers accelerated fruit maturation. Active Si also stimulated fruit formation. New Si fertilizers were used at rates of 40 kg/ha for soil application and 10 kg/ha for foliar application. The Si fertilizers demonstrated high efficiency at low rates, and could be used in different ways and for different cultivated plants.

Keywords: wheat, vegetables, silicon, rate of fertilizer, active silicon, synergetic effect

SOME NEW PERSPECTIVES FOR PREDICTING THE SILICON SUPPLYING POTENTIAL OF SOILS IN THE SOUTH AFRICAN SUGAR INDUSTRY

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Early field studies conducted with sugarcane in South Africa have highlighted the abiotic role of silicon (Si) application in being more effective than lime in correcting Al and Mn toxicity in the strongly acid oxisol soils in the high altitude areas of the KwaZulu-Natal Midlands. Four out of five field trials located on these soils produced significant responses to the application of calcium silicate, varying from 9 to 24 tc/ha. Recent studies at the South African Sugarcane Research Institute have emphasized the important biotic role of applied Si in improving the resistance of sugarcane to the stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae). Estimated crop and sucrose losses from *E. saccharina* damage rank as the most important factors limiting productivity in the South African sugar industry. While numerous methods for determining plant-available Si in soils have been proposed, ranging from acid, neutral to alkaline extractants, they all have limitations as no extractant works equally well on all soils. Despite the fact that trial results have indicated that the Si requirement of sugarcane is a function of soil type, parent material and properties such as soil pH, texture, organic matter and plant available Si, very few diagnostic systems consider the potential role that these play in improving the basis of Si recommendations for sugarcane.

Plant tissue testing methods based on determining the total Si content of specific leaf or stalk tissue material have had more success in predicting the need for Si treatment. There have, however, been problems with the interpretation of the results due to a lack of standardisation of crop age and timing of leaf samples. The mineral composition of plant tissue depends on dynamic factors of nutrient uptake, distribution, redistribution and interactions with other nutrients. There has been increasing interest in the use of ratios between elements as an alternative approach to interpreting leaf analysis, where leaf samples cannot be taken at the correct physiological stage. Results from recent studies indicate that the N:Si ratio in the top visible dewlap sample is better correlated with potential *E. saccharina* damage than Si alone and that sugarcane with values in excess of 2:1 are associated with increasing risk of *E. saccharina* damage.

An improved system for predicting the Si supplying potential of soils and Si use efficiency is proposed based on extractable Si, soil parent material, soil type, texture, pH and exchangeable Al saturation. Attention is also focused on the potential merits of other plant tissue nutrient ratios with Si associated with high yielding cane, which formed part of a previous study to assess the merits of Diagnosis Recommendation Integrated System (DRIS).

Keywords: sugarcane, silicon, soil and leaf tests, *Eldana saccharina*, DRIS, nutrient ratios

GREENHOUSE EVALUATION OF EFFECT OF SILICON SOIL APPLICATIONS FOR CONTROL OF VERTICILLIUM WILT OF POTATOES

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Verticillium wilt is a vascular disease occurring in potato producing areas throughout the world. Infection causes wilting and yellowing of leaves, resulting in premature senescence of the foliage, a shortened growth period and subsequent yield loss. Verticillium wilt is difficult to control due to the long viability of microsclerotia, the broad host range and the inability of fungicides to affect the pathogen once it enters the vascular tissue. A number of studies indicate a benefit from silicon (Si) nutrition in plants by increasing resistance to pathogenic fungi, firstly by acting as a physical barrier to infection, and secondly by activating natural defence mechanisms in the plant such as the production of phytoalexins and accumulation of phenolic compounds. A greenhouse trial was undertaken to determine the efficacy of Si soil applications for the control of Verticillium wilt of potatoes. Potato tubers (cv. Caren) were planted in pots filled with sandy soil infected with *Verticillium dahliae* and in uninfected soil. The soil was treated as follows: untreated control, 0.11 g/kg soil Si fume (100% Si), 0.45 g/kg soil lime, slag (30% Si) and fly-ash (50% Si). Plants were examined 12 weeks after planting for the presence of yellowing and wilting symptoms. Stems were air-dried, ground and plated on a selective medium to quantify the inoculum levels. Progeny tubers of uninfected plants were grown in infected soil to determine their resistance to Verticillium wilt. Si treatments resulted in a decrease of 50, 96 and 100% in number of microsclerotia/g dry stem material for Si fume, fly-ash and slag treatments respectively, whereas lime treatment resulted in an increase of 91% in number of microsclerotia/g dry stem material. Progeny tubers of Si fume treated plants showed 57% less yellowing and wilting symptoms relative to the untreated control. Based on results in the greenhouse, further research will focus on evaluation of Si soil applications alone and in combination with a biological control agent in the field, as well as mode of action studies.

Keywords: potato, silicon, Verticillium wilt, disease management

CHARACTERIZATION OF SILICON TRANSPORTERS FROM RICE AND MAIZE

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Wide variation exists in silicon (Si) concentration in shoots of different species, attributed to the ability of plant roots to take up Si. The gene *Lsi1*, which controls Si uptake in rice, was recently identified. *Lsi1* belongs to the nodulin 26-like major intrinsic protein (NIP) subfamily. The transport protein was localized at the plasma membrane on the distal side of root exodermis and endodermis, where Casparian strips exist. In this study, protein encoded by *Lsi1* was characterized using the *Xenopus laevis* oocyte expression system. Si transport was higher in the oocytes expressing *Lsi1* than in the control. A kinetic study showed that Si transport activity increased linearly with increasing external Si concentrations. Furthermore, *Lsi1* showed efflux activity for Si, indicating that *Lsi1* is a bidirectional transporter. To examine substrate specificity of *Lsi1*, comparison was made of transport activity for water and four non-charged molecules, glycerol, urea, boric acid and arsenite. *Lsi1* showed transport activity for water, urea, boric acid and arsenite, but not for glycerol. However, Si transport activity was not (or less) affected by equimolar urea or boric acid, and was inhibited by $HgCl_2$ treatment, but not by low temperatures. Among the NIP subgroup, OsNIP2:2 showed transport activity for silicic acid, whereas OsNIP1:1 and OsNIP3:1 did not. It is proposed that *Lsi1* and its close homologues form a unique subgroup of NIP with a distinct ar/R selectivity filter, located in the narrowest region on the extra-membrane mouth, and regulates substrate specificity of the pore. Also isolated and characterized were three maize Si transporters, *ZmLsi1*, *ZmLsi2* and *ZmLsi6*, which are homologues of rice Si transporters. Each gene shared >80% identity between maize and rice. Both *ZmLsi1* and *ZmLsi6* showed Si influx transport activity, while *ZmLsi2* showed efflux activity when expressed in *X. laevis* oocyte. mRNA of *ZmLsi1* and *ZmLsi2* were expressed mainly in roots, while *ZmLsi6* was also in the shoot. Immunostaining showed that *ZmLsi1* was localized at the plasma membrane of root epidermis, hypodermis and cortex, while *ZmLsi2* was in the endodermis. In contrast, *ZmLsi6* was localized in the xylem parenchyma cells of leaves. *ZmLsi1* and *ZmLsi6* showed polar localization similar to rice *Lsi1* and *Lsi6;* however, *ZmLsi2* did not. Results suggest that *ZmLsi1* and *ZmLsi2* are involved in uptake of Si from roots and *ZmLsi6* is responsible for transport out of the xylem, thus regulating distribution in leaves.

Keywords: rice, maize, silicon, transporter, NIP, Aquaporin

SILICON TRANSPORTERS IN MAIZE AND BARLEY - COMPARISON OF SILICON TRANSPORTERS IN DIFFERENT PLANT SPECIES

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There is wide variation in shoot silicon (Si) concentration between different species, and this difference is attributed to the ability of the roots to take up Si. Recently, two genes, *Lsi1 and Lsi2*, which control Si uptake, were identified in rice. *Lsi1* and *Lsi2* had Si influx and efflux transport activity, respectively. mRNA of *Lsi1* and *Lsi2* are mainly expressed in the roots, and their expressions were decreased by continuous Si supply. Both *Lsi1* and *Lsi2* are localized in the plasma membrane of exodermis and endodermis cells where Casparian stripe exists, with *Lsi1* on the distal side and *Lsi2* on the proximal side.

