# Silicon
## IN AGRICULTURE

# Program Agenda and Abstracts

**September 26-30, 1999 • Lago Mar Resort**
**Fort Lauderdale, Florida USA**

**Silicon IN AGRICULTURE**

**Lago Mar Resort and Club**
**Fort Lauderdale, Florida**
**September 26-30, 1999**

## *Welcome to the Silicon in Agriculture Conference!*

We are pleased that you have joined us for the first international conference on silicon in agriculture. We are gathered together with colleagues from around the world to discuss the role and function of this important element in agriculture.

We have designed a program that covers many aspects of this element, keeping our overall objective for good science and a good time on a parallel course.

An important aspect of the conference will be getting to know our colleagues in silicon science on a personal basis. We hope that this interaction will lead to the identification of the most important topics for future research, and the formulation of techniques, conventions, and strategies for conducting these studies in collaborative efforts with new-found colleagues cutting across disciplines and international borders.

The organizing committee is very appreciative of the financial support we have received to help defray conference expenses. Our sponsors are recognized in this book, and we ask that you join us in thanking them for their contribution. Without their support, programs like this would not be possible.

The IFAS Office of Conferences and Institutes (OCI) also deserves a special note of appreciation for handling the many details that have gone into organizing this conference. The Silicon in Agriculture Conference Coordinator, Ms. Nikki Rogers, and the conference planning team will be available to assist you throughout the conference.

We look forward to making your stay at the Lago Mar Resort and Club a memorable one; we hope you will find the conference both enjoyable and thought provoking.

Sincerely,

*Lawrence E. Datnoff*
*Gaspar H. Korndorfer*
*George H. Snyder*

Silicon in Agriculture Organizing Committee

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# *Sponsor Appreciation*

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# *Agenda and Topics*

## Sunday, September 26, 1999

| | |
|---|---|
| 4:00pm-6:00pm | **Registration** |
| 6:00 pm-8:00pm | **Welcome Reception** |

## Monday, September 27, 1999

| | |
|---|---|
| 7:30am | **Continental Breakfast** (Fountainview Lobby) |
| 8:00am | **General Session** (Lakeview) |
| 8:00am | *Dr. Lawrence Datnoff* (USA) – **Welcome** |
| 8:10am | *Dr. Emanuel Epstein* (USA) – **Silicon in Plants: Facts vs. Concepts** (p. 3) |
| 9:10am | *Dr. Jian Feng Ma* (Japan) – **Silicon as a Beneficial Element for Crop Plants** (p. 3) |
| 10:10am | **Refreshment Break** (Fountainview Lobby) |
| 10:30am | *Dr. John Raven* (UK) – **Silicon Transport at the Cell and Tissue Level** (p. 4) |
| 11:30am | **Lunch** (on your own) |
| 12:00pm-5:30pm | **Poster Presenters Set-up displays** (Oceanview North and Oceanview South) |
| 1:30pm | *Dr. Allan Sangster* (Canada) – **Silicon Deposition in Higher Plants** (p. 4) |
| 2:30pm | *Dr. Wim Voogt* (Netherlands) – **Silicon in the Nutrient Solution for Soilless Grown Horticultural Crops** (p. 5) |
| 3:30pm | **Refreshment Break** (Fountainview Lobby) |
| 4:00pm | *Dr. Gaspar Korndorfer* (Brazil) – **Effect of Silicon on Yield** (p. 5) |
| 4:30pm | *Dr. Christopher Deren* (USA) – **Plant Genotype, Silicon Concentration, and Silicon Related Responses** (p. 6) |
| 5:00pm | **Evening Free** (dinner on your own) |

## Tuesday, September 28, 1999

| | |
|---|---|
| 7:30am | **Continental Breakfast** (Fountainview Lobby) |
| 8:00am | **General Session** (Lakeview) |
| 8:00am-12:00pm | **Poster Presenters Set-up displays** (Oceanview North and Oceanview South) |
| 8:00am | *Dr. Richard Belanger* (Canada) – **The Mode of Action of Silicon as a Disease Preventing Agent in Cucumber** (p. 6) |
| 9:00am | *Dr. Lawrence Datnoff* (USA) – **Use of Silicon to Reduce Fungicides and Enhance Host Plant Resistance** (p. 7) |

| | |
|---|---|
| 9:30am | *Dr. George Snyder* (USA) – **Methods for Silicon Analysis in the Plant, Soil and Fertilizers** (p. 7) |
| 10:00am | **Refreshment Break** (Fountainview Lobby) |
| 10:30am | *Dr. Gary Gascho* (USA) – **Silicon Sources for Agriculture** (p. 8) |
| 11:00am | *Dr. Vladimir Matichenkov* (Russia) – **The Relationship of Silicon to Soil Physical and Chemical Properties** (p. 8) |
| 11:30am | **Lunch** (on your own) |
| 1:30pm | *Dr. Jose Alvarez* (USA) – **Economics of Silicon** (p. 9) |
| 2:00pm | *Dr. Suzanne Berthelsen* (Australia) – **Silicon Research Down Under: Past, Present and Future** (p. 9) |
| 2:30pm | *Dr. Jan Meyer* (South Africa) – **Past, Present and Future Silicon Research in the South African Sugar Industry** (p. 10) |
| 3:00pm | *Dr. Kiyoshi Ishiguro* (Japan) – **Review of Research in Japan on the Roles of Silicon in Conferring Resistance against Blast Disease in Rice** (p. 11) |
| 3:30pm | **Refreshment Break** (Fountainview Lobby) |
| 4:00pm | *Dr. Anne S. Prahbu* (Brazil) – **Silicon from Rice Disease Control Perspective in Brazil** (p. 11) |
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## Wednesday, September 29, 1999

| | |
|---|---|
| 7:30am | **Continental Breakfast** (Fountainview Lobby) |
| 8:00am | **General Session** (Lakeview) |
| 8:00am-5:00pm | **Buses depart for Big Cypress Reservation** *(lunch provided)* |
| 6:30pm | **Beach Party Cookout** (Outside Ocean Grill) |

## Thursday, September 30, 1999

| | |
|---|---|
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| 8:30am | *Dr. James Menzies* (Canada) – **Plant Related Silicon Research in Canada** (p. 12) |
| 9:00am | *Dr. Hailong Wang* (New Zealand) - **Agricultural Utilization of Silicon in China** (p. 13) |
| 9:30am | *Dr. Chon-Suh Park* (Korea) – **Silicon's Influence on Plants** (p. 13) |
| 10:00am | **Refreshment Break** |
| 10:30am | **Formulation of an International Collaborative Agenda for Silicon in Agriculture** |
| 12:00pm | **Conference Concludes** |

# Oral Abstracts

- Presenting authors appear in **bold**.
- Abstracts are listed by order of presentation.

## Silicon in Plants: Facts vs. Concepts

***Emanuel Epstein***

University of California, Davis, CA, USA

The facts of Si in plant life are one thing; the concepts regarding Si in plant physiology are another thing altogether. Most terrestrial plants grow in media dominated by silicates, and the soil solution bathing roots contains Si at concentrations exceeding those of P by roughly a factor of 100. Plants absorb the element and their Si content is of the same order of magnitude as that of the macronutrient elements. The general plant physiological literature, however, is nearly devoid of Si. The reason for this marked discrepancy is the conclusion that Si is not an "essential" element because most plants can grow in nutrient solutions lacking Si in their formulation. Such Si-deprived plants are, however, experimental artifacts. They may differ from Si-replete plants in (i) chemical composition; (ii) structural features; (iii) mechanical strength; (iv) various aspects of growth including yield; (v) enzyme activities; (vi) surface characteristics; (vii) disease resistance; (viii) pest resistance; (ix) metal toxicity resistance; (x) salt tolerance; (xi) water relations; (xii) cold hardiness; and probably additional features. The gap between plant physiological facts and plant physiological concepts must be closed. The facts of Si in plant life will not change; hence it is the concepts regarding the element that need revising.

## Silicon as a Beneficial Element for Crop Plants

***Jian Feng Ma***[1], *Yasuto Miyake*[2] and *Eiichi Takahashi*[3]

[1]Faculty of Agriculture, University of Kagawa, Kagawa, Japan
[2]Okayama University, Okayama, Japan
[3]Kyoto University, Kyoto, Japan

Silicon (Si) has not been proven as an essential element for higher plants, but its beneficial effects on growth are reported in wide variety of crops, including rice, wheat, barley, cucumber, tomato. Si fertilizers are applied to crops in several countries for increased productivity and sustainable production. Plants take up Si in the form of silicic acid. After silicic acid is transported to the shoot, it is concentrated through loss of water and is polymerized as silica gel on the surface of leaves and stems. Evidence is lacking concerning the physiological role of Si in plant metabolism, and the beneficial effects of this element are only observed in plants that accumulate Si. Thus, the silica gel deposited on the plant surface is thought to contribute to the beneficial effects of Si. Beneficial effects of Si are small under conditions of optimal growth, but become obvious when plants are stressed. In this review, the effects of Si under mineral stresses (Al toxicity, P deficiency and excess, Na, Mn and N excess), climatic stresses (low temperature, typhoon, low light), and biotic stresses (diseases) will be discussed.

## Silicon Transport at the Cell and Tissue Level

*John A. Raven*

University of Dundee, Dundee, UK

The predominant Si compound in the soil solution is silicic acid, and the baseline condition for Si transport into and within a plant with no membrane channels or transporters which can move Si compounds is the movement of silicic acid across membranes by dissolving in the lipid phase of the membrane ('lipid solution' transport). Based on the best current estimates of 'lipid solution' permeability of membranes to silicic acid (~ $10^{-10}$ m $s^{-1}$), even the lowest Si contents in plants cannot be explained in terms of the soil solution silicic acid concentration and the lipid solution mechanism, and a component of silicic acid entry coupled to transpiratory water uptake is required. For *Oryza* and, under some conditions, *Hordeum* and *Phaseolus*, active influx of silicic acid is needed to account for the observed silica content. Further work is needed as to the mechanism of active transport of silicic acid following the lead of the characterization of $Na^+$-coupled transport in a diatom, and on how silicic acid is coupled to water transport (involving aquaporins?), and on the phloem mobility of silicic acid.

