

**CALIBRATION AND CATEGORIZATION OF PLANT
AVAILABLE SOIL SILICON IN DIFFERENT RICE
ECOSYSTEMS FOR EVALUATING DROUGHT AND
DISEASE RESISTANCE IN RICE GENOTYPES**

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GKVK, BANGALORE**

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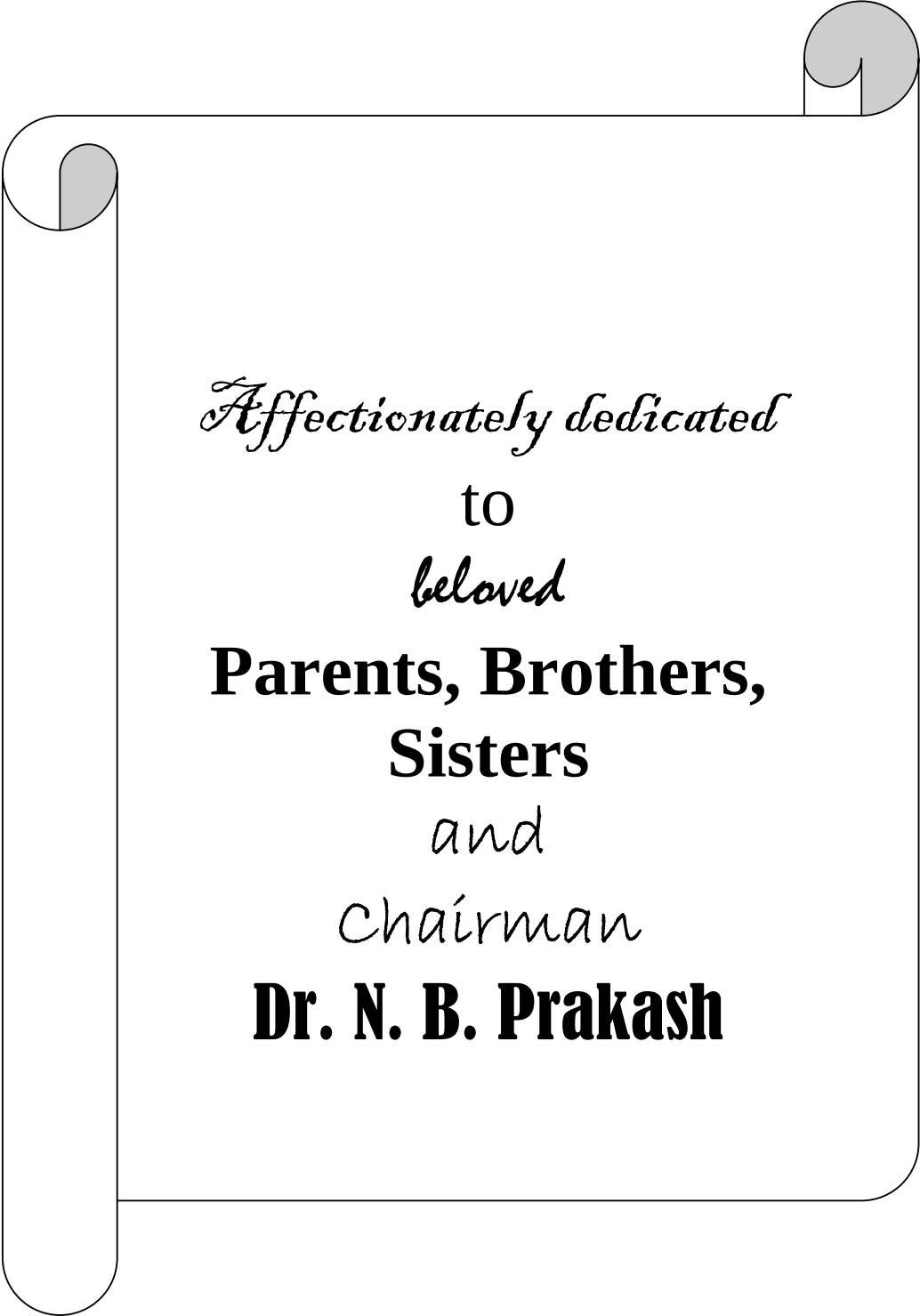
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Thesis submitted to the
UNIVERSITY OF AGRICULTURAL SCIENCES, BANGALORE
in partial fulfillment of the requirements for the award of the degree of
DOCTOR OF PHILOSOPHY (*AGRICULTURE*)
IN
SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

BANGALORE

JULY 2007



Affectionately dedicated

to

beloved

Parents, Brothers,

Sisters

and

chairman

Dr. N. B. Prakash

**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
UNIVERSITY OF AGRICULTURAL SCIENCES,
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CERTIFICATE

This is to certify that the thesis entitled “**Calibration and categorization of plant available soil silicon in different rice ecosystems for evaluating drought and disease resistance in rice genotypes**” submitted by **Mr. NARAYANASWAMY, C.** for the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** of the **University of Agricultural Sciences**, Bangalore is a record of research work done by him during the period of his study in this University under my guidance and supervision and thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

BANGALORE
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CALIBRATION AND CATEGORIZATION OF PLANT AVAILABLE SOIL SILICON IN DIFFERENT RICE ECOSYSTEMS FOR EVALUATING DROUGHT AND DISEASE RESISTANCE RICE GENOTYPES

C. Narayanaswamy

ABSTRACT

The plant available soil Si content of Mangalore, Ponnampet and Mudigere as extracted by ammonium acetate and acetic acid ranged from 7.1 to 64.6 and 15.9 to 78.4 ppm, respectively. The soils of Ponnampet recorded lowest available Si followed by Mangalore and highest available Si was recorded in Mudigere soils. In general, 0.5M acetic acid extractable available Si was higher than the ammonium acetate extractable. It was observed that nearly 75 to 85 per cent of the studied soils were categorized as low (< 20 ppm) to medium (20 - 40 ppm) in available Silicon content. The plant available soil Si extracted by various extractants irrespective of the soils used for the study was in the order of 0.005M H₂SO₄ > 0.1M citric acid > N NaOAc-2 > N NaOAc-1 > 0.5M acetic acid-3 > 0.5M acetic acid-2 > 0.5M acetic acid-1 > 0.01M CaCl₂ > 0.5M NH₄OAc > distilled water-4 > distilled water-1. Among the methods studied, plant available Si extraction with N NaOAc-1 appeared to be the most suitable for evaluating Si availability followed by extraction with 0.5 M acetic acid-2 and N NaOAc-2. These extractants showed the highest degree of significant correlation with the per cent Si and its uptake in straw and grain. The critical levels for plant available Si in the soil as extracted by different extractants ranged from 14 ppm (distilled water-1) to 207 ppm (0.005 M H₂SO₄). There was wide variation in low, medium and high categories of plant available Si for different extractants calculated based on per cent relative yield. The critical level of Si in straw and grain were 2.9 and 1.2 ppm, respectively. There was a greater variation in Si accumulation among different rice genotypes studied. Rasi recorded maximum Si uptake followed by BI-33. The Si accumulation was highest at harvesting stage followed by flowering stage and least at maximum tillering stage. The silicon accumulation was maximum in submerged conditions than aerobic conditions. The grain and straw yields increased significantly with the application of silicon at 117 kg Si ha⁻¹ as calcium silicate along with varied N levels at both the locations over non silicon treated plots. Interaction between Si and N was positive and found to be statistically significant in obtaining higher grain and straw yields, reduced per cent blank spikelets and insects and diseases.

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Introduction

I. INTRODUCTION

Rice occupies a pivotal place in India's national food and livelihood security. Under conditions of expanding urbanization and per capita income, a minimum growth of 2.5% in food grain production is needed annually. This will involve producing 300 million tons of food grains by 2010. Rice occupies an area of over 44 million hectares (Duncan, 2005) and has the largest untapped yield potential. Rice yields are either decelerating/ stagnating/ declining in the post-green revolution era mainly due to imbalance in fertilizer use, soil degradation, type of cropping system practiced, lack of suitable rice genotypes for low moisture adaptability and disease resistance.

Rice is a Silicon (Si) accumulator plant. No other crop requires as high Si as required by rice. Si plays a significant role in imparting both biotic and abiotic stress resistance and enhances productivity. Si is also the only element known that does not damage plants upon its excess accumulation. High accumulation of Si in rice has been demonstrated to be necessary for healthy growth and high stable production. For this reason, Si has been recognized as an “agronomically essential element” in Japan and silicate fertilizers have been applied to paddy soils (Ma *et al.*, 2001b). In recent years Si has been regarded as quasi-essential element (Epstein, 1999 and 2005). Several studies suggest that Si enhances disease resistance in plants, imparts turgidity to the cell walls and has a putative role in mitigating the metal toxicities. It is also suggested that Si plays a crucial role in preventing or minimizing the lodging in the cereal crops, a matter of great importance in terms of agricultural productivity.

Three international conferences on SILICON IN AGRICULTURE were held at Ft. Lauderdale, FL, USA in 1999, Tsuruoka, Yamagata, JAPAN in 2002, and Uberlandia, MG, BRAZIL in 2005. As such, many of the plant scientists from India are still unaware of the importance of silicon in agriculture especially as it relates to plant health and soil productivity. In India, though

research on silicon has been initiated earlier, the necessity for silicon fertilization to the rice crop has not been widely evaluated as in other countries.

Information on the importance of Si in Indian rice farming system is limited (Prakash, 2002). There is need to identify the nature and magnitude of the Si status of different rice eco-systems and thereby developing suitable Si management agenda for obtaining or sustaining rice yield potentials of improved rice cultivars. Since yield responses of rice to Si application are related to available Si in soils and the Si content of rice plants, there is a need for evaluation of simple and rapid extractant for determination of available soil Si based on the crop response and its uptake. Several extractants are being employed in different countries for determination of plant available soil Si. Most of them apply an anion to replace adsorbed Si and have been tested by determining the correlations between Si analyzed in the extract and crop yield. Not all of them were intended to extract the complete amount of plant available Si, Hence, there is need for evaluating suitable extractant to determine available soil Si based on the crop uptake.

Rice genotypes are known to differ with respect to acquisition, translocation and accumulation of Si (Winslow *et al.*, 1997). Evaluation of lowland, upland and aerobic rice genotypes for Si use/acquisition efficiency, its usefulness in characterizing the association of Si accumulation; and resistance to biotic and abiotic stress without compromising on the qualitative and quantitative traits, is of great importance. However, information on extent of accumulation of silicon at different growth stages of different rice genotypes under different rice ecosystems is limited. It is also important to know the variation in accumulation of Si among different rice genotypes under reduced moisture regimes.

Before fertilizer recommendation is to be done, it is necessary to find the critical limits for a particular nutrient in soil and plant for plant growth and

development which would indicate the degree of deficiency and the amount of nutrient to be applied as a fertilizer to correct the deficiency (Korndorfer *et al.*, 2001). Although, critical limits for many nutrient elements are available for Indian soils, there is no information with respect to Si in Indian rice soils. It is necessary to find the critical limits for Si in soil and plant for obtaining optimum rice yields.

Application of nitrogenous fertilizers is an important practice for increasing rice yields. However, when applied in excess it may limit yield because of lodging, promote shading and susceptibility to insects and diseases. These effects could be minimized by the use of Si (Ma *et al.*, 2001 and Munir *et al.*, 2003). Silicon has been reported to raise the optimum level of nitrogen in rice. Hence there is need to study the effect of silicon and nitrogen interaction in rice to achieve higher yield.

Information on status of available Si in different rice ecosystem, most suitable soil test method to determine the plant available Si in soils, critical levels of Si in soils and plant for optimum rice yields, accumulation of Si in different rice genotypes under both aerobic and submerged rice cultivation system and interaction effect of Si and N on growth and yield of rice is very much lacking in Indian rice farming. With this in view, the present investigation was undertaken with the following objectives.