This study isolated and characterized four maize and barley Si transporter genes *ZmLsi1*, *ZmLsi2*, *HvLsi1* and *HvLsi2,* which are homologues of rice Si transporters. Each gene shared more than 80% identity between maize, barley and rice. Similar to rice Si transporters, both *Lsi1*-like transporters, *ZmLsi1* and *HvLsi1*, showed Si influx transport activity, while *ZmLsi2* and *HvLsi2* showed efflux activity when they are expressed in *Xenopus* oocyte. mRNA of these genes were expressed mainly in the roots. However, in contrast to rice *Lsi1*, the expressions of *ZmLsi1* and *HvLsi1* in the roots were not affected by continuous silicon supplement up to seven days. On the other hand, the expression of *ZmLsi2* and *HvLsi2* were decreased by one-third by Si supply for three days. Immunostaining showed that *ZmLsi1* and *HvLsi1* were localized at the plasma membrane of root epidermis, hypodermis and cortex, while *ZmLsi2* and *HvLsi2* were only in the endodermis. In addition, *ZmLsi1* and *HvLsi1* showed polar localization similar to rice *Lsi1*, whereas *ZmLsi2* and *HvLsi2* did not.

A previous study showed that the uptake capacity of Si by the roots is much higher in rice than in maize and barley. From this study, it is likely that the different cellular localization of Si transporters between maize, barley and rice may be responsible for the difference in root Si uptake capacity. Coupling of *Lsi1* and *Lsi2* in the same cell contributes to the efficient transport of Si in rice, whereas in maize a`nd barley, the cellular localization of *Lsi1*-like and *Lsi2*-like proteins were different, resulting in low transport efficiency.

Keywords: rice, maize, barley, silicon, transporter, localization

EFFECTS OF SILICON APPLICATION TO NITROGEN RATE AND SPLITTING ON AGRONOMIC CHARACTERISTICS OF RICE (*ORYZA SATIVA* L.)

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A field experiment was conducted in northern Jouybar to evaluate silicon (Si) and nitrogen (N) application rates and splitting on the agronomic characteristics and lodging resistance mechanisms in rice. The experiment was conducted as spilt-spilt plots in a randomized complete block design with three replications. Treatments consisted of 69 and 138 kg N ha^{-1} (applied as 150 and 300 kg ha^{-1} urea, respectively) as the main plot, two Si rates of 0 and 250 kg ha^{-1} (0 and 1250 kg ha^{-1} calcium silicate) as sub-plots, and four N splits as sub-sub plots, which were applied at four plant growth stages. Results showed that Si application decreased the number of days to first stage tillering, flowering (50%), panicle initiation stage and full head stage. N applied at 138 kg ha^{-1} induced a significant decrease in the number of panicles per m^2, percentage of filled spikelets, the weight of 1000 grains and the bending moment (lodging). The moment of bending was reduced by the application of Si, that also resulted in increased percentage of filled spikelets and grain yield, but reduced the weight of 1000 grains. The highest number of tillers per hill, length of panicle and percentage filled spikelets was also achieved by splitting treatments at 25 to 33.33% at the transplanting, panicle initiation and full head stages. The application of nitrogen at four growth stages (after transplanting, at first tillering, at panicle initiation and full head stage) induced an increase in the 1000 grains weight and decreased the bending moment (lodging). The effects of interactions of the three factors were not significant on agronomic characteristics.

Keywords: rice, silicon, nitrogen, bending moment, lodging, grain yield

STATUS OF SILICON IN SOILS OF MIDDLE EGYPT

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An investigation of soil silicon (Si) was carried out on the alluvial soils of the Nile valley as well as those of the transitional belts of the desert plateaus in Middle Egypt. Amounts of water-soluble Si ranged between 0.05 and 2.34 mg SiO_2/100 g soil. Fine textured soils showed the highest values of soluble Si. Determinations carried out on different values of soil:water ratios showed that, in most cases, soluble Si gradually increased by increasing dilution. Values obtained from four successive extractions of 1:20 soil:water suspensions, revealed that there was a gradual increase of soluble Si with increasing number of extraction and the highest values were obtained from the third extraction. Relatively smaller amounts of soluble Si were obtained when centrifugation was applied than when normal filtration was used. Some positive or negative correlations were found between the studied Si fractions and sand, silt, clay, organic matter, CEC and total carbonate. Amorphous Si determined in the different soils ranged between 0.06 and 3.34%. Fine textured soils showed the highest values of amorphous silica. Si increased from the desert plateaus toward the Nile stream. As a percentage of total Si fraction, amorphous Si was found to constitute from 0.07 to 7.55%. Total Si as SiO_2% varied greatly from one site to another and ranged between 40.18 and 90%. The highest values were obtained from the coarse-textured soils which are located in/or near both Eastern and Western plateaus, while the lowest values were obtained from the alluvial soils of medium to heavy texture grades.

Keywords: silicon, total silicon, amorphous silica, water-soluble silicon

PHYSIOLOGICAL CHANGES WITH SILICON APPLICATION TO IMPROVE SALT TOLERANCE IN WHEAT GENOTYPES UNDER SALT STRESS

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The effect of exogenous application of silicon (Si) on the growth and physiological response of salt stressed wheat genotypes was investigated. Two contrasting wheat genotypes, SARC-3 (salt tolerant) and Auqab-2000 (salt sensitive), were grown in hydroponics containing 150 mM NaCl (control) with and without 2 mM Si. Shoot growth of plants grown in Si amended treatment was significantly more than in the control. The plants receiving Si in root medium had slightly higher chlorophyll and water contents in their leaves. The membrane stability index in leaves was more in Si fed plants than Si deprived plants. Electrolyte leakage percentage was significantly lower in SARC-3 than in Auqab-2000. Sodium uptake by plant roots was estimated by the nutrient depletion technique. Sodium uptake was significantly lower in Si fed plants. The exposure of plants to salinity stress in the presence of 2 mM Si reduced the Na influx in plant roots by influencing the kinetic parameters, viz. Km and Vmax. The Km value for Na uptake increased from 27 to 73 mM and 12 to 71 mM, respectively, in Auqab-2000 and SARC-3, and the Vmax value was reduced to 40%. However, further verification of the results is warranted under field conditions.

Keywords: wheat, silicon, tolerance, genotypes

MOVEMENT OF SILICON THROUGH *SACCHARUM OFFICINARUM* (SUGARCANE) AND ITS EFFECT ON *PUCCINIA MELANOCEPHALA* (BROWN RUST)

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

Keywords: sugarcane, silicon, *Puccinia melanocephala*, brown rust

CALIBRATION, CATEGORIZATION AND STATUS OF PLANT AVAILABLE SILICON IN DIFFERENT RICE SOILS OF SOUTH INDIA

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Calibration of field crop response to nutrient availability acts as a basis for making fertilizer recommendations from soil and tissue analysis. The purpose of this study was to evaluate and summarize silicon (Si) fertilization of rice and plant available Si status in different soils of south India. A greenhouse pot study was conducted in 18 rice soils using KRH-2 rice hybrid as a test crop. The experiment consisted of four levels of Si as calcium silicate, with three replications. The grain and straw yields were recorded from each pot and samples were analyzed for Si content. Significant increases in grain and straw yields were noted due to application of calcium silicate. Maximum yield increases due to application of Si were noted in soils at Mangalore, followed by Ponnampet and Mudigere. The critical level (the point below which response to Si fertilizer is expected) for plant available Si in the soil as extracted by different extractants ranged from 14 ppm (distilled water-1) to 207 ppm (0.005 M H_2SO_4). There was wide variation in low, medium and high categories of plant available Si for different extractants, calculated on per cent relative yield. Of the extractants used, Si extraction with N NaOAc-1 appeared to be the most suitable for evaluating Si, followed by extraction with 0.5 M acetic acid-2 and N NaOAc-2. The plant available Si content of soils of different agroclimatic zones of Karnataka state, south India, ranged from 6.4 to 140.6 ppm, and 30, 60 and 10% of soil samples were categorized as low (<47 ppm), medium(<47 to 102 ppm) and high (>102 ppm), respectively, as extracted by 0.5 M acetic acid-2.

Keywords: rice, silicon, extractants, soil testing, calcium silicate, relative yield

SILICON ALLEVIATES THE TOXICITY OF CADMIUM AND ZINC IN MAIZE (*ZEA MAYS* L.) GROWN ON A CONTAMINATED SOIL

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Silicon (Si) presents a close relationship with the amelioration of heavy metal phytotoxicity. This work was carried out to evaluate the effects of Si application to soil on the amelioration of metal stress to maize grown on a contaminated soil amended with Si (0, 50, 100, 150 and 200 mg kg^{-1}) as calcium silicate ($CaSiO_3$). Additionally, the bioavailability of cadmium (Cd) and zinc (Zn), and their distribution in soil fractions, were studied. The results showed that adding Si to a Cd and Zn contaminated soil effectively diminished the metal stress and resulted in biomass increment in comparison to metal contaminated soil not treated with Si. Such outcome was clearly independent of the calcium silicate effect on elevating pH, and relied on Cd and Zn immobilization in soil. Si altered the distribution of the metals in soil fractions, decreasing the most bioavailable pools and increasing the allocation of metals to more stable fractions such as organic matter and crystalline iron oxides.