## Silicon Deposition in Higher Plants

***Allan G. Sangster***[1], *Martin J. Hodson*[2] and *Helen J. Tubb*[2]

[1]York University, Toronto, ON, Canada
[2]Oxford Brookes University, Oxford, England

Silica deposits, commonly called phytoliths, occur in cell walls, cell lumens or in intercellular spaces and external layers. These deposits frequently possess a characteristic morphology, which reveals their tissue and taxonomic origin. Silicification occurs in roots and the shoot including leaves, culms and, in grasses, most heavily in the inflorescence. Deposits occur in epidermal, strengthening, storage and vascular tissues.

Silicification is reported in the Pteridophyta and the Spermatophyta, including gymnosperms and angiosperms. Dicotyledon families containing Si accumulators of considerable agricultural significance include the Fabaceae, Cucurbitaceae and Asteraceae. Among the monocotyledons, the Cyperaceae and Poaceae (Gramineae) are pre-eminent.

Biogenic silica structure is affected by ambient physico-chemical conditions mediated by tissue maturation, pH, ionic concentrations and cell wall structure. This will be illustrated by reference to work we have conducted on the development of silicification in wheat seedlings.

Silicified tissues may have several functions including support and protection against pathogens and predators. Phytoliths may also sequester toxic metals, and we will give examples principally from our recent work on the codeposition of aluminum and silicon in cereals and conifers. Some phytoliths have been implicated as carcinogens. Phytoliths are being increasingly used in archaeology as they often retain their morphology in sediments long after the plant has died and the organic matter has broken down.

## Silicon in the Nutrient Solution for Soilless Grown Horticultural Crops

*W. Voogt* and *C. Sonneveld*

Research Station for Floriculture and Glasshouse Vegetables, Naaldwijk, The Netherlands.

With the change over to soilless growing media in the glasshouse industry in the Netherlands, a lack of knowledge about the role of Si in crops became manifest. It was found that in these systems the Si uptake was dramatically reduced in comparison with soil grown crops. Investigations were carried out on the effects of Si application in soilless culture. With cucumber, melon, courgette, strawberry, bean, rose and Aster ericoïdes, the Si contents were increased as result of the Si supply in the root environment, whilst with tomato, sweet pepper, lettuce, gerbera, and carnation the uptake was almost negligible. Results showed that cucumber, rose and strawberry could benefit from enhanced Si concentration in the root environment, since total yield was increased and powdery mildew was suppressed. Despite the minor uptake of Si in lettuce and bean, it was found to affect the Mn distribution in the plant.

Initially severe problems with blocking of the irrigation system occurred, because of instability of Si sources. These were solved by the introduction of potassium metasilicate. The use of polysilicates was found to be less effective.

## Effect of Silicon on Yield

***Gaspar H. Korndörfer***

Federal University of Uberlandia, Uberlandia, MG, Brazil

Integrated management of 13 physiologically essential nutrients, namely six macronutrients: nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium and seven micronutrients iron, manganese, zinc, boron, copper, molybdenum, and chloride are generally considered by agronomists for increasing and sustaining crop yields. However, there are non-essential elements that under certain agroclimatic conditions enhance crop yield by promoting several physiological processes.

The past and current literature on the effect of silicon (Si) fertilization on crop yield and its potential benefits in increasing and sustaining crop production will be discussed. Rice and sugarcane grown in rotation on organic and sandy soils in south Florida have shown positive agronomic responses to pre-plant applications of calcium silicate slag.

The recognition of proper Si management to increase and/or sustain crop productivity appears to be greater in temperate countries than in tropical countries. However, due to desilication in which soils (minerals) lose Si as a result of leaching, subtropical and tropical soils are generally low in plant-available Si and may benefit from Si fertilization. Silicon content in some regions might be limiting to sustainable crop production. In addition, Si depletion can occur as a result of intensive cultivation practices and continuous monoculture of high-yielding cultivars.

## Plant Genotype, Silicon Concentration, and Silicon-Related Responses

***C. W. Deren***

University of Florida-IFAS, Everglades Research and Education Center, Belle Glade, USA

Silicon concentration in plants influences many responses including insect, nematode, and disease resistance, nutrient status, transpiration and possibly some aspects of photosynthetic efficiency. In many crops, cultivars (genotypes) vary for these same traits. The association of genotypic variation for Si concentration with several plant responses has been the subject of studies that investigated the possibility of breeding or selecting cultivars for Si-limiting environments. This paper briefly reviews research on genotypic variability of sugarcane and rice for silicon concentration, and describes research in Florida on silicon-related responses of cultivars such as disease response, photosynthesis and N and P concentration.

## The Mode of Action of Silicon as a Disease Preventing Agent in Cucumber

***Richard R. Bélanger***[1], *Anne Fawe*[1] and *James G. Menzies*[2]

[1] Centre de Recherche en Horticulture, Université Laval, Québec, Québec, Canada
[2]Agriculture and Agri-Food Canada, Winnipeg, Manitoba, Canada

Silicon has been exploited for its prophylactic properties against plant diseases for hundreds of years. Its role as a disease-preventing product has been well documented but the mechanisms by which it exerts its beneficial properties *in planta* remains poorly understood. For a long time, the observation of a systematic accumulation of silica in cell walls and appositions occurring at pathogen penetration sites led to the conclusion that this parietal strengthening was responsible for the increased resistance of plants to diseases. However, recent evidence suggests that silicon would also play an active role in reinforcing plant disease resistance by stimulating the expression of its natural defense reactions. Incidentally,

in the cucumber-powdery mildew system, this latter mechanism appears to be predominant, if not exclusive. A better understanding of this rather unique property of silicon could be exploited to optimize its use in agriculture and to help decipher how plants can be naturally stimulated to protect themselves against pathogens.

## Use of Silicon to Reduce Fungicides and Enhance Host Plant Resistance

***Lawrence E. Datnoff***[1], *Kenneth W. Seebold*[2] and *Fernando J. Correa-V*[3]

[1]University of Florida-IFAS, Everglades Research & Education Center, Belle Glade, FL, USA
[2]UniRoyal Chemical Company, Bethany, CT
[3]CIAT, Colombia

Silicon can control several important diseases of rice, including blast (*Magnaportha grisea*), brown spot (*Cochliobolus miyabeanus*), sheath blight (*Thanatephorus cucumeris*), leaf scald (*Monographella albescens*) and grain discoloration (species of *Fusarium*, *Bipolaris*, and others). Control of several of these diseases such as blast and brown spot equals that achieved by fungicides. Hence, the number of fungicide applications and rates could be reduced significantly. Residual activity of silicon was effective for disease control in the second year crop and was comparable to a first year silicon application or a full rate of a fungicide. Research revealed that silicon could enhance control of partially-resistant cultivars to the same general level as completely-resistant cultivars to both blast and sheath blight. These findings suggest that silicon could be employed in a IPM program for reducing fungicide use and enhancing host plant resistance in controlling important rice diseases worldwide.

## Methods for Silicon Analysis of Plant Tissue, Soil, and Fertilizer

***George H. Snyder***

University of Florida Everglades Research and Education Center, Belle Glade, FL, USA

The classical method for determining total Si content of various materials has been conversion of insoluble silicates into sodium silicate through high temperature fusion with sodium hydroxide, or other sodic bases. The Si then can be determined by a variety of methods, including gravimetric, colorimetric, and absorption/emission spectrometry. Silicon also has been determined gravimetrically in plant tissue as the residue after acid digestion. We have developed a simple, inexpensive, and rapid method for solubilizing Si in plant tissue that facilitates analysis of a large number of samples. When analyzing soils and fertilizers, a method for gauging the plant available Si, rather than total Si, generally is desired. A number of soil-test methods have been developed. Some require extended incubation periods, field-moist soil, or other procedures that inhibit adoption by routine soil-testing laboratories. Silicon extracted by acetic acid has been correlated to Si uptake by rice and rice grain yield. Using this method, the Everglades Soil Testing Laboratory analyses nearly five thousand samples annually. Since Si fertilizer sources differ in Si content and Si solubility, analytical methods have been developed for predicting their relative ability to provide plant-available Si. We use a column leaching method based on Si elution in Tris buffer (pH 7) for the evaluation of potential silicon soil amendments. However, greenhouse and field evaluations are essential for making final determinations.

## Silicon Sources for Agriculture

*Gary J. Gascho*

University of Georgia, Tifton, GA, USA

Characteristics of an acceptable Si source are: a high content of soluble-Si, physical properties conducive to mechanized application, ready availability, and low cost. Since Si is the second most abundant element in the earth's crust, finding sources of Si is easy. But, Si is always combined with other elements and most sources are insoluble. Responses of crops to soluble-Si applications in sands (largely $SiO_2$) provide an example of the insolubility of one source. A few sources are soluble, but too costly for general use. Potassium silicate is used as a foliar spray for disease control in some high value crops and sodium silicate has been used to supply Si in research. Calcium silicates have emerged as the most important sources for soil applications. Of those, calcium meta-silicate (wollasonite, $CaSiO_3$) has been the most effective source in many locations with low concentrations of soluble-Si in soils. Such a material, supplied as a slag byproduct from the high temperature electric furnace production of elemental P, is applied extensively to Everglades mucks and associated sands planted to sugarcane and rice. Thermo-phosphate, a commercial fertilizer used in Brazil to supply P, Ca, and Mg, also supplies soluble-Si due to high temperature manufacturing process effects on its magnesium silicate ingredient.

## The Relationship of Silicon to Soil Physical and Chemical Properties

***Vladimir V. Matichenkov*** and *Elena A. Bocharnikova*

Institute Basic Biological Problems, Russian Academy of Sciences, Pushchino, Russia

Soil minerals control physical and chemical soil properties. Silicon is a basic mineral formatting element. The aim of our investigation was to obtain information about the effect of silicon fertilization on physical and chemical soil properties. Silicon fertilization has been reported to result in increased soil exchange capacity, improved water and air regimes, transformation of P-containing minerals, formation of alumosilicates and heavy metal silicates. All these effects are caused by the change in soil mineral composition as a result of silicates addition (silicon fertilizers) and/or formation of new clay minerals. Both types of minerals are characterized by high biogeochemical activity. They have large surface area and are able to adsorb water, phosphates, K, N, Al, and heavy metals. Absorption may occur as chemosorption or physical sorption. Cations (Al, heavy metals) usually are chemosorded on silicon-rich surface and lose their mobility. Phosphates and N are weakly adsorbed and remain in plant-available form. Amorphous silica, montmorillonite, and vermiculite represent the newly-formed minerals. These minerals effect the soil solution composition, and physical and chemical properties. The amounts of amorphous silica, monosilicic acids and polysilicic acids in the soil are closely related to each other. Monosilicic acids regulate chemical properties of soil solution. Polysilicic acids have an effect on soil physical properties. Numerous microorganisms present in the soil influence the clay formation process.