1. To know the available silicon status in soils of different rice ecosystems
2. To evaluate different extractants for plant available silicon in different rice soils
3. To calibrate and categorize the plant available silicon in different rice soils

4. To know the silicon acquisition and uptake by rice under aerobic and submergence condition
5. To know the effect of silicon and nitrogen and their interaction on yields component through enhanced disease resistance

*REVIEW
OF
LITERATURE*

II. REVIEW OF LITERATURE

Rice is considered to be a silicon (Si) accumulator plant and tends to actively accumulate Si to tissue concentrations of 5% or higher (Epstein, 1994). Silicon is the only element known that does not damage plants upon excess accumulation. Recently Si has been regarded as quasi-essential element (Epstein, 1999). Information on the importance of Si in Indian rice farming system is limited (Prakash, 2002). There is need to identify silicon deficient soils, for determining needed rates of silicon fertilization and for assessing various silicon fertilizer sources. Evaluation of rice genotypes for Si use/acquisition efficiency, its interaction effect on Nitrogen, resistance to biotic and abiotic stress, evaluation of best suitable extractants and optimum silicon in soils and tissues for silicon fertilization is of great importance. The limited recent review related to the present investigation under the following headings

- 2.1 Forms of silicon and status of silicon in soils
- 2.2 Importance of silicon in agriculture
- 2.3 Evaluation of suitable extractants for determination of available Si in rice soils
- 2.4 Uptake and accumulation of silicon in different rice genotypes
- 2.5 Optimum silicon contents in soils and plants for higher yields
- 2.6 Interaction of silicon with nitrogen and other nutrient elements

2.1 Forms of silicon and status of silicon in soils

Mineral soils develop from rocks or sediments and are mainly composed of primary crystalline silicates such as quartz, feldspars, mica and secondary silicates, especially clay minerals (Iler, 1979 & Conley *et al.*, 2005). More over they contain Si of biogenic origin (Jones, 1969) and pedogenic amorphous silica (Drees *et al.*, 1989). Silicon also occur in soil as complexes with Fe, Al, heavy metals and organic matter (Farmer *et al.*, 2005)

Silicic acid is also dissolved in soil solution with some part of the silicic acid adsorbed to soil minerals, particularly oxides and hydroxides of iron and

aluminium (Hansen *et al.*, 1994 & Dietzel, 2002). Dissolved silicic acid in soil solutions primarily occurs as monomeric or oligomeric silicic acid (Iler, 1979).

Knight and Kinrade (2001) reported that monomeric silicic acid (H_4SiO_4) dissociates into $\text{H}^+ + \text{H}_3\text{SiO}_4^-$ above pH 9 and into $2\text{H}^+ + \text{H}_2\text{SiO}_4^{2-}$ above pH 11. Oligomeric silicic acid is only stable at high concentration of silicic acid at pH >9. In most of soils and natural waters only undissociated monomeric silicic acid occurs (Dietzel, 2000).

The Si compounds in the soils are classified into soil solution and adsorbed Si forms (Monosilicic and polysilicic acids), amorphous forms (phytoliths and silica nodules), poorly crystalline and microcrystalline forms (allophane, immogolite and secondary quartz) and crystalline forms (primary silicates: quartz, feldspars & secondary silicates: clay minerals) (Daniela *et al.*, 2006). The dissolution of Si in paddy soils is influenced by soil temperature, soil redox potential, soil pH and Si concentration in soil solution (Sumida, 1992).

The average available Si status of eight different soil types of Kerala (South India) as adjudged by four different extractants revealed that Silica extracted by 0.025 M citric acid ranged between 250 to 1500 kg ha⁻¹ with an average of 700 kg ha⁻¹ (Nair and Aiyer, 1968). Nayar *et al.* (1982 a) reported that in 5 out of 9 soils (mostly belonging to red and laterite groups) studied, silicon content ranged from 8 to 83 ppm and considered to be highly deficient. Subramanian and Gopalaswamy (1990) reported that the plant available Si status of rice growing soils Kanyakumari, Madurai, Chinnamannur of Tamilnadu were 29, 70 and 40 ppm, respectively. The plant available soil Si (mean) extracted by N NaOAc (pH 4.0) in soils of Orissa and Andhra Pradesh were 139 and 278 ppm respectively (Nayar *et al.* (1982a). However, there is no national database on Si availability in Indian soils although it's available in other countries of the world. It is apparent from the reviewed literature (Prakash, 2002), that most of the paddy soils studied was deficient in Si.

2.2 Importance of silicon in agriculture

Rice is considered as silicon accumulator and is prone to various stresses if the available soil silicon is low for absorption. Production of 5 t/ha of grain yield of rice is estimated to remove about 230-470 kg elemental Si from soil, depending upon soil and plant factors. Absorption will be about 108 % more than the nitrogen content. Adequate supply of silicon to rice from tillering to elongation stage increases the number of grains per panicle and the percentage of ripening (Korndorfer *et al.*, 2001). It is also suggested that the silicon plays a crucial role in preventing or minimizing the lodging incidence in the cereal crops, a matter of great importance in terms of agricultural productivity.

2.2.1 Silicon and biotic stresses

Seebold *et al.*, (2001) have tested the effects of Si on several components of resistance to blast using susceptible, partially resistant and completely resistant rice cultivars. They reported that regardless of cultivar resistance, incubation period was lengthened and the number of sporulating lesions, lesion size, rate of lesion expansion and number of spores per lesion were significantly reduced by Si application. Similar results were also noticed by Onodera, (1917), Maekawa *et al.* (2001).

Miyake and Takahashi (1983) reported that by increasing the Si concentration in the culture solution, the Si content in the cucumber shoot increased, resulting in a reduced incidence of powdery mildew disease. The Si content of leaves increased proportionally to the increased Si concentration in the culture solution, the incidence of powdery mildew decreased in strawberry (Kanto, 2002). Silicon deficiency in barley and wheat leads to a poor growth habit and increased powdery mildew susceptibility (Zeyen, 2002).

Datnoff *et al.* (2005) reported that the occurrence of brown spot, stem rot, sheath brown rot on rice, fusarium wilt and corynespora leaf spot on cucumber and several diseases in Turf grass were decreased significantly by the application of higher levels of Calcium silicate as a source of Si.

Liang and Abandonon (2005) reported that application of silicon at varied levels helps in significant reduction of damages caused by various insects, pests and diseases in soils of South Africa. Savant *et al.* (1997) noticed that application of silicon suppresses insect pests such as stem borer, brown plant hopper, rice green leaf hopper, and white black head plant hopper and non insect pests such as leaf spider and mites. Similar results were also noticed by Sasamoto (1961) and Sujatha *et al.* (1987).

Two possible hypothesis for Si enhanced resistance to diseases and pests have proposed by Cherif *et al.* (1994). In the first one, Si deposited on the tissue surface acts as a physical barrier and other one is that Si functions as a signal to induce the production of phytoalexins. Similar results also noticed by Datnoff *et al.* (2003).

2.2.2 Silicon and abiotic stresses

Takahashi, (1966) reported that Silicon application increases the resistance of rice to radiation stress. The growth recovery of radiation treated plants was much faster with silicon supplied plants compared to that of the plants without Si supply.

Water deficiency leads to the closure of stomata and subsequent decrease in the photosynthetic rate. Silicon can alleviate the water stress by decreasing transpiration by forming silicon cuticle double layer. Silicon deposition can reduce the transpiration rate by 30 percent in rice (Ma *et al.*, 2001a). The effect of silicon was pronounced under water stressed conditions (Low humidity) than rice that cultivated under non stressed conditions (high humidity) (Ma *et al.*, 2001a).

Silicon application in rice is effective in alleviating the damage caused by climatic stress such as typhoons, low temperature and insufficient sunshine during summer season (Ma *et al.*, 2001a). Agarie *et al.* (1998) observed that

electrolyte leakage caused by high temperature (42.5°C) was less pronounced in the leaves grown with Si than in those grown without Si.

2.2.3 Silicon and Chemical stress

Silicon plays a vital role in alleviating the heavy metal toxicity, nutrient toxicity, nutrient imbalance, salinity and so on.

Ma and Takahashi (1990a) noticed that Si supply resulted in a larger increase of the dry weight of rice shoot at a low P level (14 mM) than at a medium level (210 mM). Application of silicon helps in alleviating the adverse effects caused due to the application of excess N fertilizers (Morimiya, 1996) and Ohyama (1985).

An alleviative function of Si on Mn toxicity was observed in hydroponically cultured rice (Okuda and Takahashi, 1962), barley (Williams and Valmis, 1957), bean (Horst and Marschner, 1978) and pumpkin (Iwasnki and Matsumura, 1999). Silicon was also effective in alleviating Fe excess toxicity in rice (Okuda and Takahashi, 1962).

The beneficial effect of Si under salt stress was observed in rice (Ye *et al.*, 1999), wheat (Ahmad *et al.*, 1992) and barley (Liang *et al.*, 1996). Matoh *et al.*, (1986) reported that shoot and root growth of rice was inhibited by 60 percent in the presence of 100 mM NaCl for three weeks, but Si addition significantly alleviated salt induced injury.

Aluminium toxicity is a major factor limiting crop production in acid soils. Ionic Al inhibits root growth and nutrient uptake (Ma *et al.*, 2001b). Alleviate effect of Si on Al toxicity has been observed in sorghum, barley, maize, rice and soyabean (Cocker *et al.*, 1998).

2.3 Evaluation of best suitable extractants for rice soils

The addition of Si in various forms to crops has been shown to have many beneficial effects (Datnoff *et al.*, 2001). The fertilizer recommendation through soil test was highly recommendable, so the best suitable extractants for determination of plant available silicon which were standardized and adopted in different countries were presented below.

Acquaye and Tinsley (1965) used citric acid (0.1M) as an extractant in estimation of plant available silicon in soils and this extracts specifically adsorbed silicon apart from water soluble silicon. Similar results were also noticed by Sauer and Burghardt (2000).

Fox *et al.* (1967) compared several extractants to extract plant available Si from an oxisol of Hawaii. They found an increasing extraction capacity of different extractants in the following order: $\text{H}_2\text{O} \sim \text{CaCl}_2 \sim \text{Ca}(\text{NO}_3)_2 \sim \text{Ca}(\text{OAc})_2 < \text{MgSO}_4 < \text{Ca}(\text{H}_2\text{PO}_4) < \text{HOAc}$. It was noticed that Calcium phosphate extracted the greatest amount of Si in different soils of Hawaii.

Fox *et al.* (1967) and Khalid *et al.* (1978) used the water as extractant to determine the water soluble silicon fraction in soils. The weakest extractant after water was CaCl_2 , which only extracts the easily soluble Si fraction (Berthelsen *et al.* 2001). Haysom and Chapman, (1975) compared 0.01M CaCl_2 , 0.5M ammonium acetate, and 0.005 M sulphuric acid for their ability to extract plant available Si from soils and found that silicon extracted by CaCl_2 showed the highest correlation to sugarcane yield ($r^2 = 0.82^*$).

Imaizumi and Yoshida (1958), Ayres (1966) and Wong and Halis (1970) used acetate buffer solutions to extract plant available Si from soils. Snyder (2001) reported an acetic acid extraction, used at soil testing laboratory at the university of Florida everglades research and education center (EREC) as the standard method to analyze plant available Si in soils used for rice farming. Nonaka and Takahashi (1990) reported that acetate extraction was too strong

for soils previously fertilized with calcium silicate, because it dissolved a part of non available Si from the fertilizer.

Continuous shaking for 16 hours with 0.005M sulphuric acid dissolves specifically adsorbed Si from clay silicate minerals, so that the amount of plant available Si were overestimated (Hurney, 1973).

Nayar *et al.* (1977) compared N sodium acetate buffer (pH 4.0) with three other chemical extractants (distilled water, 0.2N HCl and 0.025 M citric acid) and it was found that extracting power of different extractants for Si as: 0.2N HCl > 0.025 M citric acid > N acetate buffer > water. Silicon extracted by citric acid showed better correlation with the Si uptake by the rice plants.

The phosphate anion was used to extract adsorbed Si from soils to assess plant available Si (Khalid *et al.*, 1978) in volcanic soils of Hawaii. Kato (1998) reported that in contrast to acetate buffer extraction, phosphate buffer did not over estimate the silicon availability in soils previously fertilized with silicates. Similar results were also noticed by Snyder (2001).

Korndorfer *et al.* (1999) evaluated four different extractants (0.5M acetic acid, NaOAc (pH 4.0), 0.01 M CaCl_2 and distilled water) and found that 0.5M acetic acid gave the best estimate for the available silicon in upland rice soils of Minas Gerais, Brazil.

Berthelsen *et al.* (2001) reported that CaCl_2 extracts the easily water soluble Si, and that of acetate, acetic acid and phosphate acetate dissolves some of exchangeable Si, while citric acid and sulphuric acid extracts specifically adsorbed Si. Since the latter two extracts were very acid and longer time of shaking resulted in over estimation of plant available silicon in soils.