Keywords: maize, silicon, soil remediation, heavy metals, soil contamination

THE *IN VITRO* AND *IN VIVO* EFFECTS OF SILICON ON FUSARIUM WILT ON POTATOES

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Fusarium wilt is a disease of global importance resulting in huge agricultural losses if not controlled. In South Africa, *Fusarium oxysporum* is the most important causal agent of potato wilt and there are no reliable control measures available. Silicon (Si) is essential for normal growth and development of plants, as well as in improving host plant resistance to pathogen attack. Although Si has been shown to improve host resistance to various plant pathogens, its effect has not been investigated on *F. oxysporum*. In this study, the *in vitro* effect of potassium silicate (KSi) (20.7% silicon dioxide) and other Si sources was investigated. Potato dextrose agar (PDA) was amended with different concentrations of KSi, namely 0, 5, 10, 20, 40 and 80 ml KSi per litre agar. Following addition of KSi (pH 12.7), the pH of PDA solutions increased from 5.2 to 8.8, 9.6, 10.2, 10.6, and 10.8, respectively. To determine whether increase in pH alone has an effect on the growth of *F. oxysporum* on PDA, pH controls were included, in which pH was adjusted to the respective values using potassium hydroxide. Plates were inoculated with *F. oxysporum* and percentage inhibition was calculated seven days after inoculation. At 80 ml KSi L^{-1} PDA, the growth of *F. oxysporum* was inhibited by 92%, while 40 ml L^{-1} PDA showed only 5% growth inhibition. Interestingly, at low concentrations of 5, 10 and 20 ml L^{-1} PDA, *F. oxysporum* growth was enhanced, resulting in negative inhibition of -44.50%, -44.5% and -30.9%, respectively ($P>0.001$). Since there was no growth inhibition with the pH controls, Si was shown to be entirely responsible for growth inhibition. The effect of different Si soil amendments, namely silicon ash (~99% Si), slag (30% Si), and fly ash (50% Si) on potato tuber yield was investigated. A lime (calcium carbonate) treatment was included as pH control. Tuber yield results showed a definite increase in yield when compared to the negative control. Further research is necessary to confirm the efficacy of Si soil amendments in controlling Fusarium wilt of potatoes.

Keywords: potato, silicon, Fusarium wilt, potassium silicate, slag, pH

DYNAMIC OF THE UPTAKE AND ACCUMULATION OF SILICON IN WHEAT, RICE, SOYBEAN AND BEAN IN NUTRIENT SOLUTION

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Rice (*Oryza sativa*) and wheat (*Triticum aestivum*) are silicon (Si) accumulators. These species have an active mode of silicon uptake. Soybean (*Glycine max*) and bean (*Phaseolos vulgaris*) are non-accumulators. This study investigated Si uptake by four crop species widely different in Si uptake capacity. These species germinated in quartz sand and were cultivated in nutrient solution. Seven-day old seedlings were transferred to a full-strength nutrient solution with two plants per 2 L plastic pot. Two treatments were established for each crop: (i) without Si and (ii) with periodic addition of Si (0.9 mM Si) applied as $SiOH_4$ freshly prepared from sodium silicate. The quantity of Si absorbed by the plants was calculated from the concentration of the element remaining in the solution (per week), determined by the spectrophotometric method exploring flow injection analysis system (FIA). Rice and wheat have active transport of this element, and the dynamic absorption curves for Si for these cultures tended to be similar. Si accumulation was proportional to the development of the plants. As non-accumulators of Si, with passive or rejective transport of Si, bean and soybean showed no significant increase in Si absorption within the plant. After a large absorption in the first week of growth, the absorption curve fell and stabilized. Si absorption in soybean had reached a value of 0.1 mM L^{-1} at the termination of the experiment.

Keywords: rice, wheat, soybean, bean, silicon, absorption

SILICON AND GERMANIUM UPTAKE AND TRANSPORT BY PLANTS USING GE/SI RATIO AND SI ISOTOPES

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Plants strongly impact the continental cycle of silicon by taking up Si, forming phytoliths and restituting biogenic opal to the soil. The similar inorganic geochemical pathways of Ge and Si provide useful tracers of the Si cycle. However, Ge uptake and transport through plants and the impacts on Ge/Si ratio of phytoliths are still poorly understood. This study investigates Ge uptake and accumulation and Ge/Si fractionation in plant parts and solutions from (i) bananas cultivated in hydroponics, (ii) bananas sampled *in situ,* and (iii) horsetails sampled *in situ*. These data are compared with $d^{29}Si$ measurements in banana plants. Ge/Si ratios were calculated after determination of Ge content by HR-ICP-MS and Si content by ICP-AES. Isotopic compositions were measured by MC-ICP-MS Nu Plasma in dry plasma mode with external Mg doping: $d^{29}Si$ vs NBS28 ± 0.08‰ (± $2\sigma_{SD}$). Bananas and horsetails were shown to accumulate Ge in plant roots (*in situ*: Ge/Si_{roots} = 2-22 µmol/mol). Shoots displayed lower Ge/Si ratios (*in situ*: Ge/Si_{shoots} = 0.0-1.7 µmol/mol) without any fractionation between aerial plant parts. No discrimination of Ge occurred at the root-solution interface. This would indicate that Ge follows the transpiration stream just as Si, but is not discriminated between shoot parts. This contrasts with the discrimination of heavy Si isotopes (1) at the root-solution interface, plant adsorbing preferentially light Si isotopes (*in vitro* banana: fractionation factor ^{29}e = -0.40‰), and (2) within the shoots, inducing heavier signatures in upper shoots (*in situ* banana: $d^{29}Si$ = -0.09 to +0.56‰ from lower to upper shoots). Low values of Ge/Si ratio reported in previous studies in root phytolith compared to high Ge/Si values measured here in bulk roots suggest that Ge is organically trapped in plant roots. Si isotopes indicate physiological discrimination mechanisms of Si within the plant. Thus, both the Si isotopic fractionation and Ge/Si fractionation in plants provide new insights to better understand Ge and Si uptake and transport through the plant, and hence tracing Si recycling through the plant within the continental Si cycle.

Keywords: banana, horsetails, silicon, germanium, Ge/Si ratio, Si isotopes

RESPONSE OF SUGARCANE TO SILICON LEVELS AND SOURCES IN MEDIUM DEEP BLACK SOILS

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Field experiments were conducted to study the response of sugarcane variety Co86032 to different levels of silicon (Si) in three consecutive crop seasons. The medium deep black soils under experiment were normal to slightly alkaline. The Si was applied as calcium silicate at rates of 0, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 kg ha^{-1}, and the recommended NPK fertilizers were applied at 250 kg ha^{-1} N, 115 kg ha^{-1} P_2O_5 and 115 kg ha^{-1} K_2O. The treatments were applied in a randomized block design with three replicates. The pooled results revealed that cane yield was significantly increased at 400 kg ha^{-1} Si (142.8 t ha^{-1}) over the control (124.5 t ha^{-1}) and on a par with increased levels of Si. The cane juice quality with respect to brix, sucrose and purity was not affected by Si application. However, commercial cane sugar yield increased by 2.8 t ha^{-1} over the control due to the increase in cane yield in Si-applied plot. Sheath moisture, available P content in soil and leaf P content increased in Si-applied plots. The pest infestation and disease incidence in Si-applied plots was found to be almost negligible. In the succession of these experiments, different Si-containing sources such as thermal power station fly ash and bagasse ash were applied at a level of 400 kg ha^{-1} Si and compared with calcium silicate. The application of fly ash and bagasse ash increased cane yields over the control by 23.7 t ha^{-1} and 26.1 t ha^{-1} respectively, and were found equally as beneficial as calcium silicate.