## Economics of Silicon

*Jose Alvarez* and *Lawrence Datnoff*

University of Florida, Belle Glade, FL, USA

Despite the prolific research conducted in crop production and other aspects of silicon application, little is known about the potential economic benefits of its use in agriculture. Although some physical benefits obtained are impressive, the relative high cost of the material could make silicon application unprofitable in some areas of the world.

The purpose of this presentation is to show an economic analysis of two crops and one rotation: rice, sugarcane, and rice-sugarcane rotation. The first case demonstrates the potential economic benefits taking into account the research conducted and the areas where rice is grown or could be grown. The second case does the same for sugarcane. The last case pertains to a specific rice-sugarcane rotation in the Everglades Agricultural Area of south Florida. The three cases seem to indicate that silicon has a tremendous potential for increasing farm revenue. This advantage is especially useful in times of decreasing farm product prices.

## Silicon Research Down Under: Past, Present and Future

*Suzanne Berthelsen* and *Andrew Noble*

CSIRO Land and Water, Townsville, Australia

Ninety five percent of Australia's sugarcane is grown on the narrow coastal plain that stretches along northeastern coast of Queensland. The most northern area, from Tully to Mossman, has a unique combination of landforms and climate that gives rise to a range of soils that are not always comparable to those in the southern sugarcane growing regions. In general, these soils have been under sugarcane production for up to 130 years, and apart from low levels of soluble soil silicon (Si) resulting from natural weathering and leaching processes, there is evidence of declining Si levels following long-term sugarcane production.

Early research into silicate materials in the 1970's was confounded by the influence of the associated cations (e.g. Ca) accompanying the Si source, and the inability to predict responsive soils. Recent field applications of silicate materials have resulted in substantial yield increases on certain soil types. Consequently, current research has concentrated on delineating the areas and soil types with sub-optimal soil Si levels. Future work involves extending soil surveys to develop Si risk assessment maps for the wet tropics of north Queensland, and with the establishment of field trials to assess the efficacy of selected Si based amendments and develop optimal rates and response functions.

## Past, Present and Future Silicon Research in the South African Sugar Industry

*Jan H. Meyer* and *M. Keeping*

SASA Experiment Station, Mount Edgecombe, South Africa

The relative efficiencies of calcium metasilicate slag and calcium carbonate are summarized from the results of a number of glasshouse and field experiments conducted in the South African Sugar Industry since 1970. In four out of the five field trials, significant yield responses ranging from 9 to 24 tons cane/ha were obtained from both the calcium silicate slag and lime treatments. On average, the silicon based treatments were 5% better than the lime treatments. In one trial where the ameliorants were incorporated to a depth of 65cm, calcium silicate increased yield significantly ($P>0.01$), whilst the response to lime did not attain a level of statistical significance. All ameliorants caused a reduction in exchangeable Al in the soil and a reduction in manganese uptake. With treatments containing silicon the increased yields were associated with an increase in the silicon concentration in the plant.

Current research is focused on the association between silicon assimilation and host-plant resistance to the stalk borer *Eldana saccharina* Walker (Hymenoptera:Vespidae). Recent evidence from a large scale pot trial in which sugarcane was treated with calcium silicate and artificially infested with *E. saccharina* at 9.5 months, showed a significant reduction of 33.7% in borer damage and 19.8% in borer mass. Scanning of leaf samples by Near Infra Red Spectrometry suggests that up to 60% of the variation in *Eldana* resistance can be accounted for by the leaf silicon content.

# Review of Research in Japan on the Roles of Silicon in Conferring Resistance against Blast Disease in Rice

*Kiyoshi Ishiguro*

Tohoku National Agricultural Experiment Station, Morioka, Japan

In 1917, I. Onodera showed that rice plants affected by blast disease tended to contain less silicon than those that remained healthy. This was probably the first report that suggested an effect of silicon on blast resistance. Since then, many researchers have demonstrated that applying silicon to the soil causes higher silicon levels in rice and, as a consequence, an increase in blast resistance. Several hypotheses were proposed up to the 1950's to explain this phenomenon. Most importantly, the fact that silicon is mainly localized in the leaf surface supports the hypothesis that the silicon layer may act as a physical barrier against penetration by the blast fungus. However, this cause-effect relationship has not yet been fully accepted. Application of silicon to commercial rice paddy fields became popular, after the effectiveness of readily available silicate slag on blast disease was demonstrated in 1952. The use of silicate slag reached a peak in the early 1970's. However, the amount of research has declined since the 1960's. This is probably because the interests of most blast researchers have changed to investigating more clear-cut blast disease countermeasures such as the use of fungicides and highly resistant genetic resources.

# Silicon from Rice Disease Control Perspective in Brazil

***Anne S. Prabhu***[1], *Morel P. Barbosa Filho*[1], *Marta C. Filippi*[1], *Lawrence E. Datnoff*[2] and *George H. Snyder*[2]

[1]Embrapa Arroz e Feijão, Santo Antônio de Goiás, GO, Brazil
[2]University of Florida, IFAS/EREC, Belle Glade, FL, USA

Rice blast and grain discoloration are mainly responsible for significant losses in grain yield and quality both in upland and irrigated ecosystems in Brazil. Rice planting in rotation with soybean in extensive, contiguous areas and high input technology provided a conducive environment to diseases which were hitherto unimportant such as sheath blight in irrigated rice and take-all in upland rice. Even though varietal resistance constitutes a major component in rice disease management, it should be integrated with long-term benefits of silicon fertilization. A field study conducted with genotypes showing wide variability for grain discoloration and different rates of $SiO_2$ showed promising results. Initial greenhouse inoculation tests are encouraging in controlling leaf blast at the vegetative phase with silicon. The logical extension of firmly established existing concepts on silicon and rice disease management should rely on multidisciplinary approach and inter-institutional collaboration. Extensive on farm trials at hot spot locations for diseases will compliment the experimental results and increase the speed and efficacy in accomplishing the desired goals.

## Effects of Silicon Fertilization on Disease Development and Yields of Rice in Colombia

***Fernando J. Correa-Victoria***[1], *Lawrence E. Datnoff*[2], *Kensuke Okada*[1], *Denis K. Friesen*[1], *Jose I. Sanz*[1] and *George H. Snyder*[2]

[1]Centro Internacional de Agricultura Tropical, CIAT, Cali, Colombia
[2]University of Florida, Belle Glade, FL, USA

The savannas of Colombia contain soils (Oxisols) constrained by silicon (Si) deficiency. Since upland rice production is expanding into this region, field experiments were conducted over two years on three representative soils to determine the extent to which Si deficiency may constraint rice yields and favor disease development. The experiments were complete factorials and included different levels of Si, P and varieties. Sources of Si tested included both calcium metasilicate and calcium silicate slag. Lime was applied to equalize lime value and Ca levels across treatments.

Silicon significantly reduced all observed rice diseases. Leaf blast severity and neck blast incidence were reduced from about 26% and 53% in non-amended plots to 15% in Si-amended plots. Leaf scald severity was reduced from 42% to 6% in Si-amended plots, while grain discoloration was reduced from 4.2 to 1.0 in Si-amended plots. Si application increased rice yields by about 40% on all three soils. A residual effect was also noted for reducing disease development and increasing yields. By amending these soils with Si, a very effective and potentially sustainable method for upland rice production and management of rice diseases appears available.

## Plant-Related Silicon Research in Canada

***James G. Menzies***[1], *Richard R. Bèlanger*[2] and *D. L. Ehret*[3]

[1]Agriculture and Agri-Food Canada, Winnipeg, Manitoba, Canada
[2]Universitè Laval, Quèbec, Canada
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Silicon is a common but generally minor element found in the majority of living organisms as amorphous silica ($SiO_2.nH_2O$) and soluble silicic acid ($Si(OH)_4$). Its physiological essentiality is recognized in several protists and vertebrates, but in higher plants, its biological role is not well understood. In Canada, research into the significance of silicon to higher plants has focused on the importance of silicon in plant growth and development, and how this element can be utilized in agriculture. Three main areas of research conducted in Canada will be discussed; 1) the deposition of Si in organs and cells of higher plants, 2) the ability of silicon to help control plant diseases and 3) the use of silicon as an inert dust to control insects in post-harvest products.

## Agricultural Utilization of Silicon in China

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The first research on potential uses of Si-containing industrial by-products as fertilizer and soil amendments in China was carried out in late 1950s. Si fertilizer production and utilization has increased steadily since 1970s, and most Si fertilizers have primarily been used to improve rice production by enhancing resistance of rice plants to diseases and lodging. Field trial results conducted in recent years demonstrated that not only rice but many other crops had positive responses to Si. The increased yield by Si fertilization has mainly been attributed to enhanced crop resistance to diseases, lodging, drought and other environmental stresses such as salt and heavy metal toxicity, and optimized crop nutrient balance. It has also been found that applying Si together with other nutrients such as Zn and Mn as well as N, P, and K, can significantly increase the beneficial effect of Si.

This paper provides an overview of the soil Si fertility and history of Si fertilization research and practices in China, highlights the research effort to understand the interactions between Si and other nutrients, and to improve the efficiency of Si fertilization. This is followed by recommendations for future research on Si in China.

## Silicon's Influence on Plants

***Chon-Suh Park***

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The first field trial of sodium silicate for rice grown in marine deposit soils in mid 1950's showed no effects. However, furnace slags provided some effects for most of the paddy soils. Ground wollastonite has been found to be more effective, improving growth of rice under the balanced supply of N, P and K in more than 90% of Korean paddy soils containing less than 130 mg $kg^{-1}$ of available $SiO_2$ in top soils since 1960.

Intensive studies on the paddy soil fertility Basement models based on the soil test results, including available silica, have been started for the sustainable production of rice since 1970s. They may also be used for various upland crops of grass species such as maize, wheat and barley.

In the future, the use of those models may also be tested for the protection from environmental hazards due to the emission of green house gases such as nitrous oxide or methane either from the soil or through the plants.

# Poster Abstracts

- Presenting authors appear in **bold**.
- Abstracts are listed alphabetically by country and last name of presenting author.
- Poster numbers are indicated in parenthesis at the end of abstract titles.
- Posters will be organized by poster number at the Tuesday evening poster session.