Kato (1998) reported that the combination method of extraction of silicon by phosphate buffer solution after the incubation under submerged

condition was found to be the best method to estimate available silicon in paddy soils of Japan.

The silicon extracted by acetic acid was correlated to silicon uptake by rice and rice grain yield in soils of Florida (Snyder, 1991). The chemical method of extraction by using sodium acetate buffer (pH 4.0) was the most widely used extractant in Japan to measure available silicon in paddy soils (Imaizumi and Yoshida, 1958).

The silicon extracted with 0.5 M acetic acid appeared most suitable for evaluating Si availability, followed by extraction with citric acid at 1%. These methods provided the best correlations with rice straw and panicle Si percentage ($R^2 = 0.899^{**}$, $R^2 = 0.768^{**}$, and $R^2 = 0.839^{**}$, $R^2 = 0.774^{**}$ respectively). These methods, being rapid and effective in extracting Si in comparison to other methods, appear to be the most suitable for routine soil testing for Si in the Everglades Agricultural Area in South Florida. (Filho *et al.*, 2001).

Shigezumi *et al.* (2002) reported that extraction by using phosphate buffer solution was found to be superior over other methods of extraction of available silicon in soils of Japan.

The sodium acetate buffer extracted the greatest amounts of Si (0 to 509 mg kg⁻¹), followed by acetic acid (1 to 239 mg kg⁻¹) and calcium chloride (3 to 109 mg kg⁻¹) in organic and mineral soils of Florida. Acetic acid and sodium acetate buffer soil-test Si values were fairly well correlated ($r = 0.77$) and both methods performed well across a wide range of soils. Results with calcium chloride were poorly correlated with acetic acid ($r = 0.73$) and also poorly related to sodium acetate buffer ($r = 0.57$). After considering only the subset of soils testing at or below the critical value, the correlation ($r = 0.84$) between acetic acid and sodium acetate buffer extractions was improved (Rodrigues *et al.*, 2003).

Wang *et al.*, (2004) evaluated seven extractants viz., deionized (DI) water, 0.5 M acetic acid, 1 M sodium acetate buffer (pH 4.0), 0.5 M ammonium acetate (pH 4.8), 0.1 M hydrochloric acid, 0.5 M citric acid, and Mehlich -III, to determine plant available silicon in 30 Louisiana soils. The amount of extractable Si resulted from the use of different extractants was in the order of Mehlich III > citric acid > HCl > acetic acid > acetate buffer > NH₄OAc > DI water, as determined by colorimetry. Silicon extracted by different extractants was well correlated among citric acid, HCl, acetic acid, acetate buffer, and NH₄OAc ($R^2 = 0.611$; $P < 0.001$). Water and Mehlich III showed poor correlations with other extractants ($R^2 = 0.430$).

Extraction techniques for plant-available Si include extractions with water, CaCl₂, acetate, acetic acid, phosphate, H₂SO₃, H₂SO₄, and citrate. The extractants show different capabilities to desorb silicic acid, with H₂SO₃, H₂SO₄ and citrate having the greater extraction potential (Daniela *et al.*, 2006).

2.4 Uptake and accumulation of silicon in different rice genotypes

Van, (1980) reported active silicon uptake in the crops like rice, sugarcane and wheat. These crops were also considered as silicon accumulators since its A/M (Actual Si uptake/ mass flow supply of silicon) ratio was greater than unity. Ma *et al* (2001) noticed that the lateral roots contribute to the Si uptake in rice plant, but not root hairs.

The importance of genotypic (i.e. cultivar) variation in Si content of rice was investigated by Deren *et al* (1994). Both among and within cultivar genotypes, these investigators found a significant negative correlation between Si concentration and disease severity. However, the correlation was much stronger within genotypes than among genotypes. Similar genotypic trends were found by Winslow (1992) on Si deficient mineral soils of West Africa.

Ma *et al.* (2002) reported that the silicon concentration of barley grain showed large variation, ranging from 0 to 3600 mg kg⁻¹ in standard varieties (SV) and from 0 to 3800 mg kg⁻¹ in BCCAM barleys. The silicon concentration was much lower in hull-less barley than in hulled barley. The variation in Si concentration in plant species was largely due to efficiency of plant roots for Si acquisition (Takahashi and Hino, 1978). Genotypic variation in rice for Si supplementation was documented and its effects were found to enhance productivity (Savant *et al.*, 1997)

Ma *et al.*, (2001a) investigated the role of root hairs and lateral roots in the Si uptake using two rice mutants, defective in the formation of root hairs (RH2) and lateral roots (RM109). It was found that the lateral roots contribute to the Si uptake in rice plant, whereas root hairs do not. Analysis of F₂ populations between RM109 and Wild Type (WT) showed that Si uptake was correlated with the presence of lateral roots and genes controlling formation of lateral roots and Si uptake were dominant. Silicon uptake by GR1 was significantly lower than that by WT at both low and high Si concentrations. Concentration of silicon in the xylem sap of WT was 33-fold that of the external solution, but that of GR1 was 3-fold higher than the external solution at 0.15 mM Si. Uptake of silicon by WT was inhibited by metabolic inhibitors including NaCN and 2, 4-dinitrophenol and by low temperature, whereas Si uptake by GR1 was not inhibited by these agents (Ma *et al.*, 2002).

Rice showed highest uptake ability of silicon followed by wheat, sorghum, maize, rye and barley. A significant variation in silicon uptake capacity was noticed among rice genotypes at varied levels of silicon application (Ma and Tamai, 2002).

The difference in Si accumulation has been attributed to the ability of the roots to take up Si. Three different modes of Si uptake have been proposed for plants having different degrees of Si accumulation, viz., active, passive, and rejective processes of uptake. Plants with an active mode of uptake take up Si faster than water, resulting in the depletion of Si in the uptake solution. Plants

with a passive mode of uptake take up Si at a rate that is similar to uptake rate of water, thus, no significant changes in the concentration of Si in the uptake solution. By contrast, plants with a rejective mode of uptake tend to exclude Si, which is demonstrated by the increasing concentration of Si in the uptake solution (Liang *et al.*, 2005).

Liang *et al.* (2005) reported that the Si uptake and transport in Cucumber was active and independent of external Si concentrations, in contrast to the process in *Vicia faba*.

2.5 Optimum silicon in soils and plants for higher yields

Rice is a silicon accumulator plant. In order to produce 5 t ha⁻¹ of grain yield, normally 230 to 470 kg of Si is removed per crop from the soil and intensive rice cultivation without silicon fertilization contributing for declining or stagnating rice yield in many countries (Savant *et al.*, 1997). Calibrated soil test for a particular nutrient needed for plant growth and development will indicate the degree of deficiency of that nutrient and the amount of the nutrient to be applied as a fertilizer to correct the deficiency. Before a fertilizer recommendation can be made from a soil test, the soil analysis should be calibrated with crop response in the field or greenhouse.

Since 1955, Japanese farmers have increased and sustained average rice yield up to 6 t ha⁻¹ (IRRI, 1993). This could be due to adoption of a balanced integrated nutrient management that includes Si fertilization. Yield increase of 10-20% was common when Si was added and may exceed 30% or more when leaf blast was severe (Yoshida, 1981 & Savant *et al.*, 1997). Rice grown in South Florida on organic and sandy soils often has higher yields and less disease when fertilized with silicon (Datnoff *et al.*, 1997 and Savant *et al.*, 1997).

In India, though research on Si has been initiated long back, the available data is not adequate to make any recommendations for Si fertilization in rice farming (Prakash, 2002). Studies have indicated that irrigated rice varieties with greater Si content were lower in both leaf and neck blast. Upland rice, grown in a non flooded aerobic environment is also responsive to Si supplementation (Rabindra *et al.*, 1981).

Rice requires large amounts of Si for healthy plant growth and development. Under the warm sub humid tropical conditions of India, Si removed by 12 rice cultivars (90-140 days duration) grown on an Inceptisol during the dry season varied from 204 to 611 kg Si ha⁻¹ when grain yields ranged from 4.6 to 8.4 t ha⁻¹ (Nayar *et al.*, 1982a).

In 5 out of 9 soils (mostly belonging to red and laterite groups) studied, silicon content ranged from 8 to 83 ppm and considered to be highly deficient (Nayar *et al.*, 1982b).

Silicon depletion has been noticed with intensive cultivation of high yielding varieties in traditional rice growing soils of many countries, if farmers are not replacing the Si removed by rice. However, sustained high rice yields in Japan are most likely due to the widespread application of silicate slag at rates of around 1.5 to 2 t ha⁻¹ (Kono, 1969 & Takahashi *et al.*, 1990).

Relatively large amounts of plant available Si appears to be very important for both robust growth and fungal disease resistance of rice (Winslow, 1992 & Datnoff *et al.*, 1997, 2001). In terms of yield components, silicon increases the number of spikelets per panicle (Ma *et al.*, 1989; Deren *et al.*, 1994; Takahashi, 1995), spikelet fertility (Takahashi, 1995), and the mass of grains (Balastra *et al.*, 1989). Although many rice-growing soils initially contain significant quantities of Si, repeated rice cropping can reduce Si levels to the point that Si fertilization becomes beneficial for growth and disease resistance (Savant *et al.*, 1997).

Research conducted in 16 provinces of China (where rice is the most common grain crop) during 1979-1999 showed yield increases from 0 to 400 %, depending on the severity of Si deficiency (Wang *et al.*, 2004). The situation in China is particularly important because of its large land area in Asia, where most of the rice is grown, that is being treated with Si, and the potential for other areas. Si applications have beneficial impacts on rice yields in many areas of the world.

Korndorfer and Gascho (1998) observed that both soil and plant parameters were significantly affected by the Si sources and rates used. Difference in rice growth habit, plant height, and dry matter yield and leaf coloration were more favorable in treatments containing calcium silicate, wollastonite and thermo phosphate, when compared to other sources.

Optimum silicon in straw required for higher rice yields was 3.4 percent and classified as high when Si concentration was $>34 \text{ g kg}^{-1}$, medium when in between 17 and 34, and low when $<17 \text{ g kg}^{-1}$ based on the percent relative yield (Korndorfer *et al.*, 2001). If the percent relative yield is less than 75 considered to be low, between 75 to 95 considered to be medium and more than 95 percent is considered to be high in available soil and tissue Si (Cope and Rouse., 1973).

Snyder *et al* (1986) reported that approximately 30 g kg^{-1} of silicon (dry weight basis) needed for optimum production. In the absence of adequate silicon in soils, disease infestation was severe and decreased the grain yields. The soils containing 10 mg L^{-1} or less of acetic acid extractable silicon generally require silicon fertilizer to produce a maximum grain yield and those containing 25 mg L^{-1} of silicon or more generally do not require silicon fertilization (Snyder, 1991).

Rice based cropping system in India covers an area of about 44.6 M ha, which is associated with many soil related factors (Savant *et al*, 1997). Many reports in the literature suggested that depletion of plant available soil silicon in

soils where rice is intensively cultivated could be the possible soil related limiting factor contributing to declining rice yields (Nayar *et al.*, 1977, Chinnaswami and Chandrashekar, 1978, Savant *et al.*, 1997, Prakash, 2002, Mongia and Chhabra, 2001, Sadanandan and Vergeese, 1968 & Singh, 2003).

Silicon content of rice is higher than the “essential elements” like N, P and K (Takahashi 1995, Savant *et al.*, 1997). Si is the only element that does not damage the plant when accumulated in excess. The definition of essentiality does not hold good for Si as it does not supplement or substitute for any element, or show deficiency symptoms of its own. But it has been grouped under “beneficial” element as it has manifolds of positive effects on general health, growth and productivity of rice, barley, sugarcane etc. (Epstein, 1999 & Ma *et al.*, 2001b).

Numerous studies have shown that disease resistance of rice increases in response to Si fertilization in soils (Savant *et al.*, 1997). Silicon has been shown to suppress fungal diseases such as rice blast (*Magnaporthe grisea*, teleomorph; *Pyricularia grisea*, anamorph), brown spot (*Cochliobolus miyabeanus*, teleomorph; *Bipolaris oryzae*, anamorph), leaf scald (*Gerlachia oryzae*), sheath blight (*Rhizoctonia solani*, teleomorph), stem rot (*Sclerotium oryzae*, teleomorph), and a complex of fungal and bacterial pathogens that cause grain discoloration (Datnoff *et al.*, 1991, 1992 & 1997; Seebold, 1998 & Winslow, 1992) both under lowland and upland growing conditions.