Keywords: sugarcane, silicon, calcium silicate, fly ash

EFFECT OF OLIGOMERIC SILICON AND LOW DOSE BORON AS FOLIAR APPLICATION ON WETLAND RICE

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Rice and sugarcane are silicon (Si) accumulator plants. Each crop removes large amounts of Si from the soil and intensive cultivation without Si fertilization contributes to declining or stagnating yields in many countries. The importance of ortho/oligomeric silicic acid as a foliar spray in rice, sugarcane and other crops has not been adequately documented in scientific journals. In modern agriculture, nutrient solutions are mostly deficient in ortho (soluble and bioavailable) silicic acid and the added silicates are unable to compensate for this deficiency. Silicic acid is sometimes included in formulations of nutrients and its bioavailability depends on various factors. Boron is also an essential micronutrient for agricultural crops. Boric acid is also used as fungicide, insecticide and herbicide at high concentrations. Combinations of Si and boron in food additives or as medicaments are known from the literature. However, studies on silicic acid in combination with boron and their performance on growth and development of different crops are limited. In 2007 and 2008, field experiments were conducted on the effect of foliar Si (Kondes, Netherlands) and low dose boron on rice grown in the hilly and coastal zones of Karnataka, respectively. There were seven treatments with three replications in a randomized complete block design. Foliar Si was applied 20 days after transplanting rice seedlings, with an interval of 15 days for four and five times. Grain yields were significantly increased over the control by application of 2 and 4 ml L^{-1} oligomeric Si plus half the recommended doses of insecticide and fungicide in both years. The highest grain yields of 6679 and 5172 kg ha^{-1} were in plots receiving 4 ml L^{-1} oligomeric Si plus half the recommended dose of insecticide and fungicide respectively during 2007 and 2008. No yield increase was observed with the application of 8 ml L^{-1} oligomeric Si alone plus half the recommended doses of insecticide and fungicide at both locations. A significant increase in straw yield was observed with application 2 and 4 ml L^{-1} oligomeric Si alone and along with half the recommended insecticide and fungicide. The increase in straw yield was observed only during 2007 in the hilly zone and in 2008 in the coastal zone.

Keywords: rice, silicon, orthosilic, oligomeric, foliar silicon, boron

ASSESSING THE EFFECTIVENESS OF SILICON CONTENT MATERIALS AGAINST BLAST DISEASE OF RICE

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The effectiveness of silicon-enriched materials in controlling blast disease was conducted on rice plants grown in pots in a net house. This research was initiated to find natural silicon (Si) substrate/s against artificially induced blast disease in rice plants. Nine treatments were applied in this experiment, comprising three Si content materials: ash, rice husk and Na_2SiO_3. Each Si content material was applied in two doses. The chemical Hinosan was sprayed twice at 15-day intervals after disease symptoms were expressed. A diseased control and a healthy control were also maintained to compare the effectiveness of the Si-enriched materials in reducing blast disease. Ash (200 g/pot) yielded good results in controlling blast, followed by Na_2SiO_3 (10 g/pot) considering leaf blast as well as neck blast incidence. Grain weight was also higher in ash treated plants (200 g/pot) followed by rice husk treated plants (50 g/pot). The finding suggests that ash might be a good organic Si substrate to reduce blast disease. Further studies in the glasshouse and field are required to clarify this finding.

Keywords: rice, silicon, blast disease, disease management, natural silicon substrate

EFFECT OF THE FOLIAR APPLICATION OF SOLUBLE OLIGOMERIC SILICIC ACID AND LOW DOSE BORIC ACID ON PAPAYA TREES

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There is limited information about the effects of foliar application of silicon (Si) to horticultural crops such as apples, potatoes and rice. Because of the relatively simple and environmentally friendly type of fertilisation required, a study on papaya cultivation was performed in Colombia. The objective was to determine the effects of foliar sprays with OSAB (= oligomeric silicic acid + boric acid = Agroforce®) on plant development (height and stem diameter), the production and quality of the fruit and the infection rate of the papaya tree. Four different treatments were employed, each one with four replications, on units randomly spread throughout the terrain. The dosages of the four treatments were: A = placebo (control), B = 2.7 litres OSAB/ha, C = 5.4 litres OSAB/ha and D = 2.7 litres OSAB/ha plus trace elements. All Si applications showed better growth of the trees compared to the placebo, as well as an increase in height (+4.7%, +7.8%, +6.3%), diameter (+1.4%, +8.2%, +7.3%) and fruit production (+8.7%, +11.9%, +13.2%) from treatments B, C and D, respectively. Although the flavor of the fruits in treatments B and D were superior to A, the flavor of A (placebo) was better than that of C. The B treatment showed the highest reduction in disease. These initial tests also showed that a 20-40% reduction in pesticide use is realistic. Although the flavor of treatment B fruit is slightly better than that of treatment D fruit, treatment D nevertheless showed the best and most economical production of fruit over the three Si treatments.

Keywords: papaya, silicon, foliar application, silicic acid , boric acid, yield

SILICON IN THE CONTROL OF DISEASES ON RICE, SORGHUM, AND SOYBEAN

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Silicon (Si) is absorbed from soil in large amounts that are several times greater than those of other essential macronutrients in certain plant species. Its beneficial effects have been reported under biotic and abiotic stress conditions. The first study evaluated the importance of active Si uptake in rice to control brown spot. Some components of host resistance were evaluated in plants from cultivar Oochikara and *Lsi1* mutant (low silicon 1; deficient in active Si uptake) that were inoculated with *B. oryzae* growing in hydroponic culture amended with 0 or 2 mmol Si. Si content in plant tissue from both cultivar Oochikara and *Lsi1* mutant in the +Si treatment increased, respectively, by 219 and 178%. Plants from cultivar Oochikara took up 112% more Si than plants from *Lsi1* mutant. The incubation period (IP) of brown spot on leaves of plants from cultivar Oochikara increased in about 6 h in the presence of Si, and relative infection efficiency (RIE), area under brown spot progress curve (AUBSPC), final lesion size (FLS), rate of lesion expansion (r), and area under lesion expansion progress curve (AULEPC) were significantly reduced, respectively, by 65, 75, 33, 36 and 35%. In the presence of Si, the IP increased in 3 h on plants from the *Lsi1* mutant, but the RIE, AUBSPC, FLS, r, and AULEPC were only reduced, respectively, by 40, 50, 12, 21 and 12%. In the second study, the effect of Si rates on some components of sorghum resistance to anthracnose was studied. Two 2x5 factorial experiments, consisting of two sorghum lines (BR005 and BR009, resistant and susceptible, respectively) and five Si rates (0, 0.06, 0.12, 0.24 and 0.30 g Si/kg of soil) were arranged in a randomized design with three replications. Si content in leaf tissue increased relative to the control by 55 and 58%, respectively, for the susceptible and resistant lines. There was no significant change in Ca content on leaf tissue for either of the lines; therefore the variations in Si accounted for differences in the level of disease response. The IP for the resistant line was not affected by Si rates. The latent period (LP) was not evaluated in the resistant line due to the absence of acervuli. For the resistant line, Si rates had no significant effect on area under anthracnose index progress curve (AUAIPC). By contrast, in the susceptible line, a positive quadratic regression model best described the effect of Si rates on IP, LP, and AUAIPC. The results from these studies underscore the importance of Si to increase rice and sorghum resistance to foliar diseases. Results from field and glasshouse studies on the use of KSi sprays as an alternative strategy for the control of soybean rust, indicate that foliar application of KSi has great potential for reducing soybean rust intensity. This information may be invaluable in areas where soybean is grown as a monoculture, and where high yielding but susceptible cultivars cannot be grown because of the occurrence of frequent severe epidemics.

Keywords: rice, sorghum, silicon, foliar disease, monocots, rice mutant

THE EXTRACTABILITY OF CR(III) AND NI FROM SOILS OF SOUTH AFRICA'S EASTERN HIGHVELD AS INFLUENCED BY AN EXTERNAL SOURCE OF SILICON

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The use of steel plant slag as liming material in the agricultural region of South Africa's Eastern Highveld necessitated an investigation into the mobility of the potentially toxic elements Cr(III) and Ni. Apart from determining the extractabilty of Cr(III) and Ni over a period of five rewetting and drying cycles, this study investigates the effect of an external source of silicon (Si) on Cr(III) and Ni mobility. Si has been shown to immobilize certain heavy metals. It was hypothesised that the Si released due to the dissolution of Si containing slag might be incorporated into the crystal structure of layered double hydroxide and oxyhydroxide precipitates, thus forming phyllosilicate precursors. In addition, metal hydroxides (Fe, Al, Mn) in the natural soil environment may act as templates or catalysts to initiate monomeric silicic acid condensation into Si polymers. This in turn might act as reactive sites for subsequently poorly ordered Si precipitation and the occlusion of Cr(III) and Ni, or adsorption thereof, onto the negatively charged, open-framework Si polymers. In order to study this, three mineralogically contrasting soils were contaminated with 15 mg kg^{-1} Cr(III) and 10 mg kg^{-1} Ni and subjected to five rewetting and drying cycles. Apart from the treatments receiving Cr(III) and Ni concentrations, a 20 mg kg^{-1} Si was included. The extractability of Cr(III) and Ni was determined using 0.1 M $Mg(NO_3)_2$ and 0.02 M diammonium EDTA. There were two main findings: (i) although a significant difference in Cr(III) and Ni extractabilty was noted, contradictory evidence was gathered regarding the immobilisation of both elements over the mentioned rewetting and drying cycle period, and (ii) a thermokinetically favoured amorphous Ni silicate phase appears to render Ni less mobile in soils exhibiting a low affinity for the element and more mobile in the soil that did sequester the element fairly effectively. The latter point was, however, only observed for the $Mg(NO_3)_2$ extractable Ni fraction and is therefore regarded as significant when researching mechanisms of heavy metal sequestration, although not substantial in rendering Ni more mobile or less mobile under field scale conditions. This amorphous Ni silicate phase may yet stabilise, and therefore neccecitates an investigation into the long term effect of Si on heavy metal extractability.