# AUSTRALIA



***Graham Kingston***

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Sugar mills produce nutrient rich waste products (filter mud and furnace ash). In Australia, these materials are returned to cane fields in nutrient management or soil amelioration plans. Generally, yield responses are attributed to N, P, K and Ca constituents of the wastes. However, yield responses have also been reported where the above nutrients have been adequately supplied from fertilizer sources. Thus sugar mill wastes have earned a reputation for *"mysterious capacity"* to ameliorate soils with low natural fertility. How might we explain such responses?

This field experiment, on a gleyed podzolic soil (redoxic hydrosol) involved comparison of sugar mill ash alone and a sugar mill filter mud /ash mixture with supply of nutrients equivalent to the latter, from fertilizers. Data were acquired over two years, for first and second ratoon crops. The following conclusions were obtained: There was a good cane yield response to both sugar mill wastes in first and second ratoon crops; phosphorus, potassium, calcium and trace elements in the wastes did not improve yield; yield benefits of the sugar mill wastes were attributed to reduced bulk density and better nitrogen and silicon nutrition; sugar mill wastes resulted in higher levels of soil and leaf silicon than other treatments; and filter mud/ash increased soil nitrogen supply - ash alone did not. So silicon in ash may have improved nitrogen use efficiency. Silicon may be part of the mysterious benefits of sugar mill wastes.



*Michael B Haysom* and ***Graham Kingston***

Bureau of Sugar Experiment Stations – Brisbane and Bundaberg, Queensland, Australia

Silicon (Si) is emerging as an important nutrient for sugarcane in Australia and overseas. Large yield responses to Si were recorded in field experiments in north Queensland and Si is involved in response to sugar mill wastes containing ash. Advice for use of Si based amendments is likely to be based on soil analysis.

The following methods were used: Crushed cement building board waste was applied to three soils (euchrozem [volcanic], yellow podzolic & sand [sedimentary]); sugar mill wastes (filter mud / ash mixture and ash) were applied to a gleyed podzolic soil; soil samples from 0 - 25cm zone were assayed for extractable Si in: 0.005M $H_2SO_4$, 0.01M $CaCl_2$ and 0.5M Acetic acid at pH 2.5 and also buffered to pH 4.8; leaf samples were assayed for Si; and relative cane yield was calculated for the gley podzolic site. The conclusions were as follows: Soil Si extracted in sulfuric acid and calcium chloride provided useful indices of plant available Si across soil types. Sulfuric acid and pH 2.5 acetic acid extractable Si were most closely related to the yield response on a gleyed podzolic soil. Therefore, 0.005M sulfuric acid holds promise as the basis of a Si soil test.

## Some Effects of Silicon in Potting Mixes on Growth and Protection of Plants against Fungal Diseases ................ (13)

***Sally Muir***[1], *Cheang Khoo*[1], *Bernadette McCabe*[1], *Glen Fensom*[2], *Cath Offord*[2], *Julie Brien*[2] and *Brett Summerell*[3]

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Cucumbers, snapdragons and paper daisies were grown in an organic and sand based Control Mix (CON), +Si Mix (SIM = CON + Silicate) and Ricehull Ash Mix (RAM). Molybdate reactive Si in 1:1.5 DTPA extracts of mixes was 2.25-2.55mg/L for CON, 14.1-15.0mg/L for SIM and 11.4-13.6mg/L for RAM. Growth of cucumbers and paper daisies in RAM and SIM was significantly ($P \leq 0.05$) greater than for those grown in CON. Plants grown in RAM accumulated more Si than those grown in SIM, which contained more Si than those from CON. Snapdragons grown in SIM and CON were larger and flowered earlier and than those in RAM. Only bases of snapdragons grown in RAM contained more Si than plants from other mixes, at $P=0.06$.

Incidence and severity of an incidental infection of powdery mildew (*Sphaerotheca fuliginea*) was less for cucumbers grown in RAM at 6 and 10 weeks and SIM at 6 weeks than those grown in CON. Severity of infection of paper daisies by black mould (*Colletotrichum gloeosporioides*) was least when grown in RAM. Commonly used horticultural substrates contain less Si compared with the trial mixes and may contribute to reduced growth and increased susceptibility of potted plants to fungal diseases.

# BRAZIL

## Response of Upland Rice to Calcium Silicate Applications................................................(24)

***Morel P. Barbosa Filho***[1], *George H. Snyder*[2], *Lawrence E. Datnoff*[2] and *Osmira F. da Silva*[1]

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In Brazil, upland rice is cultivated mainly in Oxisols that are low in soil fertility including low Si in relation to Fe and Al oxide. An experiment was conducted, under greenhouse conditions, with the objective of evaluating the response of rice to $SiO_2$. The treatments consisted of six doses of $SiO_2$ (0.0, 0.75,1.50, 2.25, 3,00, 3.75 g pot$^{-1}$ containing 6 kg of soil) in the form of wollastonite, (Vansil–10, 50% of $SiO_2$) and three rice cultivars (Caiapó, Carajas, and Confiança). The relationship between $SiO_2$ rates and grain yield was linear and significant ($Y = 3.895 + 0.159x$, $r^2 = 0.638$). The highest grain yield increase of 23%, in relation to control was obtained with the application of 3.0 g pot$^{-1}$ of $SiO_2$ corresponding to 1 t ha$^{-1}$. The cultivar Confiança consistently showed the highest tissue concentration of Si followed by Carajas and Caiapó. The application of $SiO_2$ also increased the pH and soluble Si in soil. Upland rice responded to $SiO_2$ applications, but the magnitude of response was greater at the highest calcium silicate dose and varied according to the cultivar.

## Use of Crushed Basaltic Scoria as a Silicon Source for Rice ....................................................(4)

***Jorge de Castro Kiehl***[1], *Marcelo Castro Pereira*[2] and *Marina Gonçalves*[2]

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[2]Undergraduate student

An experiment has been carried out since June 1999 to study the efficiency of crushed basaltic scoria in supplying available silicon to rice plants. The scoria was mixed to 3 kg samples of a medium-textured Red-Yellow Latosol and a sandy Quartz Sand soil at rates of 0, 70, 140 and 240 t ha$^{-1}$ and placed in ceramic pots. The soil samples were moistened to 50% of the WHC and incubated for 20 days in the greenhouse. Soluble silicon was extracted from the soil by 0.5 M acetic acid solution and determined by colorimetric method, using ascorbic acid as the reducing agent.

In both soils, the extracted silicon increased linearly with the applied rates of basaltic scoria. For the highest rate applied, silicon content raised from 30 to 58 mg kg$^{-1}$ (93% increase) in the Red-Yellow Latosol, and from 18 to 35 mg kg$^{-1}$ (94% increase) in the Quartz Sand.

In continuation, three rice crops will be successively cultivated in the pots. Nutrients will be added in proper amounts, but no extra basalt scoria will be applied. For each crop, both dry matter and grain yields will be evaluated, as well as the amount of silicon absorbed by the plants and the soluble silicon content of the soil.

## Evaluation of Soil Extractants for Silicon Availability in Upland Rice ........................................ (5)

***Gaspar H. Korndörfer***[2], *Nívia M. Melo Coelho*[1], *Claúdia Tokiko Mizutani*[1] and *George H. Snyder* [3]

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Generally, silicon is not considered an element "essential" for plant growth. However, many workers have shown that Si improves the growth of rice and other Gramineae species. Therefore, quantification of Si in soils and plant tissue would be an important routine analysis performed in agriculture research laboratories. The suitability of four extraction methods (acetic acid 0.5 mol $L^{-1}$, buffer pH 4.0, calcium chloride 0.0025 mol $L^{-1}$ and water) for estimating the amount of available Si in soil for upland rice was determined. Four soil types corresponding to the following classes were used: Typic Acrustox - isohyperthermic (LEa), Typic Acrustox - isohyperthermic (LVa), Rhodic Acrustox - isohyperthermic (LRd) and Ustoxic Quartzipsammentic - isohyperthermic (AQa), created in each of the soils by applying calcium silicate. Upland rice was grown to maturity in pots of each soil in the greenhouse. Among the extractants studied, the acetic acid 0.5 mol $L^{-1}$ gave the best estimate for Si availability in soil. The Si content found in the leaves was highly correlated with extractable Si by the acetic acid 0.5 mol $L^{-1}$ method.

## Characteristics of an *In Situ* Opalized Vegetative Axis in a Brazilian Oxisol and Possible Plant Pathological Implications .............................. (38)

***Igo F. Lepsch***[1], *Selma S. Castro*[2], *Thomas R. Fairchild*[3], *Gaspar H. Korndörfer*[1] and *Ana F. Mandarin-de-Lacerda*[4]

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Hollow, white siliceous cylinders identified as *in situ* partially opalized branched vegetative axis have been found in an Oxisol in SW Minas Gerais. The main axis is about 4-5m long and 15cm diameter with a continuous wall of silicified outermost xylem tissues a few millimeters thick. Bark and more internal tissues were decomposed, and are being studied by SEM, X-ray fluorescence and diffraction, micromorphology and soil analysis. Organic matter is not preserved, but cell lumina have been replicated, and some cell walls with bordered pits have been permineralized. SEM locally revealed a relict botryoidal texture suggestive of original opal, now converted to low-trydimite. Si was dominant but some Zn and Cu also were detected. "Available" Si in the adjacent soil increased with depth (3 to 30 ppm), and morphologic studies suggests *Cecropia sp.* Soil both inside and immediately outside the cylinder contained numerous biopedotubules with opal fragments. Silicification evidently occurred recently or subsequently. Some *Cecropia* in the region have symptoms reminiscent of citrus blight, common in the area. The tantalizing possibility that silicification may be involved with this disease is currently under study.

## Silica in Biodynamic Agriculture Since 1924.........................(7)

***Andreas A. W. Miklós*** and *Jennyfer M. Karall*

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The regular use of silica in Biodynamic Agriculture started in the beginning of the 20$^{th}$ century. Biodynamic Agriculture, a pioneer agroecological movement evolved from eight lectures given in 1924 by R. Steiner. Among the recommendations for agricultural purposes, Steiner suggested the use of certain highly diluted substances.