The yield increase through Si application was largely attributed to advantage gained in grain filling and grain weight because of better translocation of photosynthates (Rani and Narayanan., 1994 and Rani *et al.*, 1997).

Silicon fertilization has also been shown to significantly decrease fungal disease susceptibility of rice grown on the highly-weathered and Si deficient upland mineral soils of West Africa (Winslow, 1992). A similar pattern was

also found on highly weathered savannah soils in Columbia (Datnoff *et al.*, 1997).

The genotypic differences among rice were mainly explained by their ecotypic affinities, those belonging to the tropical japonica ecotype exhibited 93% higher husk Si concentrations than indica ecotypes (Winslow *et al.*, 1997).

Adequate levels of Si in plant controls rice blast thus minimizing the usage of fungicides, and providing positive environmental benefits (Seebold, 1998 & Seebold *et al.*, 2000). Silicon concentration and husk discoloration observed in upland rice cultivars shown to have negative correlation (Winslow *et al.*, 1997). Brown spot disease was reported to be severe in the absence of adequate Si. In resistant rice genotypes, Si helps in blocking fungal penetration through synthesis of organic-Si complexes and also formation of physical barrier of hydrated silica beneath the cuticle of the epidermis (Ishiguro, 2000).

Korndorfer *et al* (2001) reported that the critical level for silicon was 19 mg L⁻¹ in Florida soils as calculated by Cate and Nelson (1971) procedure. The amount of silicon necessary to correct silicon deficiency in the soil and to obtain optimum rice yield was 1500, 1120 and 0 kg ha⁻¹ for low, medium and high level in the soils respectively.

Korndorfer *et al.* (2001) reported that there was an average increase of 1007 kg ha⁻¹ in grain yield due to the application of Si in the form of Calcium silicate. Faria (2000) noticed a linear increase in rice yield (20%) as a function of calcium silicate as silicon source applied to rice fields.

Beneficial effects of Si have been demonstrated for many plant species, especially when these plants are submitted to stress (Takahashi, 1995; Faria, 2000; Datnoff *et al.*, 2001). The role played by Si in the plants can be linked to a reduction in the toxic effects of aluminum, manganese and iron. It is also responsible for regulating transpiration, which is the likely reason for the resistance shown by many plant species to water deficit conditions. Further it

helps in protecting the plants against pest and diseases (Cocker *et al.*, 1997, Ma *et al.*, 1997; Datnoff *et al.*, 2001).

Brown spot disease was reported to be severe in the absence of adequate Si. In resistant rice genotypes, Si helps in blocking fungal penetration through synthesis of organic-Si complexes and also formation of physical barrier of hydrated silica beneath the cuticle of the epidermis (Ishiguro, 2000).

It was shown that sugarcane productivity increased from 17 to 30 %, whereas production of sugar rose from 23 to 58% with increasing Si fertilization. One of the most important functions of Si was the stimulation of the plant's defense abilities against abiotic and biotic stresses. Literature data demonstrated that improved sugarcane nutrition brought about by fertilization with Si was shown to reinforce the plant's protection properties against leaf freckle, sugarcane rust, and sugarcane ring spot. In addition, Si fertilization has a more positive effect than liming on the chemical and physical properties of the soil. (Matichenkov and Calvert, 2002).

The importance of silicon in rice cultivation has been noticed in some countries like Japan, USA, Phillippines, Brazil, Korea, and Thailand. However, there is no national database on silicon availability in Indian soils although it's available in other rice growing countries in the world (Prakash, 2002).

Soluble silicon (Si) has enhanced the growth and development of several plant species including rice, sugarcane, and most other cereals crops. Researchers at the University of Florida conducted experiments to determine if bermudagrass can accumulate silicon and if silicon could enhance host plant resistance to *Bipolaris cynodontis*, the causal organism of leaf spotting and melting out of bermudagrass. There was a significant linear increase in silicon accumulated in the leaves of bermudagrass as the rate of calcium silicate amended to the soil increased. Silicon also was very effective in suppressing leaf spot development on bermudagrass caused by *B. cynodontis*. The percent leaf spot severity was reduced by 38.9% compared to untreated controls. These

results suggest that when soils low or limiting in plant available silicon are amended with a soluble source of silicon, the resistance of Bermuda grass against leaf spotting caused by *B. cynodontis* can be enhanced. It was also suggested that fungicides could be better managed if used in combination with silicon for controlling diseases in turf. (Datnoff and Rodrigues, 2003).

Plant dry weights for inoculated plants increased as the Si rates increased from 0 to 1.92 g pot⁻¹. The greatest dry weight increase was observed in plants inoculated with Si at booting and panicle exertion stages. Si fertilization was considered as promising method for controlling sheath blight in areas where soils were Si deficient (Rodrigues *et al.*, 2003).

2.6 Interaction of silicon with nitrogen and other nutrient elements

The silicon was found to be positive interaction with the applied nitrogenous (N), phosphatic (P) and potassic (K) fertilizers. Available review in relation to interaction effect of silicon with nutrient elements and nitrogen in particular is given below.

Idris *et al.* (1975) reported that application of silicon significantly increased the rigidity of rice stalk and this increase was remarkably higher at lower doses of nitrogen. The larger quantities of nitrogen greatly reduced the efficiency of silicon in imparting rigidity to plants.

The rice yields are declining due to the excessive application of nitrogenous fertilizers. But the application of Si has the potential to raise the optimum N rate due to synergistic effect, thus enhancing the productivity of low land rice soils (Kono, 1969 & Ho *et al.*, 1980). Application of N tends to decrease Si uptake in rice, and fertilizers containing NH₄⁺-N may decrease it more than NO₃⁻-N (Kono and Takahashi, 1958 & Wallace, 1989).

Fertilizing with excessive N tends to make rice leaves droopy, whereas Si keeps them erect. Yoshida (1981) reported that 10 percent increase in the photosynthetic rate due to improved erectness of leaves by proper silicon management and consequently a similar increase in yield.

Salt accumulation is known to be detrimental to photosynthetic gas exchange in rice leaves, reduced sodium uptake mitigated by Si, cause enhancement in photosynthetic rate. Addition of Si significantly reduced leaf sodium concentration and increased both assimilation rate and stomatal conductance and increased transpiration. Further, with the addition of Si, increased stomatal conductance in some rice genotypes viz., GR-4 > IR- 36 > CSR-10 was observed even in presence of salt (Mongia and Chhabra, 2000).

Nitrogen is the most common nutrient that limits rice production. Deficiency symptoms are frequently characterized by general chlorosis (yellowing) of leaves and a reduction in overall plant vigor and growth. At flowering, N deficient plants are stunted and have fewer tillers and smaller heads than healthy plants. Grain yield reduced primarily through a reduction in panicles. Nitrogen is essential for plant growth and development, and was often a limiting factor for high productivities. However, when applied in excess it may limit yield because of lodging, especially for cultivars of the traditional and intermediate groups, and promote shading and disease problems. These effects could be minimized by the use of silicon (Ma *et al.*, 2001).

The effect of Si on pre-infection and post-infection physiological plant response has unlimited prospects for blast control at the vegetative phase. The ratio of N/Si plays an important role in the incidence of rice blast, leaf scald and sheath blight (Prabhu *et al.*, 2001).

Munir *et al* (2003) reported that nitrogen fertilization increased the number of stems and panicles m⁻² and the total number of spikelets, reflecting on grain productivity. Excessive tillering caused by inadequate nitrogen fertilization reduced the percentage of fertile stalks, spikelet fertility and grain

mass. Silicon fertilization reduced the number of blank spikelets per panicles and increased grain mass. Similar kind of results were noticed by Yoshida *et al.*, (1969) in rice growing soils of Japan and noticed that the leaf erectness decreased with increasing N application, but silicon application increases the leaf erectness, decreases mutual shading caused by dense planting and high N application. Excess N also increases susceptibility to various diseases in rice but silicon decreases the occurrence of diseases in rice.

The dry matter accumulated at ripening stage of 30 rice genotypes, linearly increased with increased accumulation at both early and late season (Jiang *et al.*, 2004). Nitrogen, Phosphorus, Potassium and Silicon accumulated at the rate of 3.76:1:4.55:7.10 at early season and 2.88:1:4.54:8.09 at late season. Silicon was largely distributed in stem and leaf sheath at early season but distributed largely in panicle at late period.

Silicon and nitrogen interaction was found to be non significant in obtaining higher yield of rice. But increased application of Si and N alone resulted in significant increase in yield attributes except test weight (Singh and Singh. 2005 and Singh *et al.*, 2006).

*Materials
and
Methods*

III. MATERIALS AND METHODS

The present investigation was undertaken to study the calibration and categorization of soil and plant silicon for higher rice yields in soils of Karnataka. The details of the methods and procedures used in various experiments are described in this chapter.

3.1 Soil sampling for available silicon status of rice growing soils.

To know the available silicon status in different rice growing soils, forty representative soils were collected from each location i.e., Mangalore (*Typic Kandiusults*), Ponnampet (*Ustic Palehumults*) and Mudigere (*Ustic Paleustults*). The details of the sampling areas are presented in Table 1 and Fig. 1. The samples were air dried, hand pounded and stored in polyethylene bags. The physical and chemical properties, available silicon were estimated as per standard procedures given in Table 2 and 5. The soils were categorized as low, medium and high based on the plant available soil silicon status (Korndorfer *et al.*, 2001).

3.1 Evaluation of different extractants for plant available silicon in rice soils.

3.2.1 Soil sample collection and different extractants

Eighteen surface (0-30cm) soils were collected in bulk from different locations viz., Mangalore (*Typic Kandiusults*), Mudigere (*Pale ustults*) and Ponnampet (*Ustic Palehumults*) based on the initial soil available silicon content. The details of the bulk samples collected are presented in Table 3. After processing, soils were subjected to analysis of available silicon by using ten different extractants viz., 0.5M NH₄OAc (Fox *et al.*, 1967), N NaOAc (pH 4.0) (Korndorfer *et al.*, 1999), N NaOAc (pH 4.0) (Imaizumi and Yoshida, 1958) 0.5M acetic acid (Snyder, 2001), acetic acid (Korndorfer *et al.*, 1999), acetic acid (Snyder, 1991), 0.01M CaCl₂ (Korndorfer *et al.*, 1999), water (Khalid *et al.*, 1978), 0.1 M citric acid (Acquaye and Tinsley, 1965) and H₂SO₄ (Hurney, 1973) by adopting standard procedures given in Table 4.

3.2.2 Greenhouse experiment

Based on the initial plant available soil Si content, six soils (two samples each from low, medium and high category in plant available soil Si content) from each locations of Mangalore (*Typic Kandiusults*), Mudigere (*Paleusults*) and Ponnampet (*Ustic Palehumults*) were selected for bulk soil sampling. A greenhouse pot culture study was conducted at K-Block, UAS, GKVK, Bangalore, during summer 2007. The treatment details are given below.

Number of soils	: 18
Condition	: Submergence
Number of replications	: 03
Rice variety/ hybrid	: KRH-2
Recommended NPK	: 100:50:50 kg ha ⁻¹
Season	: Summer 2007

Six kilograms of soil was taken in each plastic pot and submerged condition was maintained. Two seedlings (twenty one day old) of rice variety KRH-2 were transplanted per pot and recommended doses of NPK were applied. Regular plant protection practices were taken up besides maintaining the submergence level throughout the crop period. The straw and grain yield were recorded at the time of harvesting and expressed in g pot⁻¹. The uptake of silicon by rice crop in each pot was also determined after analyzing the straw and grains for silicon concentration.

Simple correlations were worked out between available Si extracted by different extractants and percent yield response as well as silicon uptake by grain and straw from check pots (pots receiving no silicon fertilizers) to evaluate the most suitable or best extractants for assessing silicon availability in the rice soils (Rodrigues *et al.*, 2003).

3.3 Calibration and categorization of plant available silicon for rice

Based on the initial available soil Si content, six bulk soil samples (two samples each from low, medium and high category in available Si content) from each of the three locations viz., Mangalore (*Typic Kandiusults*), Mudigere (*Paleusults*) and Ponnampet (*Ustic Palehumults*) were collected from 0 to 30 cm depth. A greenhouse pot culture study was conducted at K-Block, UAS, GKVK, Bangalore, during summer 2007. The details of the bulk samples collected and initial soil properties were presented in Table 3. The treatment details are given below.