Keywords: silicon, chromium, nickel, slag, liming

CLIMATE CHANGE AND THE AGRICULTURE SECTOR IN SOUTH AFRICA: TO STRESS OR NOT TO STRESS ... THAT IS THE QUESTION

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The evolution of the climate-landcover-population-natural resources cycle has focused attention on water for food in a climate changed future. With climate being a major determinant of agricultural production, especially in South Africa, projected first order changes in atmospheric carbon dioxide concentrations, temperature and precipitation, as well as changes to related second order climate derivatives of frost, heat units, chill units and soil moisture are assessed for South Africa. Illustrations of projected shifts in optimum growth areas and yields of key crops, as well as shifts in pests/disease occurrences and irrigation water demand lead to concluding remarks on anticipated future stresses in the agriculture sector of South Africa and on potential adaptation issues.

Keywords: climate change, agriculture

POTATO PRODUCTION AS INFLUENCED BY SOIL APPLICATIONS OF SILICON

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Potato (*Solanum tuberosum*) has become the fourth highest produced food crop in the world and is exceeded only by maize, wheat and rice. The potato crop is capable of reducing the world's food shortages. It is widely cultivated but difficult to produce due to exposure and susceptibility to biotic and abiotic factors which reduce tuber yield and quality. Silicon (Si) is a non-essential nutrient element that has proven to be beneficial to plants in terms of yield, protection from fungal diseases and improved uptake of phosphorus. To determine the effect of Si on potato production and quality, pot trials were conducted in a glasshouse. A slag containing Si was used as a soil amendment in comparison to lime. Due to the high demand for fertilizers by the potato crop, other nutrient elements were added to the soil through fertigation every 7 to 14 days, depending on the growth stage of the plants. Plants were irrigated with distilled water when necessary to maintain a moisture level of about 75 to 80%, and weekly observations were made. Potato tuber peels and flesh were analysed separately to evaluate where Si had accumulated the most. From the observations there was a distinct difference between plants amended with lime and with slag. Tuber weight was improved by application of slag. There was a significant rise in soil pH from both lime and slag which in turn influenced vegetative and tuber growth. These results support past reports on the positive effects of Si in crop production, therefore making the application of Si a viable approach for improving potato production.

Keywords: potato, silicon, slag, soil pH

CALCIUM SILICATE AS SILICON SOURCE AND ITS INTERACTION WITH NITROGEN IN AEROBIC RICE

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Aerobic rice is expected to enhance productivity of rice per unit of water consumed. Being projected as a solution to the water crises facing farmers across all countries, fertilizer management is an important aspect that needs to be addressed. An attempt has been made to standardize the requirement of two important nutrients, Silicon (Si) and nitrogen (N), that impact productivity. Si plays a significant role in imparting both biotic and abiotic stress resistance and enhances productivity. High accumulation of Si in rice has been demonstrated to be necessary for healthy growth and high stable production. Application of N fertilizers is an important practice for increasing rice yields. However, excess N may limit rice yields due to lodging, decreased photosynthesis, enhanced mutual shading, decreased leaf erectness and increased susceptibility to biotic and abiotic stress. Si deposition in stems and leaf blades prevents the adverse effects of excess N. This investigation was aimed at evaluating the effect of Si and N, and their interactive effect on yield components of aerobic rice. In 2006, a field experiment was conducted with calcium silicate at 0, 1, 2 and 3 t ha^{-1} and N at 50, 100 and 150 kg ha^{-1} in a randomized complete block design with three replications, using BI-34 aerobic rice genotype. Application of calcium silicate at 2 t ha^{-1} was found to be effective in increasing plant height, number of tillers per hill and panicle length over the control, and resulted in 25-30% higher grain yield. Si applied as calcium silicate recorded the highest concentration and uptake in grain and straw over other treatments. Increased application of N alone decreased the number of tillers, whereas calcium silicate at 2 t ha^{-1} plus 100 kg N ha^{-1} increased the number of tillers. The highest grain yield was recorded with the application of up to 100 kg N ha^{-1} after which grain yield decreased. Although increased application of N alone significantly increased straw yield, combined application of 150 kg urea ha^{-1} plus 2 t ha^{-1} calcium silicate recorded the highest straw yield of 8079 kg ha^{-1}. Grain harvest index decreased significantly with increased application of N alone. Application of higher levels of calcium silicate alone resulted in higher accumulation of Si in straw and grain. N% and uptake in straw and grain significantly increased with increased application of N alone. However, application of higher levels of Si (3 t ha^{-1}) reduced N% in both straw and grain.

Keywords: aerobic rice, silicon, nitrogen, interaction, harvest index

SILICON-MEDIATED RESPONSES OF SOYBEAN TO UV-B RADIATION STRESS

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A study was undertaken to determine the potential of silicon (Si) for alleviating UV-B radiation stress in two soybean (*Glycine max* L.) cultivars, Kennong 18 (K18) and Zhonghuang 13 (ZH13). Depending on cultivar, the soybean plants suffered severe growth limitations under UV-B radiation. The application of Si alleviated the adverse effects on growth and development by increasing the stem length, net photosynthetic rate and leaf chlorophyll content. Concurrently, it improved the anti-oxidant activities in leaves and reduced the stomatal conductance.

Keywords: soybean, silicon, UV-B radiation, chlorophyll, soluble protein, photosynthetic rate

SILICON INDUCED RESISTANCE AGAINST POWDERY MILDEW OF ROSES CAUSED BY *SPHAEROTHECA PANNOSA*

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Environmental considerations necessitate increasing restrictions on the use of pesticides. Therefore, eco-friendly methods for plant disease suppression need to be developed. Miniature potted roses are a very important ornamental crop. World production is estimated to be more than 100 million plants per year, mainly in Denmark (about 50% of world production), the Netherlands, USA, Canada, Japan, France, Germany and Italy. Powdery mildew caused by *Sphaerotheca pannosa* var. *rosae* is one of the most widespread diseases of potted roses, and infection results in poor quality and low marketing value. Silicon (Si) mediated resistance to plant pathogenic fungi has been demonstrated in several pathosystems. Plants take up Si as silicic acid (H_4SiO_4), which is transported via the transpiration stream to accumulate as insoluble Si compounds, primarily in cell walls. Thus, enhanced resistance of Si-treated plants to pathogenic fungi has been suggested to result from a greater resistance to pathogen penetration of host tissue. This study investigated the possibility of controlling powdery mildew in potted roses using Si as the inducer. A bioassay was established with four rose cultivars, namely 99/9496-19, 95/5166-1, 98/8285-1 and “Smart”, representing different genetic backgrounds and different levels of susceptibility. Plants were watered with increasing concentrations of Si in a nutrient solution, and were inoculated with a defined density of a virulent powdery mildew isolate. Susceptibility to powdery mildew was determined by scoring and evaluating the incubation/latency period and percentage coverage with sporulating colonies, and was correlated to the Si-content in the leaves. Disease reduction ranged from 20-35% after Si treatment compared to the controls.

To study whether induced resistance is involved in the Si-mediated protection, the infection biology and defence responses are compared between plants treated with Si and control plants. Quantitative light and fluorescence microscopy are used for time-course investigations of the primary stages of the infection, and host cell reactions to infections will be examined. Structural and biochemical defence responses in the host are examined further by histochemical staining methods for phenolic substances and Reactive Oxygen Species (ROS), which are known to be involved in inhibition of biotrophic pathogens such as powdery mildews. Enzyme assays are used to quantify defence-related enzymes such as PR-proteins and important antioxidants. Finally, quantitative real time is used to study expression of defence-related genes.