One of these substances was silica: especially prepared (quartz, pulverized very finely: ≤0.2mm) and highly diluted (4g/60liters $H_2O$/ha) which constitutes the so-called "preparation 501", that is sprayed on plants in order to enhance the effects of light. This was recommended for improving longitudinal growth and a finer tissues' structure; to increase elasticity, flexibility and resistance in cereal's stems; to intensify the synthesis of chlorophyll and the absorption of light; to promote greater contents of sugars and protein; to increase silicon deposition in roots, stems, leaves and fruit; to enhance food's storage capacity; to intensify colors and shininess of plants, and the yields of certain crops; to improve ripening and taste and increase the product's aroma. In fact, higher food quality has always been one of the main purposes of biodynamic agriculture.

KOLISKO was one of the first to research some of these effects, from 1931 to 1934. More recently, other experiments were carried out by KLETT in 1968, WISTINGHAUSEN in 1979, ABELE in 1987 and others, in which the relationship between different light conditions and the use of preparation 501 confirmed its effect.

ABELE in 1973 tested the effects of preparation 501 on sugarbeets, potatoes, spring wheat, barley and oats. There was a slight increase in the sugar content of sugarbeet and also in the content of crude protein in potatoes and cereals. This suggests an influence of silica on carbohydrates and crude protein synthesis, even when used in very high dilutions. Abele obtained higher yields for sugarbeets and cereals, observing a significant positive effect especially in shadow treatments. This result is a confirmation of those first obtained by KOLISKO in1939 according to which preparation 501 reproduced light effects even in deficient light conditions. JONES and HANDRECK in 1967 confirmed silica's importance in the plant's morphological and structural development, inducing, as a consequence, higher resistance against insects and fungi. The same had been observed by GERMAR in1934, when he added colloidal silicic acid to cereals.

All these compensation (regulation) effects of silica have been studied in Biodynamic Agriculture research since the beginning of the century. In Brazil, such research is only just starting: the potential effects of preparation 501 and its very low costs may very soon become interesting for important branches of agroecological agribusiness, especially sugarcane, citriculture, soybean and essential oils. This paper intends to show the contribution of the Steiner's indications about the effects of highly-diluted (preparation 501) on plant development and the quality of agricultural products.

## Silicon and *Theobroma cacao* ................................................ (14)

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Witches broom of *Theobroma cacao* is caused by the basidiomycete, *Crinipellis perniciosa.* This disease is endemic to the cocoa producing countries of South and Central America, and the Caribbean Islands. The pathogen infects meristematic tissues, flower cushions and developing pods. The disease now limits cacao expansion and consolidation in Brazil.

The only effective control measure is through phytosanitation and its adoption depends on the world cocoa price. The long-term solution is through use of resistant cocoa genotypes.

There is limited information regarding the relationship between mineral nutrition and disease development by *C. perniciosa* in *T. cacao.* We herein report for the first time the effect of silicon on cocoa seedling growth, and on the biology of *C. perniciosa.* Germ tube length of basidiospores of *C. perniciosa* was reduced by 250 mg/kg of Si. Mycelial growth rates varied by isolate and the most sensitive isolate of *C. perniciosa* to Si was from Altamira, PA, Brazil. The role of silicon on cocoa growth and disease resistance to *C. perniciosa* will be discussed.

## Calcium Silicate Slag in Tropical Savanna Soil. III-Effect on the Availability of Phosphorus in Soil and Sugar Cane ........................................................ (33)

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The objective was to compare the use of limestone to that of calcium silicate slag (39.9% $SiO_2$) on the availability of soil phosphorus and in sugar cane on two plantations in two acidic soils in the tropical savanna region. Thus, a pot experiment was performed at the Engineering Faculty of Ilha Solteira/ UNESP. Blocks were randomized but each one had a factorial design involving 2 levels of acidic correction (1xNC ; 2xNC), saturation was considered on bases equal to 45% (1xNC); two corrective agents (calcitic limestone and calcium silicate slag); and two soils (Quartzose Sand and Dark-Red Latosol ). 200mg/dm$^3$ of P was applied together with the corrective agents at the time of the planting of the sugar cane. The soil was analyzed 225 days after the incorporation of these products.

The calcium silicate slag in the dose 1xNC was better than limestone for increasing available P in the soil. For sugar-cane, the slag had a linear effect whereas limestone had no effect at both locations. Therefore, the silicon in the slag affected indirectly the P increase of the soil.

## Effect of Silicon Fertilization on Rice Sheath Blight Development in Brazil ................................................ (15)

*Fabrício Á. Rodrigues*[1], *Francisco X. R. do Vale*[1], *Gaspar H. Korndörfer*[2], *Anne S. Prabhu*[3], *Antônio M. A. Oliveira*[1], *Laércio Zambolim*[1] and *Lawrence E. Datnoff*[4]

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Sheath blight (*Rhizoctonia solani* Kühn) is an important disease in intensified rice production systems worldwide. This study examined the effect of calcium metasilicate (wollastonite) at the rates of 0, 2, 4, 6 and 8 Mg ha$^{-1}$ on sheath blight development. Six rice cultivars were grown on a typic acrustox (red-yellow latosol, 0-20 cm, Ki = 0.74, Si = 9.2 ppm and pH = 4.8). Linear regression models described the relationship between the assessments by highest relative lesion height (HRLH) and severity (scale ranged from 0 to 9) and silicon rates. The HRLH was reduced relative to the control by 24%, 25%, 33%, 20%, 24%, and 32% for the rice cultivars: 'Epagri 109', 'Rio Formoso', 'Javaé', 'Cica-8', 'BR-Irga 409', and 'Metica-1'. Sheath blight severity also decreased by 61%, 57%, 59%, 61%, 62%, and 60% for the rice

cultivars 'Epagri 109', 'Rio Formoso', 'Javaé', 'Cica-8', 'BR-Irga 409', and 'Metica-1' in comparison to the control.

## Response of Six Gramineae Species to Applications of Calcium Metasilicate .................................... (16)

***Fabrício Á. Rodrigues***[1], *Gaspar H. Korndörfer*[2], *Gilberto F. Corrêa*[2], *Guilherme B. Buki*[2], *Oneida A. Silva*[2] and *Lawrence E. Datnoff*[3]

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Despite its abundance and importance, silicon has received far less study than any other nutrient. Silicon concentration of plant varies by soil and plant species. This experiment evaluated the uptake of Si and Ca by six grasses by applying calcium metasilicate (wollastonite) at the rates of 0, 200, 400, 600 and 800 kg $SiO_2$ $ha^{-1}$. The grasses were grown on a typic acrustox (red-yellow latosol, 0-20 cm, Ki = 0.74, Si = 9.2 ppm and pH = 4.8). Only Si, not Ca, significantly increased with increasing calcium silicate rates. On average, Ca values ranged from 0.16 to 0.40%. Linear regression models described the relationship between plant tissue silicon concentration and silicon rate. Silicon concentration (%) in the six gramineae species increased relative to the control by 251%, 125%, 100%, 47%, 40%, and 12% for rice, oat, sorghum, corn, wheat, and rye, respectively. Although dry weights of shoots and roots were not significantly different from the non-treated control, plant heights increased significantly.

## Influence of Silicon Fertilization on Powdery Mildew Development in Cucumber ...................... (19)

*Antônio M. A. Oliveira*[1], ***Francisco X. R. do Vale***[1], *Fabrício Á. Rodrigues*[1], *Gaspar H. Korndörfer*[2] and *Lawrence E. Datnoff*[3]

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It is long known that silicon enhances the fungal resistance of many plant species. In cucumber, the addition of silicon to hydroponic nutrient solutions has helped to reduced powdery mildew (*Sphaerotheca fuliginea*) development. The effect of silicon on powdery mildew development in cucumber was determined. Silicon was added to a typic acrustox (red-yellow latosol, 0-20 cm, Ki = 0.74, Si = 9.2 ppm and pH = 4.8) as calcium metasilicate (wollastonite) at the rates of 0, 2, 4, 6 and 8 Mg $ha^{-1}$. Conidia of *Oidium* sp. were collected from infected cucumber plants from fields never treated with fungicides and brushed onto

leaves of cucumber plants ('Híbrido Caipira AG370') amended and non-amended with silicon. Silicon was able to reduce the severity of powdery mildew and the number of mildew colonies relative to the control by 30.3%, and 36%, respectively, but these treatments were not significantly different from the non-treated control. Dry weight also was not affected but leaf area increased significantly.

# CANADA

## Proof of Stable Aqueous Silicon-Sugar Complexes...............(37)

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The importance of silicon in plant physiology has been amply demonstrated. Yet, almost nothing is known of the *chemistry* that plants use to uptake and transport silicon. Indeed, although numerous proteins and naturally occurring ligands have been identified as potential silicon binding substrates, no organosilicon complexes have ever been detected under physiological conditions. Using $^{29}Si$ NMR spectroscopy, we have shown that certain aliphatic polyhydroxy molecules ("polyols") - including a number of simple sugar molecules - display an extraordinary affinity for aqueous silicate anions, forming stable monomeric polyol-silicon complexes.

The silicon in these complexes can exist in either five- or six-fold coordination by oxygen, a phenomenon previously unknown in aqueous Si chemistry. Coordinating polyols require at least four adjacent hydroxy groups, two of which must be in *threo* configuration, and coordinate to silicon via hydroxy oxygens at chain positions on either side of the *threo* pair. Such species can reasonably be expected to play a central role in the biochemistry of silicon.

# CHINA

## Effect of Silicon Fertilization on Crops Grown in the Yellow River Alluvial Plain of China ........................ (21)

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The effect of a silicon fertilizer, which is made from blast furnace slag, was tested on various plants growing in the Yellow River alluvial plain of China. The results indicated that this silicon fertilizer increased grain production 10-26% for rice, 10-15% for wheat and 15-25% for peanut. The mechanism for increased yields was based on the original low silicon content in water from the Yellow River, the lack of available silicon in the soil and the richness of trace elements in the blast-furnace-slag-made silicon fertilizer. Silicon content in water from the Yellow River system was between 0 to 10 mg/L. The concentration of available silicon in the soil ranged from 100 to 300mg/g. Moreover, the relatively high pH value and richness of Ca and Mg observed in the Yellow River alluvial soil probably negatively influenced silicon absorption.

In rural areas of China, agriculture and the farmer are always the pivotal problems in supporting China's economic development and social stability. It is estimated that five million tons of silicon fertilizer would be required per year for agricultural production in the Yellow River alluvial plain. These data suggest that the application and popularization of silicon fertilizer in the area should be enhanced.