Number of soils	: 18
Condition	: Submergence
Silicon levels	: 4 (0, 483, 966, 1448 kg ha ⁻¹ of Si as calcium silicate)
Number of replications	: 03
Rice variety	: KRH-2
Recommended NPK	: 100:50:50 kg ha ⁻¹
Season	: Summer, 2007

Six kilograms of soil was taken in each plastic pot and calculated quantity of graded levels of Si in the form of calcium silicate was applied, mixed properly and submerged condition was maintained 10 days before transplanting rice seedlings. Two seedlings of twenty one day old rice variety KRH -2 were transplanted per pot and recommended doses of NPK were applied as per the package of practices.

The uptake of silicon by the crop in each pot was also determined after analyzing the straw and grains for silicon concentration. Critical levels of available silicon for higher grain and straw yields was calculated by adopting the Cate and Nelson (1965 and 1971) procedure by plotting relative yield against silicon levels in soils and fitting a regression curve (Korndorfer *et al.*, 2001) and categorization of soil test values into low, medium and high were made by adopting the Cope and Rouse (1973) procedure.

The critical limits of soil and plants for higher yields were calculated in a graphical method by plotting the soil available Si extracted by different extractants on X- axis and relative yield on the Y- axis. A transparent overlay with a vertical line and an intersecting horizontal line so, as to maximize the number of points in the first and third quadrants and minimum number of points in the second and fourth quadrants. The soil test value corresponding to the location was taken as critical value for Si (Cate and Nelson, 1965 and 1971).

The plant and soil Si was categorized into low, medium and high by developing calibration curve between available Si extracted by different extractants with relative yield and the samples which falls below 75 percent relative yield were considered to be low, those which falls between 75 and 95 percent as medium and samples which falls above 95 percent relative yield were considered as high (Cope and Rouse, 1973).

3.4 Genotypic variation for evaluating silicon accumulation in different rice genotypes

3.4.1 Bulk soil sampling

Surface (0-30cm) soils were collected in bulk from rice fields of Agriculture Research Station, Kankanadi, Mangalore (*Typic Kandiusults*) and Zonal Agricultural Research Station, Mudigere (*Ustic Paleusults*). The soils were processed and analyzed for physicochemical properties and available silicon following standard procedures as given in Table 2 and Table 4. The initial soil properties are presented in the Table 3.

3.4.2 Greenhouse experiment

The green house study was conducted at K- Block, UAS, GKVK, Bangalore during *Kharif* 2006 with the elite lines of aerobic rice and others collected from the Department of Genetics and Plant Breeding, UAS, GKVK, Bangalore. The treatments details are given below:

Number of soils : 02

Number of silicon levels	: 02 (0 and 966 kg ha ⁻¹ of Si as CaSiO ₃)
Number of genotypes	: 04 (Rasi, BI-33, BI-43 and IRRI 49)
Conditions	: 02 (Aerobic and submergence)
Number of stages	: 03 (Maximum tillering, Flowering and Harvesting)
Recommended NPK	: 100:50:50 kg ha ⁻¹
Experimental design	: CRD factorial
Replications	: 03

After processing, five kilograms of soil was filled in the plastic pots for analysis at flowering and harvesting stage and four kilograms of soils for analysis at maximum tillering stage and calculated quantity of Si as calcium silicate was applied before 10 days of transplantation/sowing of rice seedlings/seeds. Two seedlings (21 days old) of rice varieties BI-43, BI-33, Rasi and IRRI- 49 were planted per pot. Recommended amount of fertilizers (NPK) were added as per the package of practices. Water was regularly added to the pots to maintain the submergence condition throughout the growth period. For aerobic rice condition, two seeds of rice varieties BI-43, BI-33, Rasi and IRRI- 49 were sown per pot. The pots were regularly irrigated once in 4 to 5 days to maintain the aerobic condition of the soil. The biometrical observations like plant height, number of tillers were recorded from each pot at respective growth stages before harvesting. The straw and grain samples that were collected from each pot at different growth stages were dried in oven at 70°C for 48 hours. The dry weight of each genotype was recorded. The samples were powdered using grinder and analyzed for Si adopting standard procedure (Ma *et al.*, 2001). The data obtained were subjected to statistical analysis for judging the Si accumulation at different growth stages by different genotypes.

3.5 Silicon and Nitrogen interaction on growth and yield of wetland rice

To study the effect of Si and N on the growth and yield of rice, field experiments were conducted at Ponnampet (*Ustic Palehumults*) and Mudigere

(Ustic *Paleustults*) during *Kharif* 2005 using KRH -2 hybrid rice. The treatment details are as follows.

Locations	: 02 (Ponnampet and Mudigere)
Si Levels	: 03 (0 (S1), 117 (S2) and 234 (S3) kg ha ⁻¹ of Si as CaSiO ₃)
N Levels	: 03 (50 (N1), 100 (N2) and 150 (N3) N kg ha ⁻¹ as urea)
Plot Size	: 5 x 4 m ²
Experimental design	: RCBD factorial
Replications	: 03
Variety	: KRH- 2
Season	: <i>Kharif</i> 2005

One week before transplanting of rice seedlings, the calculated quantity of Si as calcium silicate was applied to each plot (5 x 4 m²). Fifty percent of the calculated N and full dose of P and K were applied at the time of planting. The remaining 50 percent N was applied at two equal splits after 25 and 45 days of transplanting. The biometrical observations like plant height, number of tillers, spikelet sterility and insect pests (leaf roller, case worm, blue beetle and hispa) and diseases (leaf blight, brown leaf spot and bacterial leaf blight). The grain and straw yield of each treatment were recorded and expressed in kilograms per hectare. The grain and straw samples of each treatment were drawn, powdered and subjected to analysis of Si as outlined by Ma *et al.* (2002) and N by using CHNS analyzer. Samples were analyzed in duplicate and mean value was calculated. The uptake of Si and N in grain and straw and Si harvest index were calculated using standard formulae given by Fageria and Filho (2001). Statistical analysis was carried out to judge the effect of Si and N and their interaction on growth and yield of rice. The soil samples were collected before start of the experiment from both the locations and analyzed for physico chemical properties by adopting standard procedures given in Table 2 and Table 4. The data pertaining initial soil properties of the experimental locations of *Kharif* 2005 are given in Table 5. The experimental layout of the field experiments of Mudigere and Ponnampet are given in Fig. 2a and 2b respectively.

The insect pests (leaf roller, case worm, blue beetle and hispa) and diseases (leaf blight, brown leaf spot and bacterial leaf blight) were scored by adopting the standard procedures given by Amaresh and Nargund (1996) and Wang *et al.* (2007), respectively.

3.6 Determination of silicon in soil samples

3.6.1 Extraction of silicon in soils

Silicon in soils was extracted using different extractants, the details of which are given in Table 4.

3.6.2 Estimation of silicon in soils

Silicon in the extracting solution was determined by transferring 0.25 ml of filtrate into plastic centrifuge tube and then added with 10.5 ml of distilled water, plus 0.25ml of 1:1 hydrochloric acid, and 0.5ml of 10% ammonium molybdate solution (pH 7-8). After allowing for 5 minutes, 0.5 ml of 20% tartaric acid solution was added. After allowing for additional two minutes, 0.5ml reducing agent (ANSA) was added. After 5, but not later than 30 minutes following addition of the reducing agent, absorbance was measured at 630 nm using UV visible Spectrophotometer (Chemito). Simultaneously Si standards (0.2, 0.4, 0.8 and 1.2 mg l⁻¹) prepared in the same matrix were also measured using UV visible spectrophotometer (Korndorfer *et al.*, 2001).

3.7 Determination of silicon in plant samples

3.7.1 Plant sample digestion

The powdered grain and straw samples were dried in an oven at 70° C for two days prior to analysis. The sample (0.5g) was digested in a mixture of 3 mL each of HNO₃ (62%) and H₂O₂ (30%) and 2 mL of HF (46%) using microwave digester (Milestone MLS 1200) with following steps: 250 watt for 5 minutes, 500 watt for 5 minutes and venting for 5 minutes. The digested samples were diluted to 50 mL with 4 % boric acid (Ma *et al.*, 2002).

3.7.2 Estimation of silicon in plant samples

The Si concentration in the digested solution was determined as described below: 0.5 ml of digested aliquot was transferred to a plastic centrifuge tube, to this 3.75 mL of 0.2N HCl, 0.5 mL of 10 % ammonium molybdate ((NH₄)₆Mo₇O₂₄) and 0.5 mL of 20 % tartaric acid and 0.5 mL of reducing agent (Amino naphthol sulphonic acid - ANSA) was added and the volume was made up to 12.5 mL with distilled water. After one hour, the absorbance was measured at 600 nm with a UV- visible Spectrometer (Chemito) (Ma *et al.*, 2002). Similarly, standards (0, 0.2, 0.4, 0.8 and 1.2 ppm) were prepared by following the same procedure.

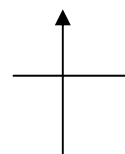
3.8 Source of silicon

Calcium silicate obtained from Excel Minerals, USA was used for the study of calibration and budgeting of Si in rice and for evaluation of genotypes for accumulation of Si under different moisture regimes. The Calcium silicate includes 30 % of Ca, 7% of Mg and 12% of Si. Calcium silicate obtained from Kashima keisan Co. Ltd., Japan was used for the field experiments to know the effect of Si and N interaction on growth and yield of rice. The calcium silicate includes 14.02% of Si (0.2M HCl soluble).

3.9 Statistical analysis

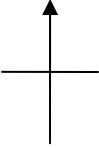
Experimental data were analyzed using analysis of variance method. All the main and interaction effects were tested at 5 percent level of significance (Sundarraj *et al.*, 1972). The correlation and regression coefficients were worked out and the results were reported at 5 and 1 percent level of significance (Sundarraj *et al.*, 1972 and Rodrigues *et al.*, 2003).

R I	R II	R III
S ₀ N ₁	S ₂ N ₃	S ₁ N ₁
S ₂ N ₂	S ₁ N ₃	S ₁ N ₂
S ₀ N ₂	S ₁ N ₁	S ₂ N ₃
S ₁ N ₃	S ₁ N ₂	S ₀ N ₂
S ₁ N ₁	S ₀ N ₁	S ₁ N ₃
S ₂ N ₃	S ₀ N ₂	S ₀ N ₁
S ₁ N ₂	S ₀ N ₃	S ₂ N ₁
S ₀ N ₃	S ₂ N ₁	S ₂ N ₂
S ₂ N ₁	S ₂ N ₂	S ₀ N ₃



Note: S₀:0 kg Si ha⁻¹ as calcium silicate, N₁: 50 kg N ha⁻¹ as urea
S₁:117 kg Si ha⁻¹ as calcium silicate, N₂: 100 kg N ha⁻¹ as urea
S₂:234 kg Si ha⁻¹ as calcium silicate, N₃: 150 kg N per ha⁻¹ as urea

Fig.2a: Field experimental layout of Ponnampet *kharif*-2005

R III	R II	R I	
S ₀ N ₃	S ₂ N ₁	S ₀ N ₁	
S ₁ N ₃	S ₁ N ₁	S ₁ N ₃	
S ₂ N ₁	S ₁ N ₃	S ₀ N ₂	
S ₁ N ₂	S ₂ N ₂	S ₂ N ₁	
S ₀ N ₁	S ₁ N ₂	S ₀ N ₃	
S ₂ N ₂	S ₀ N ₁	S ₂ N ₂	
S ₁ N ₁	S ₂ N ₃	S ₁ N ₁	
S ₂ N ₃	S ₀ N ₂	S ₂ N ₃	
S ₀ N ₂	S ₀ N ₃	S ₁ N ₂	

Note: S₀:0 kg Si ha⁻¹ as calcium silicate, N₁: 50 kg N ha⁻¹ as urea
S₁:117 kg Si ha⁻¹ as calcium silicate, N₂: 100 kg N ha⁻¹ as urea
S₂:234 kg Si ha⁻¹ as calcium silicate, N₃: 150 kg N per ha⁻¹ as urea