Keywords: miniature potted roses, silicon, induced resistance, powdery mildew, *Sphaerotheca pannosa*

EFFECT OF SILICON APPLICATION ON RICE PRODUCTIVITY IN A RICE-WHEAT CROPPING SEQUENCE

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Rice is the most important staple food crop for more than two-thirds of the population of India. The slogan ‘Rice is Life’ is most appropriate for the country, as the crop plays a vital role in national food security and provides a livelihood for millions of rural households. Rice occupies the largest acreage in the country (44 million ha), with an annual production of 90 million tonnes. The ever-increasing population needs higher production, which means increased productivity and, for nutritional security, high levels of nutrients in the rice grains. Experiments have thus far failed to establish a positive correlation between declining rice-wheat yields under irrigation and the properties of available nutrients under long-term fertility trials in intensive cropping systems. Scientists are therefore considering the possibility that a depletion of plant-available silicon (Si) in the soil due to continuous mining could be the cause of declining rice yields. This study aimed at determining the effects of recycling Si carriers on productivity in rice-wheat cropping systems. Field experiments were conducted during the rainy seasons of 1999-2000, 2000-2001, 2001-2002 and 2002-2003. The soil was a sandy clay loam (Ustocrepts), slightly alkaline at a pH of 7.2, with 0.34% organic carbon, 223 kg available N ha^{-1}, 11.3 kg available P ha^{-1}, 232.4 kg available K ha^{-1} and 301.2 kg available Si ha^{-1}. Eight Si carriers were tested: (i) control (0%), (ii) calcium silicate (100%), (iii) basic slag (100%), (iv) rice straw compost (100%), (v) rice straw compost (50%) + calcium silicate (50%), (vi) rice straw compost (50%) + basic slag (50%), (vii) basic slag (50%) + calcium silicate (50%), and (viii) rice straw compost (33%) + calcium silicate (33%) + basic slag (33%). There were three time intervals of Si application: every year, every second year and every third year, in a split-plot design with three replications. Si was applied at 150 kg ha^{-1} (100%), with the common dose of nutrients (120-60-60 kg N-P-K ha^{-1}). Highest effective tillers/hill was with rice straw compost + calcium silicate, followed by rice straw compost + basic slag. Maximum panicle weight was noted with the application of rice straw compost + calcium silicate. This was significantly higher than the control and the calcium silicate only treatments. Although application of rice straw compost + calcium silicate recorded a higher grain yield than the control, this remained on a par with the other Si carrier treatments. Similarly, straw yield was also higher with rice straw compost + calcium silicate, followed by rice straw compost + basic slag. Yearly application maintained Si availability throughout the growth and development of the rice crop. None of the interactions during the study period were significant.

Keywords: rice, wheat, silicon, Swarana (MTU 7029)

THE EFFECT OF ROW SPACING ON SILICON UPTAKE IN SUGARCANE

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The beneficial effects of bio-available silicon (Si) on plant growth are mainly attributable to the silicates that accumulate in plant cell walls. Bio-available Si is typically absorbed by plants as “monosilicic acid” (H_4SiO_4) or as “orthosilicic acid”, and is deposited in the plant cell walls mainly as silica, improving cell wall structural rigidity and strength, plant architecture and leaf erectness. These effects become more important and can be demonstrated most clearly under high-density cultivation systems.

A row spacing (RS) trial was conducted at the South African Sugarcane Research Institute (29°42'S, 31°2'E, 96 m) in a Haplic Phaeozems (WRB) soil to investigate the effects of population density on sugarcane canopy development, radiation interception and cane yield. A wagon wheel trial layout was used to create variation in RS from 0.5-3.0 m widths. Destructive sampling and leaf analysis of the top visible dewlap leaf or first fully mature leaf was done every three weeks from a crop age of five months onwards. The crop was uniformly fertilised based on soil analysis, and was irrigated to avoid water stress.

Results indicate that leaf Si% in the top visible dewlap leaf increased with crop age and that this increase became progressively greater with wider RS. Leaf Mn% and Fe% showed a downward trend with increased RS. The Mn:Si ratio in the leaf also declined sharply with increased RS to about 30% of the level at the narrow spacing. Soil analysis done after completion of the trial demonstrated a soil pH gradient that correlated with RS and population density, with a gradient from pH 5.8 at wide RS, down to pH 5.2 at narrow RS. The pH gradient made it possible to investigate the relationship between plant available Si (0.02 $N.H_2SO_4$) and soil pH, which proved to be linear (r^2=0.82), indicating 38.9 ppm Si becoming available for every one unit increase in pH.

It is hypothesised that the greater rate of depletion of bases from the soil under the closer row spacing and higher population density has led to greater soil acidification. This in turn has increased extractable Al, Mn and Fe levels at the lower pH, resulting in reduced plant available Si through precipitation of insoluble silicates of Al, Mn and Fe. Wider row spacing can therefore alleviate abiotic stress through enhanced Si uptake by the sugarcane crop. This poses the question of whether growers in high risk areas should increase row spacing as a means of enhancing Si uptake and thus improving the resistance of sugarcane to infestation by the stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae).

Keywords: sugarcane, silicon, stalk population, soil analysis, leaf analysis, stalk borer

SILICON APPLICATION ALLEVIATED SALINITY STRESS IN WHEAT (*TRITICUM AESTIVUM* L.) GROWN IN HYDROPONICS AND FIELD CONDITIONS

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Soil salinity is a major abiotic stress particularly in arid and semi-arid conditions, affecting growth and yield of higher plants. Silicon (Si) is known to alleviate a number of abiotic stresses in higher plants, including salinity stress. Two independent experiments, one in hydroponics and a second under field conditions, were conducted to evaluate the role of Si in alleviating salinity stress in two contrasting wheat (*Triticum aestivum* L.) genotypes: Auquab-2000 (salt sensitive) and SARC-3 (salt tolerant). These genotypes were grown in hydroponics with two levels of salinity (0 and 60 mM NaCl) with and without 2 mM Si. In the second experiment, both genotypes were grown in normal soil (EC=2.2 d Sm^{-1}) and naturally saline soil (EC=11.50 d Sm^{-1}) with three levels of Si: 0, 75 and 150 mg g^{-1} Si. Salinity stress significantly decreased all growth parameters, increased sodium (Na^+) concentration, and decreased potassium (K^+) concentration in shoots of both genotypes grown in hydroponics. The addition of Si in nutrient solution improved growth of both genotypes. The increase in growth due to Si was higher (75%) under salt stress than under normal conditions (15%). Under field conditions, Si significantly improved growth of genotypes under salt stress. The yield reduction under salt stress was reduced from 45% to only 4% of the maximum potential when Si was applied. Both straw yield and grain yield were higher in Auqab-2000 when grown in normal soil. The opposite was found in the saline field, where SARC-3 performed better than Auqab-2000 with respect to straw and grain yield. The addition of Si significantly improved K^+ uptake and decreased Na^+ uptake in both wheat genotypes, and increased the K^+:Na^+ ratio. Si concentration was positively correlated ($r=0.9$, $p<0.01$) with K^+ concentration in the shoots. Enhanced salinity tolerance and improved growth in wheat by Si application was attributed to decreased Na^+ uptake and translocation to shoots, and increased K^+ uptake.

Keywords: wheat, silicon, salinity, K:Na selectivity

STUDY OF SILICON EFFECTS ON WHEAT CULTIVARS UNDER DROUGHT STRESS

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The effects of exogenous silicon (Si) were investigated on the contents of proline and glycine betaine and also the activity of the major antioxidant enzymes, including catalase (CAT), superoxide dismutase (SOD), ascorbate peroxidase (APX) and peroxidase (POD), on susceptible and drought tolerant wheat (*Triticum aestivum* L.) cultivars under drought stress. A factorial greenhouse experiment was performed in a randomized complete block design with three treatments (control, drought and silicon-drought) and three replications. Total protein and chlorophyll contents were investigated to analyse the plant growth stages. Results showed that, compared to the plants treated with drought alone, Si treatment caused an increase in the activity of CAT, SOD, APX and POD, and also the contents of photosynthetic pigments and soluble protein in drought-stressed leaves of both cultivars. There was no significant difference in CAT activity between the drought and control treatments for both cultivars. Moreover, of all the studied enzymes, POD showed the highest activity under silicon treatment. The effect of Si was observed to be higher in Verynack than Pishtaz. Also, application of Si increased the proline and glycine betaine contents compared to non-Si treatment. In this research project, the effect of Si was time-dependent and became stronger as the experiments continued. It could be concluded that higher activity of antioxidant enzymes and isoenzymes electrophoretic banding patterns are dependent on the silicon treatment. This biochemical component may be used as a marker in plant response to drought stress and may also protect the plant tissues from oxidative damage. The results of the present experiment suggest that Si may be involved in metabolic or physiological changes that increase drought tolerance in the wheat plant.