## Yield Response to Si and Combined Use of SiZnMn Fertilizer in China ........................................ (23)

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Beneficial effects of Si application on yield and quality of rice as well as other crops have been achieved in the major grain production areas in China in the past two decades. Generally, critical soil available $SiO_2$ content is 95 mg/kg, but good responses to Si in rice were found in soils with available content as high as 180mg/kg. In North China critical value for winter wheat was 220mg/kg and the same yield increase effect was achieved in summer corn. In Northeast China, significant yield increases were achieved in light chernozem and brown soils in which soil available $SiO_2$ content ranged 70~140 mg/kg. Field trials demonstrated that, compared with N, P, Zn, Mn fertilizer use alone or these fertilizers combined with each other, a combined application of SiZnMn could more efficiently increase absorption of N, Zn, Mn and P by crops, improve water use efficiency and resistance to lodging. Since two or three nutrients often appears deficient in one soil in China, the combined use of SiZnMn proved best. The proper doses of Si fertilizer (calculated as $Na_2SiO_3$) were not higher than 90 kg/hm$^2$ in South and North China.

## Silicon Induced Cadmium Tolerance of Rice (*Oryza sativa L.*) Seedlings ......................................... (29)

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Cadmium ($Cd^2$+) toxicity and the effects of silicon (Si) on the cellular and intracellular accumulations and distributions of cadmium were investigated by conventional electron microscopy and EDX analysis. The Si-deprived rice plants (-Si) differed greatly in cadmium distribution in the cell walls and vacuoles of the leaves and roots in comparison to Si-amended treatments. Energy dispersive X-ray microanalysis revealed that considerable amounts of Cd could be detected in the cytoplasm, vacuole or cellular organelles in -Si rice plants, while very little was found in +Si ones. From the microchemical and microbiological point of view, cell wall templates mediated the formation of colloidal silica with a high specific adsorption property and this helped to prevent the uptake of cadmium into the cell.

## Effects of Silicon on the Seedling Growth of Creeping Bentgrass and Zoysiagrass ................................. (30)

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The effects of silicon (Si) on the seedling growth of creeping bentgrass and zoysiagrass grown in a nutrient solution with three concentrations of Si (0, 1.7mM and 5.0mM) were studied in a greenhouse chamber. Silicon promotes

turfgrass quality development including rigidity, elasticity, and traffic resistance. It also improves significantly the ability of creeping bentgrass to tolerate heat stress exceeding 45°C during the day and 35°C at night. The Si-treated seedlings produced more fresh matter over the untreated seedlings. Silicon at 5.0mM in the solution increased root length,fresh weight of roots and leaves of creeping bentgrass and zoysiagrass. The
effects of Si at 1.7mM on the root growth of zoysiagrass were not significant. In contrast, Si at 1.7mM and 5.0mM significantly increased growth effects on bentgrass. The treated seedlings increased the uptake of phosphorus and Si by shoots in comparison to the untreated seedlings as determined by quantitative EDX analysis. Thus, Si application to turfgrasses seems to be an efficient maintenance practice for improving stress resistance while enhancing agronomic and environmental benefits.

## Plant Cell Wall Template-mediated Cooperative Synthesis of Micrometer-sized Colloidal Silica ........................................ (31)

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Zoysiagrass (*Zoysia japonica L.*) is widely used in sports turf and golf courses because of its excellent functional qualities, including rigidity, elasticity, resiliency, and disease tolerance as well. In addition, this turfgrass contains considerable silica deposited in the cell wall and micrometer-sized intercellular spaces of leaf epidermal cells. Thus Si figures is a major mineral constituent of this turfgrass. Such a deposition would increase the mechanical strength of the plant cell wall, so Si acts as a compression-resistant element. That in turn may improve the ability of grass to resist traffic and lodging. It is surprising to find a pronounced difference in the roughness of leaf surface physical properties. Si deprivation usually results in diminished biological performance. We examined whether different Si chemical forms affect the morphological characteristics and the cooperative synthesis of hybrid inorganic-organic silicon materials in the turfgrass cell wall template, and we describe intriguing biological strategies to self-assemble colloidal silica through oligosaccharide of zoysiagrass cell wall template and the silica sol-based nanoparticles for the fabrication of the highly ordered silica superlattices.

The biomineral analysis of the intercellular spaces of zoysia showed continuous silica superlattice arrays of organized hexagonal close packed (h.c.p.)which were preferentially deposited on the cell wall templates when applied ast he silica sol-based nanoparticles rather than monosilicic acid molecular species. Biomineralized rods are rhombic in outline and virtually of constant size with major axes averaging 0.6μm. We find that the Si-chemical forms of applications for plant absorption and primary building block of mineralization do affect significantly the formation of the superlattice arrays comparable to the random arrays that form without nanoparticles as a control. The composition was estimated by energy dispersive X-ray (EDX) spectra on a scanning electron microscope. The resulting intact rod showed carbon, oxygen, and silicon peaks. The variations of secondary electron peaks in the elemental contents with scanning organic-inorganic interfaces were reflected in commensurate changes. High-resolution image of an individual siliceous domain revealed irregular incoherent fringes in all selected microareas.

# INDIA

## Recycling of Rice Plant Silicon and Potassium for Blast Management in Rice.............................................(11)

*C. T. Kumbhar*[1] and *N. K. Savant*[2]

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Eco-friendly, low-cost input and agronomically efficient management practices for small resource-poor rice farmers are required in the future. A field trial was conducted during the 1996-97 wet season (southwest monsoon season, June-October) in the warm subhumid tropical region of the Maharashtra State, India. The objective was to evaluate the effect of rice hull ash (RHA) (as a source of Si) integrated with rice straw (RS) (as source of K & Si) on incidence of blast disease incited by *Pyricularia oryzae* Cav., plant growth and yield of rainfed transplanted rice (*Oryza sativa* L., cv. Chimansal-39). The field trial was a split plot design with three replications. The two main treatments were basal incorporation of RS at 0 and 2.0 t $ha^{-1}$ at transplanting, and five subtreatments were 0, 0.5, 1.0, 1.5 and 2.0 kg RHA $m^{-2}$ added to the seedbed prior to sowing. Fertilizers in the form of urea briquettes containing diammonium phosphate were applied immediately after controlled transplanting, suppling 56 kg N and 14 kg P $ha^{-1}$.

The integrated use of RHA at 2.0 kg $m^{-2}$ and RS at 2 t $ha^{-1}$ significantly reduced the severity of leaf blast (24.9%) and incidence of neck blast (29.7%) in comparison to the non-treated control. Grain yield (17.8 q $ha^{-1}$) also increased over the nontreated control (13.3 q $ha^{-1}$). Thus, the use of RHA at 1 kg $m^{-2}$ of seedbed combined with RS at 2 t $ha^{-1}$ may be helpful to farmers for reducing blast incidence while increasing the rice yields without the use of fungicides.

## Recycling of Rice Plant Silicon and Potassium for Leaf Scald Management in Rice ...................................... (12)

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Eco-friendly, low-cost input and agronomically efficient management practices for small resource-poor rice farmers are required in the future. Three field trials were conducted during the 1995, 1996 and 1997 wet seasons (southwest monsoon seasons, June-October) in the warm subhumid tropical region of the Maharashtra State, India. The objective was to evaluate the effects of rice hull ash (RHA) (as a source of Si) integrated with rice straw (RS) (as source of K & Si) on incidence of leaf scald disease incited by *Monographella albescens* (Thum) (*Rhynchosporium oryzae* Hashioka and Yokogi), plant growth and yield of rainfed transplanted rice (*Oryza sativa* L., cv. Indrayani). The field trials were a split plot design with three replications. The two main treatments were basal incorporation of RS at 0 and 2.0 t $ha^{-1}$ at transplanting, and the five subtreatments were 0, 0.5, 1.0, 1.5 and 2.0 kg RHA $m^{-2}$ added to the seedbed prior to sowing. Fertilizers in the form of urea briquettes containing diammonium phosphate were applied immediately after controlled transplanting, suppling 56 kg N and 14 kg P $ha^{-1}$.

The integrated use of RHA at 2.0 kg $m^{-2}$ and RS at 2 t $ha^{-1}$ significantly reduced the incidence (34.9.%) and severity (29.6%) of the leaf scald compared to control. The reduction in the incidence and severity of this disease was 29.5% and 25.6%, respectively, over the control. Grain yield (51.2 q $ha^{-1}$) also increased over the nontreated control (39.1 q $ha^{-1}$). Thus, the use of RHA at 1 kg $m^{-2}$ of seedbed combined with RS at 2 t $ha^{-1}$ may be helpful to farmers for reducing leaf scald incidence and severity while increasing the rice yields without the use of fungicides.

## Calcium Silicate Slag Applied to Soil Increased Yield of Rice on Inceptisol of Maharashtra State, India ............... (27)

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Efficient fertilizer management practices are required for farmers to improve low yields of transplanted rice (*Oryza sativa* L.) grown on Inceptisols. A field trial was conducted on an Inceptisol during the 1996-97 *Rabi* season (December to May) in the warm sub-humid tropical region on the west coast of the Maharashtra State, India. The objective was to evaluate the effects of calcium silicate slag (CSS) on plant growth, nutrient uptake and yield of irrigated transplanted rice (var. RTN-24). The CSS containing 45.0% $SiO_2$ supplied by

Calcium Silicate Corporation, USA was applied at the rate of 0, 2, 4 and 6 t/ha to soil before transplanting. Fertilizers were applied at 60 kg N/ha and 13 kg P/ha either as basal broadcast and incorporated prilled urea and single superphosphate (PU+SSP) or deep placed 2.7 g urea briquettes containing diammonium phosphate (UB-DAP) for every four hills after transplanting with modified 20X20 cm spacing.

For both methods of fertilizers applied, the CSS improved plant growth, nutrient uptake and yield of rice. However, the CSS applied along with the deep placement of UB-DAP immediately after transplanting increased more plant growth, nutrient (N, P, K, Ca, Mg and Si) uptake and resulted in additional yield increases (1.3 to 1.4 t/ha) than in comparison to the split application of PU+basal SSP. The CSS seemed to reduce the incidence of stem borer in the rice crop. These results suggest the potential use of CSS and deep placed UB-DAP in enhancing yields of transplanted rice on Inceptisols of Maharashtra State, India.