Fig.2b Field experimental layout of Mudigere *kharif*-2005

Table 1 General information of soil sampling locations

Sl No	Mangalore*	Ponnampet*	Mudigere	Cropping system
1	Kankanadi-1	RG Village	Bijuvalli-1	R
2	Kankanadi-2	Betuvally-1	Bijuvalli-2	R
3	Kankanadi-3	Betuvally-2	Bijuvalli-3	R
4	Kankanadi-4	Beguvally-3	Halase	R
5	Kankanadi-5	B. guntahalli-1	Dhundige-1	G-R-R
6	Gurupur-1	b. guntahalli-2	Dhundige-2	G-R-R
7	Gurupur-2	Peramboor-1	Dhundige-3	G-R-R
8	Madhuperari-1	Peramboor-2	Dhundige-4	R
9	Madhuperari-2	Bittangala	Bidarahalli-1	R-G
10	Yadapadavu-1	Balagod-1	Bidarahalli-2	R
11	Yadapadavu-2	Balagod-2	Bidarahalli-3	R
12	Malali-1	Balagod-3	Bidarahalli-4	R
13	Malali-2	Balagod-4	Bidarahalli-5	R-G-B
14	Polali	Bittangala-1	Bidarahalli-6	R
15	Kinnibettu-1	Bittangala-2	Nirgandi-1	R
16	Kinnibettu-2	Bittangala-3	Nirgandi-2	R
17	Kinnibettu-3	Bittangala-4	Horati-1	R
18	Kinnibettu-4	Bittangala-5	Phalguni-1	R
19	Thumbe	Bittangala-6	Phalguni-2	G-R
20	Arakula	Bittangala-7	Phalguni-3	G-R
21	Jentimar1	Kolthodu-1	Kottigehar-1	R
22	Jentimar-2	Kolthodu-2	Kottigehar-2	R
23	Pailoti	Arthur-1	Kottigehar-3	R
24	Voga	Arthur-2	Kottigehar-4	R
25	Guruvayanakere-1	Kunda-1	Banakal-1	R
26	Guruvayanakere-2	Kunda-2	Banakal-2	R
27	Guruvayanakere-3	Kunda-3	Sabli gram-1	G-R
28	Belthangidi-1	Kunda-4	Sabli gram-2	R
29	Belthangidi-2	Kunda-5	Phalguni	R
30	Belthangidi-3	Halligattu-1	Bagasgud	R
31	Ujire-1	Halligattu-2	Anjur-1	G-R
32	Ujire-2	Begurkolli-1	Anjur-2	R
33	Ujire-3	Begurkolli-2	Anjur-3	G-R
34	Kalle-1	Begurkolli-3	Gonibeedu-1	R
35	Kalle-2	Begurkolli-4	Gonibeedu-2	R
36	Kalle-3	Hudikere-1	Maribayalu-1	R
37	Kalle-4	Hudikere-2	Maribayalu-2	R
38	Kalle-5	ARS-P-1	Maribayalu-3	R
39	Kalmanja-1	ARS-P-2	ARS-1	R
40	Kalmanja-2	ARS-P-3	ARS-2	R
41	Kalmanja-3	ARS-P-4	ARS-3	R
42	Kalmanja-4	ARS-P-5	ARS-4	R

* Cropping system both at Mangalore and Ponnampet are R- R

R – Rice, G –Ginger and B- Banana

Table 2 Methods of soil analysis

Sl No	Parameter	Procedure	Method & Reference
1	Particle size analysis	Soil was predigested with H_2O_2 , dispersed with sodium hexa metaphosphate, sand with decantation procedure, silt and clay in the suspension was measured after pipetting with Robinson pipette.	International Pipette Jackson (1973)
2	Soil reaction	Soil : water suspension (1:2.5) was measured for pH using potentiometer after standardsing with appropriate buffers.	Potentiometry Jackson (1973)
3	Electrical conductivity	Soil : water extract (1:2.5) was measured for EC using conductivity bridge.	Conductometry Jackson (1973)
4	Organic carbon	Soil was digested with $\text{K}_2\text{Cr}_2\text{O}_7$ and concentrated H_2SO_4 , the unutilized $\text{K}_2\text{Cr}_2\text{O}_7$ was back titrated against ferrous ammonium sulphate using diphenyl amine.	Wet oxidation Walkley and Black (1934)
5	Total carbon/ Total nitrogen	Soil combustion at about 950°C in CHNS analyzer and total carbon and total nitrogen was quantified using EDTA as standard.	Dry Combustion CHNS
6	Available nitrogen	Soil was oxidized and distilled with alkaline potassium chromate and then titrate against standard acid using mixed indicator.	Subbaiah and Asija (1949)
7	Available	Soil was extracted with Brays - I and	Brays & Kurtz,

	Phosphorus	estimation by spectrophotometer at 660 nm.	(1945)
8	Available Potassium	Extract the soil with 1 N (pH 7) ammonium acetate and K was estimated with flame photometer.	Flame photometry Jackson (1973)
9	Available Sulphur	Extract the soil with 1 N Sodium Acetate (pH 8.5), sulphur was precipitated with BaCl_2 + gum acasia and the turbidity was measured at 420 nm.	Turbidometry Jackson (1973)
10	Exchange Acidity	Soil was extracted with 1 N KCl, the exchange acidity was measured by titrating with standard sodium hydroxide using phenolphthalein as an indicator.	Titrimetry Baruah and Barthakur (2000)

Table 3 Initial soil properties of the bulk samples used in greenhouse study during *summer* 2007

Sl No	Sample No*	pH (1:2.5)	EC (ds/m)	OC (g kg ⁻¹)	Total C (g kg ⁻¹)	Total N (%)	Av. P (ppm)	Sand (%)	Silt (%)	Clay (%)	Acidity (c mol(p+) _{kg} ⁻¹)	Si (ppm)	
												NH ₄ OAc	Acetic acid
Mangalore													
1	1	4.9	0.11	16.5	22.3	0.08	31.2	72.0	16.5	11.5	0.02	15.7	26.2
2	4**	5.0	0.07	24.6	26.4	0.09	34.5	69.8	14.9	15.3	0.04	8.1	27.2
3	15	5.1	0.12	15.6	21.1	0.08	28.6	75.1	15.6	9.3	0.02	22.1	43.3
4	18	5.2	0.06	17.7	23.0	0.07	29.6	67.4	19.5	13.1	0.04	18.4	32.2
5	32	5.4	0.07	16.5	21.9	0.08	32.4	66.4	17.6	16.0	0.04	41.7	48.3
6	33	4.9	0.06	15.3	20.7	0.08	25.4	70.0	16.2	13.8	0.05	45.6	43.2
Mudigere													
7	35	4.9	0.04	9.3	15.5	0.06	26.5	49.5	21.5	29.0	0.32	9.7	15.9
8	40**	5.0	0.04	13.5	10.7	0.02	22.5	54.0	18.9	27.1	0.26	10.9	17.3
9	17	4.8	0.05	9.3	12.9	0.05	30.2	57.0	16.5	26.5	0.48	20.2	41.0
10	19	4.4	0.05	11.4	18.5	0.06	24.3	62.0	14.0	24.0	0.42	26.5	25.3
11	11	5.0	0.05	13.2	20.2	0.05	19.6	45.3	22.3	32.4	0.23	41.7	47.2
12	33	4.5	0.09	7.1	25.2	0.08	18.1	47.3	20.6	32.1	0.13	43.7	71.2
Ponnampet													
13	27	4.6	0.04	6.3	15.5	0.02	16.4	75.5	13.0	11.5	0.16	7.3	16.8
14	40	4.9	0.07	9.6	13.5	0.04	17.9	71.2	16.3	13.5	0.17	16.5	19.8
15	19	4.9	0.08	9.0	12.9	0.06	18.3	78.4	12.0	8.6	0.20	23.8	38.6
16	24	5.1	0.07	7.5	13.2	0.05	18.9	73.0	15.3	12.7	0.15	23.8	34.2
17	5	5.0	0.02	7.2	17.0	0.08	15.8	76.0	14.2	10.8	0.04	54.9	74.2
18	6	5.1	0.09	10.2	21.6	0.12	16.9	72.5	13.2	15.3	0.07	41.5	73.0

* Sample number details are given in Table 1

** Samples used for evaluation of rice genotypes under different moisture regimes (Objective 4)

Table 4 Initial soil properties of the experimental site during *kharif* 2005

Sl No	Soil Properties	Ponnampet	Mudigere
1	pH	4.93	4.28
2	EC (ds m ⁻¹)	0.12	0.16
3	OC (g kg ⁻¹)	3.45	18.60
4	Sand (%)	79.19	43.55
5	Silt (%)	12.70	23.15
6	Clay (%)	8.11	33.3
7	Textural class	Sandy loam	Clay loam
8	Av. N (kg ha ⁻¹)	176	442.4
9	Av. P (ppm)	16.99	6.91
10	Exch. Ca (c mol(p ⁺)kg ⁻¹)	2.45	3.15
11	Exch. Mg (c mol(p ⁺)kg ⁻¹)	1.38	2.45
12	Av. S (ppm)	15.06	12.6
13	CEC (c mol (p ⁺)kg ⁻¹)	21.6	22.4
14	BS (%)	26.9	41.1

Table 5 Different extractants and procedures used for evaluating plant available silicon in different soils

Sl No	Extractants	Soil : solution ratio	Shaking period	Reference
1	0.5 M acetic acid-1	1:10	Shaking 1 hr and 12 hrs resting	Snyder (1991)
2	0.5 M acetic acid-2	1:10	1 hr	Korndorfer <i>et al.</i> (1999)
3	0.5M acetic acid-3	1:2.5	Overnight resting and then shaking for 2 hrs	Snyder. (2001)
4	0.01M CaCl ₂	1:10	1 hr	Korndorfer <i>et al.</i> (1999)
5	Distilled water-1	1:10	1 hr	Korndorfer <i>et al.</i> (1999)
6	Distilled water -4	1:10	4 hrs	Khalid <i>et al.</i> (1978)
7	0.5 M NH ₄ OAc (pH 4.8)	1:10	1 hr	Fox <i>et al.</i> , (1967)
8	N NaOAc-1 (pH 4.0)	1:10	1 hr	Korndorfer <i>et al.</i> (1999)
9	N NaOAc-4 (pH 4.0)	1:10	Occasional shaking for 5 hrs	Imaizumi and Yoshida (1958)
10	0.1M citric acid	1:50	Shaking for 2 hrs, resting for overnight and then shaking for 1 hr	Acquaye and Tinsley (1965)
11	0.005 M H ₂ SO ₄	1:200	16 hrs	Hurney (1973)

* after shaking, centrifuged for 2 minutes at 6000 rpm using Eppendorf centrifuge 5180 and filtered.

Experimental Results

1V. EXPERIMENTAL RESULTS

The results of the investigation on the Si status and various other aspects of study viz., evaluation of best suitable extractants, development of critical limits of plant and soil Si, Si acquisition capacity of different rice genotypes under different moisture regimes and interaction effect of Si and N on the growth and yield of rice in certain rice growing acid soils of Karnataka are presented in this chapter under the following headings:

- 4.1 Available Si status of certain rice growing acid soils of Karnataka
- 4.2 Evaluation of different extractants for available Si in rice soils
- 4.3 Critical limits of plant and soil Si in rice
- 5.3 Evaluation of genotypic difference in relation to Si accumulation under different moisture regimes
- 4.5 Effect of Si, N and their interaction on growth and yield of rice

4.1 Plant available silicon status of different rice growing soils

Data pertaining to the Si status of different rice growing soils (Coastal (Mangalore) and Hilly (Mudigere and Ponnampet) zones of Karnataka are presented in Tables 6 - 9.

The Si content of Mangalore soils (Table 6) extracted by ammonium acetate and acetic acid were ranged from 8.1-46.3 ppm and 18.1-78.4 ppm respectively. The Si content extracted by 0.5M ammonium acetate and 0.5M acetic acid were recorded highest in Kalmanja-3 (46.3 ppm) and Gurupur-2 (78.4 ppm) respectively. The lowest Si content was observed in Kankanadi-4 (8.1 ppm) and Kankanadi-3 (18.2 ppm) for 0.5M ammonium acetate and 0.5M acetic acid, respectively.