Keywords: wheat, silicon, drought stress, antioxidant enzyme, tolerance

USE OF SOLUBLE SILICON AND BIOCONTROL AGENTS FOR THE INTEGRATED CONTROL OF POWDERY MILDEW OF ZUCCHINI

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Five selected biocontrol agents, combined with potassium silicate applications, were tested against powdery mildew of zucchini caused by *Podospora xanthii* (Syn. *Sphaerotheca fuliginea*). Two experiments were conducted under glasshouse and field conditions. The BCAs were sprayed weekly onto leaves, together with wetter (Breakthru®). Soluble silicon (Si) (K_2SiO_3) was drenched onto the roots at a concentration of 100 ppm every week. In the glasshouse experiments, the effect of Si on disease severity and AUDPC values were significant ($P<0.05$). Si alone reduced severity and development of the disease by 23-32%, and improved the efficacy of most BCAs by 12-14%. Significant control was achieved by all BCAs with and without Si ($P<0.001$). Although statistically not significant, disease reductions of 32-70% by Si alone, 30-53% by Strain B15 alone, and 33-65% by Strain B15 + Si were obtained in the field. Other BCAs applied alone or together with Si also reduced the disease by 9-68% and provided significantly lower AUDPC values compared to the untreated control. For most antagonists, better efficacy was obtained when Si was drenched into the rhizosphere of the plant weekly. Results of both trials showed that Si has the potential to be used together with BCAs in the management of powdery mildew. However, repeated trials and better understanding of the interactions between Si and BCAs, and details on the optimum dosage and application frequency, as well as host plant specificity and effects of the environment are needed before this integrated control of powdery mildew can be implemented optimally.

Keywords: zucchini, silicon, powdery mildew, biocontrol agents, Breakthru®, *Podospora xanthii*

UPTAKE AND DISTRIBUTION OF SILICON ON ZUCCHINI AND ZINNIA AND ITS INTERACTION WITH OTHER ELEMENTS

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Elemental analysis was conducted to determine the impact of differing application levels of silicon (in nutrient solutions) on: (1) the uptake and distribution of Si on different organs (tissues) of zucchini and zinnia; (2) its impact on the uptake and accumulation of other elements; (3) effects of powdery mildew infection the levels of selected elements of these two plants; (4) on the growth of zucchini and zinnia plants. Plants were grown in re-circulating nutrient solutions by supplying Si at different concentrations. Samples were taken from different organs of each plant and analysed using Energy Dispersive X-ray Fluorescence (EDX) and Inductively Coupled Plasma-Optical Emission Spectrometers (ICP). Accumulation of Si in leaves and roots of both plants was directly related to the concentration of the element in the nutrient solution. However, Si content of other organs of both plants remained unaffected by Si level of the solution. In zucchini, 48% of the total Si absorbed by the plant was accumulated in the leaves, followed by 35% in roots, and 17% in fruit, stem and petioles. In the case of zinnia, 54% accumulated in leaves, 30% in roots and 16% in flowers, stem and petioles. In both plants, the highest concentrations of Si were observed around the leaf areas infected with powdery mildew, and in trichomes.

Total uptake and accumulation of K in different parts of both plants increased linearly with concentration of K2SiO3 in the nutrient solution. The total accumulation of P, Ca, and Mg in both plants was maximal when Si was supplied to the nutrient solution at lower rates (i.e. 50 mg ℓ^{-1}) and extra application had no or negative effect. As little as 50 mg ℓ^{-1} Si enhanced growth of zucchini plants but not zinnia. However, extra Si did not provide further growth enhancement. Si in the nutrient solution had no effect on elemental composition and characteristics of fruits of zucchini. However, when Si was applied at >50 mg ℓ^{-1}, then the P level of the fruit was reduced by 50%. For maximum accumulation of different elements in these two plants, application of Si at 50-150mg ℓ^{-1} is recommended.

Keywords: zucchini, zinnia, silicon, uptake, distribution, powdery mildew infection

EFFECTS OF SOIL TYPE, SOURCE OF SILICON, AND RATE OF SILICON SOURCE ON DEVELOPMENT OF GRAY LEAF SPOT OF PERENNIAL RYEGRASS TURF

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Gray leaf spot, caused by *Magnaporthe oryzae*, is a destructive disease of perennial ryegrass (*Lolium perenne* L.) turf in golf course fairways in the United States. Cultural management practices often do not provide adequate control of gray leaf spot due to rapid development of the disease, high susceptibility of currently available cultivars, and host susceptibility at all stages of development. Currently, gray leaf spot is chiefly managed by fungicide applications; however, turf managers often prefer employing integrated disease management strategies with major emphasis on cultural practices coupled with fungicides that are cost effective. Effects of cultural practice such as Si amendment on development of gray leaf spot in perennial ryegrass are unknown. Studies were conducted in controlled-environment chambers and microplots where perennial ryegrass pots were buried among perennial ryegrass turf to determine the effects of Si amendment on gray leaf spot development. Plants were grown in two soil types; peat:sand mix (soil Si=5.2 mg/L) and Hagerstown silt loam (soil Si=70 mg/L). Both soil types were amended with two sources of Si: wollastonite and calcium silicate at 0, 0.5, 1, 2, 5 and 10 metric ton/ha and 0, 0.6, 1.2, 2.4, 6 and 12 metric ton/ha, respectively. Nine-week old perennial ryegrass was inoculated with *M. oryzae*. Gray leaf spot incidence and severity were assessed two weeks after inoculation. Gray leaf spot incidence and severity in perennial ryegrass significantly decreased with different rates of wollastonite and calcium silicate slag applied to both soils under both experiment conditions. Tissue Si content increased consistently with increasing amounts of Si in the soils, while disease incidence decreased consistently with increasing tissue Si content in all four soil and source combinations under both experimental conditions. These findings suggest that amendment of soil with Si may be utilized as part of an integrated gray leaf spot management strategy for perennial ryegrass turf in golf course fairways.

Keywords: turfgrass, silicon, blast, disease management, gray leaf spot, *Lolium perenne*, *Magnaporthe oryzae*

THE EFFECT OF SILICON-AMENDED SOIL ON THE PHENOLIC CONTENT OF POTATO TUBERS INFECTED WITH *PECTOBACTERIUM CAROTOVORUM* SUBSP. *BRASILIENSIS*

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The aim of this study was to investigate the effect of silicon (Si) amended soil on the phenolic formation in cell walls of potato peels, and the effect thereof on tuber resistance to *Pectobacterium carotovorum* subsp. *brasiliensis* (Pbcb). Pot trials were conducted with the following treatments: control with and without pathogen; slag (30% Si) with and without pathogen; lime treatment ($CaCO_3$) as pH control with and without pathogen. At harvest potato tubers were peeled and the total phenolics were extracted. Phenolics were identified and quantified as chlorogenic, caffeic and ferulic acids using HPLC analysis. It was found that the plants treated with Si had significantly higher levels of total phenolic compounds than the control plants. Surprisingly, the concentration of caffeic acid was higher in tuber peels than chlorogenic acid, which is usually most common. Results also showed that the concentrations of total phenolics were significantly higher in uninoculated Si treated tubers than in inoculated Si treated tubers. However, the phenolic concentration measured at harvest may not reflect conditions present during the infection period. Results suggest that pH does not play any role in phenol production; however, calcium (Ca) content in the soil appears to affect the concentration of phenolics in the tubers. *In vivo* studies on progeny tubers produced in Si amended soil showed that the rate of development of blackleg was significantly lower in Calmasil (30% Si) treated tubers than Durapozz treated tubers. These results indicate that the best Si source to use is Calmasil, since Si and Ca combined have a synergistic effect in enhancing tuber resistance. This is, however, the first such study on the effect of Si on defence responses of potatoes to soft rot and blackleg. Additional studies will focus on how much Si is absorbed or accumulated in potato plants. Preliminary data showed positive results and new possibilities for the use of Si in commercial production to improve plant health status and disease resistance, and thus a reduction in the use of chemicals.