## Effect of Calcium Silicate Slag on Plant Growth, Nutrient Uptake and Yield of Sugarcane on Two Soils of Maharashtra State, India ............................ (28)

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Attempts were made to investigate decreasing or stagnant yields of sugarcane (*Saccharum officinarum* L.) on soils of Maharashtra State, India. Two field trials on a Vertisol (Padegaon, Dist. Pune) and one field trial on Inceptisol (Dapoli, Dist. Ratnagiri) were conducted during 1997-98 to evaluate the effect of calcium silicate slag (CSS) on plant growth, nutrient uptake, yield and juice quality of two plant sugarcane varieties (CO-86032 and CO-92013). The CCS containing 45.0% $SiO_2$ was basal applied to soil at 0, 2, 4, 6, 8 and/ or 10 t/ha. Recommended levels of farmyard manure (FYM) and/ or NPK fertilizers were also applied to the soils.

In all three field trials, the application of CSS in graded levels resulted in significant increases in plant growth, cane yield and commercial cane sugar. There was improvement in brix, % sucrose and % purity of juice quality due to the CSS applications on the Vertisol at Padegaon only. The total nutrient (N, P, K, Ca, Mg and Si) uptake (kg/ha) was increased due to the application of CSS. These results suggest that considering the plant growth, yield and juice quality, the application of about 6 t/ha CSS to the sugarcane varieties was found beneficial under the given agro-climatic conditions. However, more multi-locational trials in different seasons are required to assess need of calcium silicate fertilizers for improving sugarcane yield in Maharashtra State.

# JAPAN

## New Silicon Source for Rice Cultivation: 3. Growth and Yield of Wetland Rice with Reference to Silica Gel Application ................................ (1)

***Ho Ando***[1], *Hiroshi Fujii*[2], *Tsuyoshi Hayasaka*[2], *Katsushi Yokoyama*[2] and *Hirokazu Mayumi*[3]

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It is a well-known fact that dry matter production and yield of rice are affected by its silicon (Si) content when grown under solution culture. It is difficult to identify the effect of Si on growth and yield of rice grown under field conditions, because the amount of mineralized N increases when a Si source is applied to the field. The objectives of this study were to evaluate the dry matter production and yield of rice grown under field conditions as affected by a new Si fertilizer, silica gel. Results obtained were as follows: 1) Increased rate of Si application enhanced dry weight, amount of N/leaf area (LA), and chlorophyll/LA of rice. 2) Moisture content of the leaf blade and light transmission ratio was greater in Si treated plots in comparison to the non-treated control in the afternoon. These facts suggest that the net assimilation rate of Si treated plots was greater than the non-treated controls. 3) A greater number of grains per unit area, percentage of mature grains and yield of rice were obtained in Si treated plots in comparison to the non-treated control.

## New Silicon Source for Rice Cultivation: 2. Rooting Ability and Early Growth of Wetland Rice as Affected by Silica gel Application to the Nursery Bed .......................... (2)

***Hiroshi Fujii***[1], *Tsuyoshi Hayasaka*[1], *Katsushi Yokoyama*[1], *Ho Ando*[2] and *Hirokazu Mayumi*[3]

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The early growth of rice is affected by variability among rice seedlings in a temperate region. One of the factors that relates to the variability is silicon (Si) content of rice seedlings. The application of Si to nursery bed of rice is difficult because of its high pH status. The object of this study was to estimate the rooting ability and early growth of rice plant using silica gel. The results obtained were as follows: 1) seedlings treated with Si had a higher dry weight, a

higher dry weight to plant height ratio and increased content of silica compared to the control, 2) the photosynthetic rates of individual leaves and of the plant canopy of rice seedlings were higher in the Si treatments. A greater amount of TAC was observed in the seedlings treated with Si compared to the untreated control, and 3) a greater number of roots and heavier dry weight were found in the Si treated plots than in the control.

## New Silicon Source for Rice Cultivation: 4. How Does Silicon Influence Host Resistance to Rice Blast Disease?............................................(3)

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While many researchers have demonstrated that silicon in rice plants plays an important role in the resistance against blast disease, the mechanism is not clearly defined. Based on the work of earlier researchers, we put forward several hypotheses to explain how silicon confers this resistance. One hypothesis was that the absorption of silicon in rice reduces nitrogen uptake, consequently reducing the susceptibility to rice blast. However, our experiments did not support this hypothesis, since applying silica gel to rice did not reduce nitrogen uptake. Another hypothesis was that at least one process of pathogenesis was inhibited in rice plants with higher silicon content. Our results showed no significant differences between high and low silicon concentration on spore germination rates, appressorium formation rates, the size of lesions, and sporulation capacity. Therefore, it is unlikely that these mechanisms are the primary factors of resistance. The remaining possible explanations are that silicon acts as a physical barrier against fungal penetration on the surface of leaves or that silicon promotes some physiological resistance mechanisms within the plant. Consequently, we will test these hypothesis during the early infection phase.

## New Silicon Source for Rice Cultivation: 1. Characteristic of New Silicon Source, Silica Gel ............................................ (6)

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Silicon is known to be one of the most important elements for growing rice. Many researchers have been studying the effect of silicon on plant growth and development for many years. The effect of silicon on growth and yield of plants grown under field condition may be difficult to determine because silicon fertilizers contain some alkali that may increase soil pH. Furthermore, plant diseases are often observed to be reduced when a silicon fertilizer is applied. These facts indicate that a new silicon source for crop production should be considered. We have developed a new silicon source, silica gel that could substituted for the existing silicon fertilizers used by farmers. The characteristics of this fertilizer are as follows: 1) silica gel is amorphous and has a large surface area, consequently, it is highly soluble in water, 2) milling and sieving can control the particle size of the silica gel, and the pH can range between 3 and 9, and 3) no significant difference in amount of mineralized $NH_4$-N occurred between the treatments with and without silica gel applied to the soil.

## Available Silicon in Soils Extracted with Phosphate Buffer .......................................... (32)

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Acetate buffer has been widely used in Japan to evaluate the plant available Si status of soils. However, it is known that silicon is extracted in excess when the soil has received silicate slag. We proposed a new method to estimate availability by extraction with 0.02M-phosphate buffer, pH6.95 (PB). The procedure is: Si is extracted from 1g soil with 10ml PB in a tube at 40°C for 5 hours, while stirring 5 times during extraction. The Si extracted with PB consisted of water-soluble and phosphate extractable fractions; the average ratios of water-soluble Si of 12 Andosols and 11 non-Andosols were 38% and 53%, respectively.

The result at 4 prefectural agriculture research stations showed that the Si extracted with PB correlated well with the Si content of rice plants except for a few soil types. The correlation

was not found for the acetate buffer method. The Si in Andosols tended to be higher than the amount taken up by rice plant and the overestimation was supposed to be due to the difference in the water-soluble ratios.

We concluded the PB method is useful to evaluate the available Si in soils and is better than the acetate buffer method.

## Effects of Porous Hydrated Calcium Silicate on Silicon Nutrition of Paddy Rice ........................................ (8)

***Masahiko Saigusa***, *Akiko Yamamoto* and *Kyoichi Shibuya*

Experimental Farm of Tohoku University, Naruko, Miyagi, Japan

Large amounts of porous hydrated calcium silicate (PS) fragment is produced as a industrial waste in the manufacturing process of autoclaved light weight concrete. Silicon is one of the most important elements for rice production, and thus we investigated the effect of PS as a silicate fertilizer on silicon nutrition of paddy rice. The results obtained are: (1) PS is more effective for supplying silicon to rice plant than most commercial slags that were originally used as silicate fertilizers, (2) PS supplies silicon to rice plants continually from time of transplanting to harvest. (3) Tobermorite, main component of PS, was dissolved by 53 days after rice transplanting under paddy condition, but a silica skeleton remained till harvest time. (4) Application of PS reinforced plant resistance against rice blast disease, and also increased rice grain yield. From the foregoing, PS was determined to be a superior material for silicate fertilization of rice. This work was supported in part by Program of Research for the Future from the Japan Society for Promotion of Science (JSPS-RFTF96LOO604)

# KOREA

## Influences of Silicon on the Control of Temperature and Induction of Electronic Voltages in Rice Plant Tissues ........ (36)

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Jap. x Ind. hybrid rice variety "Dasanbyeo" was grown in a water culture with silicon and without silicon to investigate the influences of silicon on the control of temperature and induction of electronic voltages in rice plant tissues.

Leaf temperatures of silicon treated rice measured by infrared imaging radiometer were 22.7° C in 25° C ambient temperature and 30.7° C in 32° C, respectively, which was 1.7° C and 3.1°

C higher than those of silicon-free plants, respectively. Leaf temperatures of silicon treated plants measured by a porometer were 30.8-32.5° C in 30-38° C ambient temperatures, which were 0.7-0.9° C higher than those of silicon-free plant. However, under conditions of high temperature with 43-48° C leaf temperature of silicon-absorbed plant was 0.2-0.4° C lower than that in silicon-free plant.

The difference in electronic voltages between silicon-free and silicon-treated plants was near 6.5 mV. There was a relatively higher difference in unit and electronic induction pattern was also different from each other.

The change in electronic voltages in silicon treated plants was stable, while it was unstable in silicon-free plants. The induction of electronic voltage in leaf blade of rice plants stimulated by hand showed a sensitive response in the silicon-free plant.

# RUSSIA

## A Proposed History of Silicon Fertilization ......................... (39)

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Early agriculturists first used plant ash as a silicon (Si) fertilizer. Over two thousand years ago, the Emperor in China mandated the use of barley or rice with manure as a fertilizer by farmers. Vergilian, 70-19 BC, suggested the use of plant ash for improving the fertility of degraded soils of Rome. The first experiment ever conducted using Si as a fertilizer was by J. Liebig in 1840. His early work helped to promote Si research in Germany, Great Britain, Japan, Russia and USA. The classic field experiment with Si was started at the Rothamsted Experiment Station in 1856. Maxwell in 1898 conducted the first soil tests on the content of plant-available (mobile) Si on the Hawaiian Islands. German scientists, Kreuzhage and Wolf (1884) and Grob (1896), explored Si's effect on plant disease resistance. Japanese scientists such as Odonera (1917) and Miyake and Adachi (1922) continued with this idea with rice that resulted in many outstanding discoveries. The Russian chemist D.I. Mendeleev suggested the use of Si fertilizers such as $SiO_2$ and $CaSiO_3$ in 1870. The first patent for using Si-rich slag as fertilizer was obtained in the USA in 1881. The first field experiments using Si as a by product from the metal industry were conducted by Cowles in 1917. In 1927, V.I.Vernadsky, an academic from Russia, declared than Si is an important element for all living organisms. Based on past and current scientific research with Si, these reviews demonstrate the possibility of developing an adequate theoretical base for silicon fertilization and its practical implementation in agriculture.