The Si status of rice growing soils of Mudigere are presented in the Table 7 and indicated that the Si extracted by 0.5 M ammonium acetate and 0.5M acetic

Table 6 Plant available silicon (ppm) by different extractants in rice soils of Mangalore

Soil No.	Name of the village	Ammonium acetate	Acetic acid
1	Kankanadi-1*	15.8	26.3
2	Kankanadi-2	16.8	23.0
3	Kankanadi-3	11.7	18.2
4	Kankanadi-4*	8.1	27.2
5	Kankanadi-5	13.6	26.0
6	Gurupur-1	25.9	34.3
7	Gurupur-2	27.8	78.4
8	Maduperari-1	15.5	31.9
9	Maduperari-2	26.7	32.1
10	Yadapadavu-1	16.3	32.9
11	Yadapadavu-2	28.5	35.0
12	Malali-1	46.3	40.0
13	Malali-2	20.2	24.3
14	Polali	26.2	37.3
15	Kinnibettu-1*	22.2	43.4
16	Kinnibettu-2	15.6	29.2
17	Kinnibettu-3	14.2	27.5
18	Kinnibettu-4*	18.4	32.2
19	Thumbe	9.9	38.7
20	Arakula	16.1	44.0
21	Jentimar-1	19.3	29.4
22	Jentimar-2	11.1	33.1
23	Pailoti	16.5	40.9
24	Voga	22.9	48.3
25	Guruvayanakere-1	20.4	19.1
26	Guruvayanakere-2	22.1	20.0
27	Guruvayanakere-3	28.2	33.9
28	Belthangadi-1	30.7	34.9
29	Belthangadi-2	35.7	42.7
30	Belthangadi-3	37.1	40.4
31	Ujire-1	35.2	52.4
32	Ujire-2*	41.7	48.3
33	Ujire-3*	45.6	43.3
34	Kalle-1	38.2	48.0
35	Kalle-2	33.3	40.8
36	Kalle-3	36.0	29.8
37	Kalle-4	38.0	30.5
38	Kalle-5	38.2	41.5
39	Kalmnja-1	35.6	30.9
40	Kalmnja-2	30.6	20.6
41	Kalmnja-3	46.3	28.3
42	Kalmnja-4	30.2	31.9
Range		8.1-46.3	18.16-78.4

* Bulk samples used for pot green house experiment

Table 7 Plant available silicon (ppm) by different extractants in rice soils of Mudigere

Soil No.	Name of the village	Ammonium acetate	Acetic acid
1	Bijuvalli-1	14.7	41.3
2	Bijuvalli-2	9.2	25.5
3	Bijuvalli-3	15.8	23.2
4	Halase	26.3	72.2
5	Dhundige-1	13.0	37.3
6	Dhundige-2	30.9	53.3
7	Dhundige-3	30.5	33.2
8	Dhundige-4	64.6	44.9
9	Bidarahalli(amaravathi estate)-1	24.7	46.7
10	Bidarahalli(amaravathi estate)-2	40.0	26.2
11	Bidarahalli(amaravathi estate)-3*	41.1	47.2
12	Bidarahalli(amaravathi estate)-4	50.8	51.9
13	Bidarahalli(amaravathi estate)-5	33.8	53.2
14	Bidarahalli(amaravathi estate)-6	33.5	44.8
15	Nirgandi-1	16.3	22.5
16	Nirgandi-2	17.0	23.5
17	Horati*	20.2	41.0
18	Phalguni-1	21.4	29.9
19	Phalguni-2*	26.6	25.3
20	Phalguni-3	26.8	48.1
21	Kottigehar-1	28.7	24.2
22	Kottigehar-2	16.5	27.5
23	Kottigehar-3	22.0	21.6
24	Kottigehar-4	24.6	21.3
25	Banakal-1	18.4	29.7
26	Banakal-2	22.6	27.0
27	Sabli gram-1	42.3	22.2
28	Sabli gram-2	42.3	22.2
29	Phalguni	58.1	49.2
30	Bagasgud	37.2	36.3
31	Anjur-1	28.9	47.6
32	Anjur-2	39.3	36.1
33	Anjur-3*	43.9	71.2
34	Gonibeedu-1	13.3	25.4
35	Gonibeedu-2*	9.7	15.9
36	Maribayalu-1	16.7	32.3
37	Maribayalu-2	18.9	36.1
38	Maribayalu-3	16.4	29.2
39	ARS-1	18.2	20.8
40	ARS-2*	10.9	17.3
41	ARS-3	19.5	29.3
42	ARS-4	21.2	37.3
Range		9.2- 64.6	15.9-72.2

* Bulk samples used for pot green house experiment

Table 8 Plant available silicon (ppm) by different extractants in rice soils of Ponnampet

Soil No.	Name of the village	Ammonim acetate	Acetic acid
1	RG Village	22.3	42.3
2	Betuvally-1	16.5	23.2
3	Betuvally-2	19.2	28.1
4	Beguvalli	15.0	28.8
5	B. guntahalli-1*	54.9	74.2
6	B. guntahalli-2*	41.5	73.0
7	Peramboor-1	13.4	23.7
8	Peramboor-2	18.4	28.1
9	Balagod-1	14.2	25.3
10	Balagod-2	20.7	35.7
11	Balagod-3	19.6	35.6
12	Balagod-4	20.3	31.5
13	Balagod-5	14.2	21.0
14	Bittangala-1	10.7	21.5
15	Bittangala-2	23.0	28.0
16	Bittangala-3	26.8	45.6
17	Bittangala-4	16.5	25.9
18	Bittangala-5	16.5	19.6
19	Bittangala-5*	23.8	38.6
20	Bittangala-6	10.7	21.5
21	Kolthodu-1	20.7	27.4
22	Kolthodu-2	16.1	27.7
23	Arthur-1	11.5	21.1
24	Arthur-2*	23.8	34.2
25	Kunda-1	13.0	24.0
26	Kunda-2	8.1	17.0
27	Kunda-3*	7.3	16.8
28	Kunda-4	17.3	25.7
29	Kunda-5	23.4	33.8
30	Haligattu-1	24.9	20.1
31	Haligattu-2	14.2	30.7
32	Begur kolli-1	14.6	26.0
33	Begur kolli-2	16.5	32.9
34	Begur kolli-3	20.7	55.5
35	Begur kolli-4	21.5	37.3
36	Hudikere-1	15.3	31.9
37	Hudikere-2	27.2	55.1
38	ARS-P-1	8.8	26.9
39	ARS-P-2	13.0	23.1
40	ARS-P-3*	16.5	19.8
41	ARS-P-4	23.4	32.6
42	ARS-P-5	14.2	21.4
Range		7.3-54.9	16.8-74.2

* Bulk samples used for pot green house experiment

Table 9 Categorization of soils based on available silicon content in rice growing soils of Karnataka

Sl. No.	Category*	Mangalore	Mudigere	Ponnampet	Total
<u>Ammonium acetate</u>					
1	Low (<20 ppm)	15	16	26	56 (45.16)**
2	Medium (20-40 ppm)	23	18	14	55 (44.35)
3	High (>40 ppm)	4	7	2	13 (10.48)
<u>Acetic acid</u>					
1	Low (<20 ppm)	3	3	4	10 (8.06)
2	Medium (20-40 ppm)	26	26	32	83 (66.9)
3	High (>40 ppm)	13	13	6	31 (25.0)

* Based on the Korndorfer *et al.* (2001)

** Values in the parenthesis indicate percentage samples

acid were ranged from 9.2 ppm to 64.6 ppm and 15.9 ppm to 72.2 ppm, respectively. The lowest and the highest Si extracted by 0.5M ammonium acetate was recorded in Bijuvalli-2 (9.2 ppm) and Dundige-4 (64.6 ppm) respectively. Gonibeedu-2 (15.9 ppm) and Halase (72.2 ppm) noticed the lowest and highest Si extracted by 0.5M acetic acid, respectively.

The data presented in the Table 8 indicated that 0.5 M ammonium acetate and 0.5M acetic acid extractable Si were ranged from 7.3 ppm (Kunda-3) to 54.9 ppm (B. guntahalli-1) and 16.8 ppm (Kunda-3) to 74.2 ppm (B. guntahalli-1), respectively in Ponnampet soil samples. The highest and the lowest Si were noticed in Kunda-3 and B. Guntahalli-1 respectively for both the studied methods.

The perusal of data (Table 9) revealed that 45.0, 44.5 and 10.5 per cent of the total soils studied were categorized as low, medium and high, respectively for 0.5M ammonium acetate method. Whereas 8.0, 66.9 and 25.0 per cent of the soil samples were categorized as low, medium and high for 0.5 M acetic acid method. It was observed that nearly 75 to 85 per cent of the studied soils were categorized as low (< 20 ppm) to medium (20 -40 ppm) in available Si content (Table 9).

4.2 Evaluation of different extractants for available silicon in rice soils

Various soil test procedures used in different countries for determination of available Si were compared through soil test crop response (correlation and regression studies) in order to select suitable soil test extractants for estimating the available Si using rice as the test crop. Eighteen bulk soil samples collected from different locations of coastal and hilly zones of Karnataka were used in the pot culture studies. The data pertaining to available Si status as estimated by different extractants, the yield parameters and plant Si content, correlation and regression between plant Si content and its uptake and available Si as

Table 10 Plant available silicon (ppm) as extracted by different extractants in rice soils

Sl No	0.5 M Acetic acid-1	0.5 M Acetic acid-2	0.5 M acetic acid-3	0.01M CaCl ₂	Distilled water-1	Distilled water-4	0.5M NH ₄ OAc	N NaOAc-1	N NaOAc-2	0.1M citric acid	0.005M H ₂ SO ₄
<u>Mangalore</u>											
1	35.6	26.8	61.1	38.9	7.3	25.6	16.4	54.3	65.4	51.0	190.6
2	29.4	31.5	69.6	34.5	7.5	20.2	14.6	56.1	65.4	90.4	204.2
3	44.9	39.5	79.4	41.3	13.2	24.9	20.9	60.3	72.3	155.4	231.4
4	40.4	41.8	75.7	39.4	12.7	28.2	29.1	69.6	78.8	143.8	236.0
5	48.1	52.6	85.1	46.2	16.2	34.5	35.9	73.3	82.1	285.2	249.6
6	37.7	43.2	71.0	32.1	15.7	32.7	39.1	58.9	72.3	153.0	204.2
<u>Mudigere</u>											
7	25.3	20.2	22.6	33.1	6.8	18.8	15.9	49.2	62.6	44.1	136.1
8	21.0	18.8	36.7	34.0	7.5	20.2	11.4	45.0	61.7	53.3	145.2
9	27.4	32.0	31.0	33.6	10.6	26.1	16.8	57.0	63.1	104.3	154.3
10	37.2	38.5	63.5	38.4	11.5	22.6	23.2	56.6	74.7	176.2	163.4
11	65.2	59.2	102.5	55.9	16.3	34.1	39.1	77.0	87.2	317.7	240.5
12	60.3	56.4	95.9	49.1	16.9	35.5	35.9	68.6	86.3	245.8	231.4
<u>Ponnampet</u>											
13	11.3	13.2	22.1	22.4	6.1	15.5	10.9	38.5	47.8	44.1	118.0
14	15.3	19.3	38.5	24.3	8.0	12.7	12.7	40.3	54.3	58.0	127.1
15	25.5	20.2	33.8	31.1	9.9	21.4	14.6	54.7	56.6	85.8	145.2
16	19.4	27.3	28.7	30.1	9.6	19.3	13.2	58.4	58.9	62.6	131.6
17	65.7	60.2	54.1	47.7	14.6	37.1	42.3	86.7	97.9	150.7	263.2
18	73.8	59.2	61.1	46.2	14.1	34.3	39.1	79.3	97.4	169.3	254.1
Mean	38.0	36.7	57.3	37.7	11.4	25.8	24.0	60.2	71.4	132.8	190.3
Range	11.3- 73.8	13.2 -60.2	22.1 – 102.5	22.4 -55.9	6.1 – 16.9	12.7 -37.1	10.9 -42.3	38.5 -86.7	47.8 -97.9	44.1 -317.7	118 – 263.2

extracted by different extractants were presented in the Tables 10, 11, 12 and 13 respectively and Fig. 3, 3A - F and 4A - F.