Keywords: potato, silicon, disease resistance, *Pectobacterium carotovorum* subsp. *brasiliensis*, phenolics

USE OF SILICON IN MANAGING POTATO DISEASES IN SOUTH AFRICA

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Although much research has been conducted on the ability of silicon (Si) to increase disease resistance in many crops, there is a dearth of such research in the potato crop. Potatoes are highly susceptible to pathogens, due to their high starch and sugar content. Conventional control methods for most of these diseases are chemical applications. However, due to environmental and health concerns, the move in agriculture is away from excessive use of chemicals. The aim of the projects in this programme is to investigate the effect of Si-containing soil amendments to increase basal resistance of potatoes to various pathogens, especially those that are soil-borne. All pathogens tested in this programme showed *in vitro* inhibition of growth at high concentrations of Si in artificial growth media. Three Si sources were tested in pot trials in order to determine the best source for pathogen inhibition and plant yield. The three sources tested were slag, fly ash and Si fume. In most cases slag showed the best results. However, the effect of slag on pH is a concern, as the incidence of common scab increases at higher pH levels. This is being investigated. Another project in this programme focuses on the effect of slag on potato yield and quality of tubers. Results will be communicated to the potato industry, and it is hoped will form part of an integrated pest management programme, in which the Si source applied raises the basal resistance of the plants to pathogens.

Keywords: potato, silicon, disease management, slag

THE EFFECT OF POTASSIUM SILICATE ON THE DEVELOPMENT OF *PHAKOPSORA PACHYRHIZI* ON SOYBEAN

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Phakopsora pachyrhizi, the causal organism of soybean rust (SBR), is a fungal pathogen causing significant soybean yield losses throughout the world. In South Africa, fungicides provide optimum control. However, with the recent emergence of silicon (Si) for the effective control of many other plant diseases, and results from initial pot trials using Si to control SBR, field trials in the 2007-2008 growing season were undertaken. To determine the effect of various concentrations of Si, in the form of potassium silicate, two applications of Si were applied at 100, 250, 500, 1000 and 2000 mg L^{-1} at 30 day intervals from the V3 growth stage. An untreated control and a treatment with Punch C (800 L ha^{-1}) were also included. Plots (3 x 3 m with four rows per plot) were arranged in a randomized complete block design with five replicates per treatment. Plants in the middle two rows were rated for percentage leaf area infected, area under disease progress curve (AUDPC) was calculated and yield was determined. Plants treated with Punch C had the lowest AUDPC (17.2), while the untreated control had the highest AUDPC (95.8). Plants treated with 2000 mg L^{-1} Si showed a significantly lower AUDPC (64.8) than all other Si treatments and the untreated control. AUDPCs from the remaining Si treatments were not significantly different from one another, but were significantly different from the untreated control. Yields of plants treated with Punch C and 2000 mg L^{-1} were not significantly different (834 and 697 g, respectively) from each other but were significantly different from the remaining Si treatments. These Si treatments were not significantly different to one another, or the control. In the 2008-2009 season, four applications of Si will be applied, to determine the effect of lower levels and greater frequencies of Si applications on disease control, compared to higher levels and fewer Si applications.

Keywords: soybean, silicon, *Glycine max*, *Phakopsora pachyrhizi*, potassium silicate, rust

INHIBITORY EFFECTS OF FOLIAR APPLIED SILICON ON POWDERY MILDEW IN GREENHOUSE CUCUMBER

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Cucumber (*Cucumis sativus* L.) is an important greenhouse crop in Norway as well as in worldwide production. Extensive seasonal and year-round cultivation is challenged due to fungal pathogens such as black spot, pythium, grey mould and powdery mildew, with the latter as the most significant disease. Based on the potential induction of plant defence mechanisms on foliar application of silicon (Si), two Si-based products, *Carbon Silpower*® and *Carbon Defence*®, were tested in commercial greenhouse production of cucumber, in order to study the effect on mildew infestation and fungal spread. The products were applied once and twice per week in two concentrations as a fine mist to leaf blades using an electric aerosol spray container. Both *Carbon Silpower* and *Carbon Defence* revealed a significant inhibitive effect on mildew compared to control plants (water only). In general, higher Si concentrations and application twice versus once per week improved the fungal inhibitive effect. The efficiency of Si-application, however, relied on sufficient mildew infection pressure to be evident. The *Carbon Silpower* tended to show a more protective effect than *Carbon Defence* against powdery mildew on cucumber. In addition, *Carbon Defence* at high concentration generated phytotoxic effects, although the mildew inhibiting effect of the product was still evident. The most effective treatment was a high concentration *Carbon Silpower* solution (6.6%) applied twice per week, inducing an 87% reduction in powdery mildew infection rate compared to the control. In addition, Si-treated cucumber plants showed a tendency of better growth, greenness and bigger leaves compared to plants receiving conventional chemical spraying.

Keywords: cucumber, silicon, powdery mildew, foliar application

SILICON TRANSPORTERS IN RICE

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Rice is able to accumulate silicon (Si) up to 10% of shoot dry weight. A large amount of Si is required for high and sustainable rice production. Recently, two transporters (*Lsi1* and *Lsi2*) responsible for the high capacity of rice for Si uptake have been identified. Silicon transported via *Lsi1* and *Lsi2* into the root stele is then translocated to the shoot by transpirational flow through the xylem. A novel Si transporter, *Lsi6*, a close homolog of *Lsi1*, was characterized. *Lsi6* is 77% identical to *Lsi1* at amino acid level. Expression of *Lsi6* in *Xenopus* oocyte showed transport activity for Si similar to *Lsi1*. Unlike *Lsi1* and *Lsi2*, *Lsi6* was expressed in the leaf sheath and leaf blades as well as in the root. In the roots, more expression of *Lsi6* was found in the root tip than in the mature zones. The *Lsi6* expression of the roots and leaf blades was decreased by Si, but that of leaf sheaths was unaffected. Immunohistological staining showed that *Lsi6* protein was localized at the xylem parenchyma in the leaf sheath and leaf blade. Moreover, *Lsi6* showed polar localization at the side facing toward the vessel. The role of the *Lsi6* in the rice Si transport was examined using knockdown mutants of *Lsi6*; T-DNA, Tos17 insertion or RNAi. The knockdown of *Lsi6* did not affect the uptake of Si by the roots. In the leaf blade and leaf sheath, suppression of *Lsi6* resulted in disordered deposition of silica and increased excretion of Si in the guttation fluid. Safranin staining and SEM-EDX analysis of the mutant leaves indicated that the density of silicified dumbbell-shape and motor cells was decreased compared with the wild-type rice. Furthermore, abaxial epidermis cells were observed to be silicified in the mutant, but infrequently in the wild-type rice. These results indicate that *Lsi6* is a transporter responsible for the transport of silicon out of the xylem and subsequently affects the distribution of Si in the leaf.

Keywords: rice, silicon, transporter

SILICON STATUS AND ITS RELATIONSHIP WITH MAJOR PHYSICO-CHEMICAL PROPERTIES OF SOILS IN THE NORTHERN HIGHLANDS OF ETHIOPIA

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Silicon (Si) is an essential nutrient for higher silicophile plant species and animals. One of the most important functions of Si is the stimulation of the plant's defense abilities against abiotic and biotic stresses. In addition, Si fertilization has a more positive effect than liming on the chemical and physical properties of the soil. To date the Si status in the soils of Ethiopia is unknown. Hence this study was conducted with the objective of understanding Si distribution in the Vertisols of the northern highlands of the country. Thirty-eight soil samples were collected from four agri-ecological zones of Tigray in order to determine Si distribution. In the Maychew area SiO_2 ranges from 515.3 to 546.2 g SiO_2 kg^{-1}, in Adigudom from 336.9 to 396.0 g SiO_2 kg^{-1}, in Wukro from 621.5 to 752.9 g SiO_2 kg^{-1}, in Axum from 442.3 to 521.5 g SiO_2 kg^{-1} and in Shire from 575.3 to 606.1 g SiO_2 kg^{-1}. The highest concentration was found in Wukro, where the sand content is 50%, and the lowest level was obtained from soils of Adigudom, where the clay content is more than 60%. Besides, the Pearson's correlation test was used to find a correlation between Si content and selected soil properties. Results showed that organic carbon 0.84* (p=0.05), silt -0.84* (p=0.05) and clay 0.84* (p=0.05) were correlated significantly. Although SiO_2 in Vertisols in the studied areas appear to be abundant, further study is recommended on the responses of silicophile plant species to Si fertilization for enhancing crop productivity.

Keywords: silicon, essential nutrient, silica, silicophile plant species and animals, Si fertilization

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