# USA

## Silicon Use in Louisiana Rice: Potential Improvements in Disease Management and Grain Yields ............................. (9)

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Sheath blight (*Rhizoctonia solani*) and blast (*Pyricularia grisea*) are major rice diseases in Louisiana, both causing significant losses in grain yield and quality. Field studies were conducted on a Crowley silt loam (1995-1997) and on a Rita muck soil (1995-1996) to determine the effectiveness of silicon soil amendments in reducing the incidence of disease and increasing grain yield of rice. Calcium silicate slag was preplant incorporated at rates of 0, 1120, 2240, 3360, 4480, and 5600 kg/ha. The cultivars Bengal and Cypress were grown in a water-seeded, pinpoint flood cultural system. Grain yield, silicon accumulation in the y-leaf, whole plant, and in the mature rice straw were determined. Disease ratings for sheath blight, blast, and brown spot (*Bipolaris oryzae*) were determined when significant disease was present.

On the Crowley silt loam soil in 1995 and 1996, grain yield increased 14 and 6%, respectively. Approximately 3360 kg/ha of calcium silicate slag were required to maximize grain yields. The average increase in silicon content over years of the y-leaf, whole plant, and mature rice straw was 30, 34, and 26%, respectively. The incidence of sheath blight was decreased in 1996-1997. Blast was decreased by calcium silicate slag applications in 1995, although the incidence of blast was very low. On the Rita muck in 1995 and1996, grain yield increased 24 and 9%, respectively. This soil required a higher application rate of calcium silicate slag to maximize grain yields, approximately 4480 kg/ha. The average increase in silicon content over years of the y-leaf and mature rice straw was 46 and 21%, respectively. Whole plant silicon content on the Rita muck was increased 53%. Sheath blight was not affected by increasing rate of calcium silicate slag in 1996, but the incidence of brown spot was significantly reduced.

Applications of calcium silicate slag to a Crowley silt loam and Rita muck soil resulted in rice yield increases and higher accumulation of silicon in the y-leaf, whole plant, and mature rice straw. Grain yield and silicon accumulation responses were higher on the Rita muck. Calcium silicate slag applications had a positive effect on the incidence of blast, sheath blight, and brown spot on both soils. These field studies indicate that silicon soil amendments offer the potential to reduce disease incidence and increase rice grain yield in Louisiana. More research is needed to determine the economic feasibility of calcium silicate slag applications to Louisiana rice soils.

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Silicon (Si) has been reported as a beneficial element for promoting the growth of monocots, particularly rice and sugarcane. However, limited research has addressed the effects of Si on container-grown ornamentals. Since most ornamental crops are grown in soilless media where the Si concentration is minimal, this study was undertaken to determine if Si could be beneficial to ornamental plant growth. Thirty-seven cultivars from 35 genera of ornamental plants were grown in a soilless medium supplemented with $K_2SiO_3$. Afterwards, plant growth and Si concentration were measured. General results indicated that all of the plants were capable of absorbing Si through their roots with large amounts found to have been translocated to the shoots, indicating that Si may play certain roles in plant metabolism. More specifically, the addition of Si: (1) significantly increased the dry weight of 16 cultivars, and (2) mitigated manganese (Mn) toxicity. Therefore, Si could be used as a fertilizer additive for improving the growth and quality of Si-responsive ornamental plants.



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This study investigated the effect of silicon on gray leaf spot, caused by *Pyricularia grisea*, in St. Augustinegrass. The experiment was a factorial with 10 replications arranged in a RCB in the greenhouse. Main effects were silicon (14 gm $CaSi0_3$ / 500 cc soil) and a non-amended control, and sub-effects were four St. Augustinegrass cultivars; Bitterblue, Floratam, FX-10 and Seville. Plants were periodically misted to provide optimum leaf wetness that promoted natural infection by *P. grisea.* Disease severity was rated over a 4 week period by estimating % gray leaf spot on individual leaflets using a Horsfall-Barratt rating scale. Silicon significantly reduced area under the disease progress curves for gray leaf spot between 44% to 78% among all the St. Augustinegrass cultivars. This element also significantly reduced the final disease severity between 2.0% to 38.8%, and final whole plant infection between 2.5% and 50.5%. Plant silicon content in Si-amended treatments for all cultivars increased between 2.2X to 3.5X over the non-amended controls. Silicon appears to be a good method for reducing gray leaf spot development in St. Augustinegrass.

## Plant Available Silicon in Selected Alfisols and Ultisols of Florida ............................................... (34)

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Plant available silicon was measured in soils from 70 locations in Florida. Forty of these were Ultisols including five soil series and thirty were Alfisols including three soil series. The average soil silicon content in Ultisols ranged from 7 ug/g in the Bonifay soil series to 15 ug/g in the Orangeburg soil series. The average soil silicon content in the Alfisols ranged from 6 ug/g in the Pineda soil series to 15 ug/g in the Winder soil series. One critical minimum concentration of silicon in the soil mentioned in the literature is 19 ug/g. Based on that concentration, corn, Bahia grass, Bermuda grass, pangola grass, chufa and cucumbers will probably respond to silicon added to the soil.

## Effects of Fertilization with Silicon on the Components of Resistance to Rice Blast ....................................................... (17)

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The addition of silicon (Si) to Si-deficient soils is known to reduce the epidemic rate of blast, caused by *Magnaporthe grisea*, in blast-susceptible and partially resistant cultivars of rice. Four cultivars of rice with differential susceptibilities to race IB-49 of *M. grisea* were fertilized with three rates of calcium silicate and inoculated with the pathogen to test the effects of Si on the components of resistance that influence epidemic rate. The following components of resistance to blast were examined: incubation and latent period, infection efficiency, lesion size, rate of lesion expansion, sporulation per lesion, and diseased leaf area. For each cultivar, the incubation period was significantly lengthened by increased rates of Si, and the numbers of sporulating lesions, lesion size and rate of expansion, diseased leaf area, and number of spores per lesion were reduced. At the highest rate of Si, 1000 kg $ha^{-1}$, lesion size and sporulation per lesion were 30-45% lower than for cultivars not treated with Si. Thus, Si acts to slow the epidemic rate of blast via reductions in lesion size and spore production per lesion.

# Root Application of Potassium Silicate Reduce Feeding Damage to Sargent Crabapple Leaf Tissues by Adult Japanese Beetles................................ (18)

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Two-year-old Sargent Crabapple *'Malus sargentii'* seedlings were subjected to 4 continuous days of 100 ml root application of potassium silicate at the rate of 0, 100, 200, and 400 ppm in August, 1998. After three days of post-treatment applications, 3 detached leaves were placed in each of 3 petri dishes along with one adult female Japanese Beetle (*Popilla japonica*) (n=3/concentrations) for 7 days. Root, stem and leaf tissue Ca, K, Mg, Na and Si were analyzed using a Coupled Plasma Spectrometer. Potassium silicate at 100 ppm concentration significantly reduced percent leaf tissue eaten by adult Japanese Beetles. The ion leakage of stem tissues of 100 and 200 ppm treated plants were significantly lower than the control and 400 ppm. These lower ion leakage effects were also observed with red-osier dogwood stem tissues at 100 ppm. The results of the tissue analysis indicate that Si and Ca levels were significantly higher in root tissues for 100 ppm treated plants compared to stems and leaves. The K and Mg levels in root tissues were higher for the control and slightly higher for 100 ppm treatments compared to stems and leaves. The Na levels in root tissues were the same for control, 100 and 200 ppm, and significantly lower in 400 ppm treatment. In a companion study, fall webworm larvae were also exposed to the same above concentrations and treatments, however, since there was not a significant effect of potassium silicate on percent leaf tissue eaten by fall webworm larvae (*Paleacrita vernata*), this suggests there may be differences between major groups of leaf-feeding insects.

# Lime Effect on Silicon Release from Silica Fume Dust........ (35)

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The objective of this study was to evaluate lime's effect on silicon (Si) release from fume dust, a byproduct dominated by silica from an electric arc furnace. Fume dust was pelletized with 10% $Ca(OH)_2$ and 10% $CaCO_3$, respectively. The releases of Si from lime-pelletized fume dusts were compared with those of pelletized fume dust via a 20-day continuous column leaching, using 10 g sample per column with 1 ml per minute of de-ionized water buffered to pH 7.0. We calculated leachate Si ion species using a geochemical model MINTEQA2/PRODEFA2, Version 3.0. We found that leachate Si concentration of lime-pelletized fume dust varied with leaching time and lime sources. The $Ca(OH)_2$ has more significant influence than $CaCO_3$ on Si release from fume dust; but $CaCO_3$ has longer residual effect than $Ca(OH)_2$. The $Ca(OH)_2$ initially (first 48 hours) reduced Si release in

spite of high leachate pH due to high-soluble Ca level (>100 mg $L^{-1}$). Maximum Si concentration occurred when leachate pH ranged from 7.5 to 9 and leachate Ca concentration was lower than 100 mg $L^{-1}$. Lime affects Si release from fume dust through its free radicals: $Ca^{2+}$ and $OH^{-}$. The former decreases Si release by precipitating the free silicate ions from the solution, while the later increases Si release from fume dust by forming silicate ions.

# VENEZUELA

## Silicon Applications for Blast Control of Rice on Two Soils Types from Portuguesa, Venezuela........................(20)

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Blast, caused by *Magnaporthe grisea* (Barr)/ *Pyricularia grisea* (Cooke)Sacc., is an important rice disease in Venezuela. During the 1997 rainy season, a study was done to evaluate the effect of different doses (0, 5, 10, 15 and 20 t/ha) of silica sand (99.64 % $SiO_2$, granulometry 51 %< 0.075 mm) to control blast in the variety Cimarron. The experiment was a completely randomized factorial (2x5) design with 9 replications conducted on two soils from the state of Portuguesa. The plants were sown in pots and maintained in tubs with water. Leaf blast was reduced using silicon by 81.6; 69.4; 46.9 and 83.7 % in comparison to the control. The injury decreased from grade 7 to 4, 4, 3 and 2. The reduction of blast incidence on the panicle using silicon was 36.5; 42.3; 42.3 and 65.7 % in comparison to the control. The magnitude of the response to silicon was better with the soil from Guanare in comparison to Acarigua. These results demonstrate that blast was controlled with the application of silica sand. Although the residual using silicon needs to be evaluated, the results indicate the possibility of using this material in an integrated blast control program.

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