4.2.1 Available Si content as extracted by different extractants

In the present investigation, eleven extractants were used for extracting the available Si from soils, viz., 0.5M acetic acid-1, 0.5M acetic acid-2, 0.5M acetic acid-3, 0.01M CaCl_2 , Distilled water-1, Distilled water-4, 0.5M NH_4OAc , N NaOAc-1, N NaOAc-2, 0.1M citric acid and 0.005M H_2SO_4 . The available Si extracted by these extractants ranged from 11.3 to 73.8 ppm, 13.2 to 60.2 ppm, 22.1 to 102.5 ppm, 22.4 to 55.9 ppm, 6.1 to 16.9 ppm, 12.7 to 37.1 ppm, 10.9 to 42.3 ppm, 38.5 to 86.7 ppm, 44.1 to 317.7 ppm, 47.8 to 97.9 ppm and 118 to 263.2 ppm respectively (Table 10 and Fig. 3). In general, soils of Ponnampet recorded the lowest Si content in all the methods followed by Mangalore and Mudigere soils (Table 10).

Available Si extracted by various extractants irrespective of the soils used for the study was in the following order: 0.005M H_2SO_4 > 0.1M citric acid > N NaOAc-2 > N NaOAc-1 > 0.5M acetic acid-3 > 0.5M acetic acid-2 > 0.5M acetic acid-1 > 0.01M CaCl_2 > 0.5M NH_4OAc > Distilled water- 4 > Distilled water-1 (Fig. 3).

4.2.2 Plant growth indices for evaluation of different extractants

The growth indices considered in soil test evaluation were per cent Si content in straw, grain and its uptake in check pots (Table 11). The grain and straw yield of rice in check pots were ranged from 19.1 to 36.7 mg pot^{-1} and 29.5 to 44.0 g pot^{-1} , respectively. The per cent Si content of grain and straw were ranged from 0.72 to 1.70 and 2.22 to 3.41 respectively. Similarly, Si uptake in grain, straw and total was ranged from 127.6 to 561.6 mg pot^{-1} , 644.3 to 1309.0 mg pot^{-1} and 847.5 to 1820.4 mg pot^{-1} , respectively for different soils. Among the soils studied, the lowest and the highest plant Si uptake was observed in soils of Ponnampet. But, highest and lowest per cent Si content

Table 11 Grain and straw yield, silicon content and its uptake by rice in different soils

Sl No	<u>Yield (g pot⁻¹)</u>		<u>Si (%)</u>		<u>Si uptake (mg pot⁻¹)</u>		
	Straw	Grain	Straw	Grain	Straw	Grain	Total
<u>Mangalore</u>							
1	34.5	24.9	2.32	0.72	799.4	178.3	977.7
2	33.5	21.1	2.49	0.60	832.8	127.6	960.4
3	37.5	28.0	2.73	1.04	1024.9	291.4	1316.4
4	26.0	21.8	3.04	1.11	1094.8	241.6	1336.4
5	29.5	25.9	2.98	1.15	878.1	296.8	1174.9
6	32.5	26.3	2.81	0.82	913.4	214.9	1128.4
<u>Mudigere</u>							
7	30.0	20.5	2.68	1.09	802.7	223.4	1026.1
8	26.0	20.3	2.48	1.15	644.3	233.1	877.4
9	33.0	20.9	2.66	1.34	877.0	279.1	1156.2
10	34.0	25.4	2.84	1.32	966.7	334.3	1301.1
11	36.0	33.1	2.99	1.70	1076.0	561.6	1637.6
12	38.0	29.5	3.41	1.41	1296.0	415.4	1711.4
<u>Ponnampet</u>							
13	29.5	19.1	2.22	1.01	653.6	193.8	847.5
14	29.5	22.0	2.46	1.08	724.5	238.1	962.6
15	27.5	23.8	2.71	1.11	745.6	263.9	1009.5
16	44.0	32.0	2.66	1.08	1170.0	344.7	1514.7
17	43.5	36.7	3.01	1.39	1309.0	511.4	1820.4
18	35.0	30.0	3.20	1.35	1118.6	404.0	1522.6
Range	29.5 to 44.0	19.1 to 36.7	2.22 to 3.41	0.72 to 1.70	644.3 to 1309.0	127.6 to 561.6	847.5 to 1820.4

was noticed in soils of Mudigere. In general, grain, straw yield, per cent Si and its uptake increased with increase in available Si content (Table 10 and 11).

4.2.3 Relationship between soil test values by different methods and crop growth parameters

Correlation and regression coefficients between soil Si extracted by different methods and per cent plant Si and its uptake are given in Table 12 and 13 respectively. The results presented in Table 12 revealed that the amount of available Si extracted by ten extractants correlated positively and significantly with grain yield, grain Si, straw Si and its uptake by straw as well as grain. But there was no significant correlation between plant available soils Si extracted by acetic acid -3 with grain yield, per cent Si in grain and its uptake. The straw yield was correlated positively and significantly with only available Si extracted by 0.5M Acetic acid-2 ($r = 0.47^*$) and N NaOAc-1 ($r = 0.49^*$). Among the different extractants, available Si extracted by N NaOAc-1 recorded highest “r” values with grain yield ($r = 0.78^{**}$), straw Si ($r = 0.85^{**}$), grain Si ($r = 0.56^*$), straw Si uptake ($r = 0.82^{**}$), and grain Si uptake ($r = 0.75^{**}$). This was followed by 0.5 M acetic acid-2 and N NaOAc-2 for all the crop parameters studied. The relationship between available Si values with the different crop parameters according to the “r” values followed the order,

❖ N NaOAc-1 > 0.5M acetic acid-2 > N NaOAc-2 > 0.5M acetic acid-1 > 0.01M CaCl_2 > 0.5M NH_4OAc > Distilled water-1 > Distilled water-4 > 0.1M citric acid > 0.005M H_2SO_4 > 0.5M acetic acid-3.

Regression analysis was carried out for available Si extracted by different extractants and crop parameters such as per cent plant Si and its uptake. The results presented in Table 13 and Fig. 3A - F and 4A - F indicated that the available Si content extracted by N NaOAc-1 method accounted for maximum regression coefficient for grain Si uptake ($R^2 = 56^*$), straw Si uptake ($R^2 = 0.66^{**}$), per cent Si in straw ($R^2 = 0.71^{**}$) and total per cent Si ($R^2 = 0.60^{**}$). This was followed by 0.5M acetic acid-2 and N NaOAc-2. But grain Si uptake

Table 12 Correlation of plant available silicon as extracted by different extractants with the yield parameters

Sl. No	Extractants	Straw yield	Grain yield	Straw Si	Grain Si	Straw Si uptake	Grain Si uptake	Total Si uptake
1	0.5M acetic acid-1	0.44	0.70**	0.76**	0.52*	0.75**	0.72**	0.80**
2	0.5M acetic acid-2	0.47*	0.75**	0.82**	0.54*	0.80**	0.74**	0.83**
3	0.5M acetic acid-3	0.20	0.45	0.63**	0.23	0.51*	0.41	0.51*
4	0.01M CaCl ₂	0.39	0.68**	0.74**	0.58*	0.68**	0.65**	0.75**
5	Distilled water-1	0.34	0.68**	0.75**	0.54*	0.71**	0.69**	0.75**
6	Distilled water-4	0.36	0.67**	0.73**	0.45	0.70**	0.64**	0.72**
7	0.5M NH ₄ OAc	0.33	0.69**	0.82**	0.48*	0.70**	0.68**	0.74**
8	N NaOAc-1	0.49*	0.78**	0.85**	0.56*	0.82**	0.75**	0.84**
9	N NaOAc-2	0.47*	0.72**	0.81**	0.53*	0.78**	0.73**	0.81**
10	0.1 M Citric acid	0.22	0.56*	0.77**	0.49*	0.56*	0.68**	0.64**
11	0.005 M H ₂ SO ₄	0.32	0.61**	0.72**	0.27	0.67**	0.52*	0.65**

**, * Significant @ 1% and 5% respectively

Table 13 Regression coefficient (R^2) explaining the relationship between percent silicon in straw, grain and its uptake and silicon extracted by different extractants in different rice soils

Sl. No	Extractants	<u>Si Uptake (mg pot⁻¹)</u>		<u>Si (%)</u>	
		Grain	Straw	Grain	Straw
1	0.5M acetic acid-1	0.53	0.55	0.29	0.67
2	0.5M acetic acid-2	0.56	0.64	0.29	0.71
3	0.5M acetic acid-3	0.16	0.26	0.05	0.39
4	0.01M CaCl ₂	0.56	0.46	0.33	0.57
5	Distilled water-1	0.47	0.51	0.24	0.62
6	Distilled water-4	0.41	0.48	0.20	0.64
7	0.5M NH ₄ OAc	0.46	0.48	0.23	0.63
8	N NaOAc-1	0.56	0.66	0.29	0.73
9	N NaOAc-2	0.53	0.60	0.28	0.65
10	0.1M Citric acid	0.46	0.31	0.35	0.55
11	0.005M H ₂ SO ₄	0.27	0.45	0.08	0.51

was not significant with the available Si extracted by any of the methods. The relationship between crop parameters and available Si extracted by different methods according to R^2 values followed the same order as noticed for available Si and different crop parameters.

4.3 Critical limits of plant and soil silicon in rice

Before fertilizer recommendation, the soil analysis should be verified with the crop response. In order to find the critical limits for Si in soil and plant, a greenhouse study was carried out in eighteen bulk soils collected from Mangalore, Mudigere and Ponnampet areas. The data pertaining to grain and straw yield, relative yield, critical levels of available Si for different extractants and straw / tissue Si are presented in Table 14, 15 and 16 respectively.

4.3.1 Effect of calcium silicate as Si source on grain and straw yield of rice

A significant increase in grain and straw yield were noticed due to the application of calcium silicate as Si source in all the soils (Table 14 and Fig. 5). Amongst the soils; 1, 3, 4 and 14 showed higher yield response up to 1448 kg Si ha⁻¹ application. Similarly, soils 2, 5, 6, 9, 10 and 13 have recorded higher grain yield due to the application of Si up to 966 kg ha⁻¹ and showed declining trend thereafter. Few soils (viz., 7, 8, 11, 12, 15, 16, 17 and 18) were responded to the applied Si up to 483 kg ha⁻¹ and further application neither increased nor decreased in grain yields. In general, soils of low to medium in available Si have responded greatly to the applied Si in obtaining higher grain yield and soils containing higher levels of Si have responded moderately to application of Si. Among the soils studied, soils of Mangalore have responded greatly to the added Si followed by soils of Ponnampet and least response was observed in soils of Mudigere. Similar trend as observed due to the effect of Si on grain yield was also noticed in straw yield (Table 14 and Fig. 5).

Table 14 Effect of graded levels of silicon on grain and straw yield of rice in different soils of Karnataka

Location	Sl. No	Grain yield (g pot ⁻¹)					Straw yield (g pot ⁻¹)				
		< -----Si (kg ha ⁻¹)----->					< -----Si (kg ha ⁻¹)----->				
		0	483	966	1448	CD (0.05 %)	0	483	966	1448	CD (0.05 %)
Mangalore	1	24.9	32.2	37.9	40.9	3.84	34.5	38.0	50.0	52.5	2.35
	2	21.1	31.1	36.7	36.6	1.73	33.5	42.0	44.5	42.5	2.60
	3	28.0	36.5	33.0	38.0	1.24	37.5	38.5	41.0	39.5	1.32
	4	21.8	25.2	28.2	30.2	1.78	26.0	27.3	30.0	34.0	4.65
	5	25.9	31.4	32.1	32.0	1.40	29.5	41.0	37.5	49.0	2.91
	6	26.3	26.6	31.5	21.2	2.03	32.5	34.5	34.5	48.5	1.91
Mudigere	7	20.5	27.4	24.8	25.3	1.04	30.0	21.5	30.0	30.0	2.87
	8	20.3	26.7	24.4	21.9	1.50	26.0	29.0	27.0	25.5	1.80
	9	20.9	30.6	29.2	29.8	1.44	33.0	35.0	33.0	33.0	2.65
	10	25.4	34.9	37.7	38.9	1.78	34.0	36.0	37.0	37.0	4.40
	11	33.1	35.6	30.5	34.0	1.77	36.0	37.0	40.5	37.5	4.30
	12	29.5	30.5	28.9	30.6	2.42	38.0	36.0	37.0	36.5	3.04
Ponnampet	13	19.1	24.0	25.1	24.0	0.71	29.5	33.0	28.0	29.0	2.50
	14	22.0	28.5	33.3	37.1	3.04	29.5	32.5	35.5	35.5	3.32
	15	23.8	29.1	24.4	26.4	1.00	27.5	33.5	29.0	30.5	3.12
	16	32.0	39.1	37.1	32.0	2.64	44.0	45.0	39.5	41.0	3.65
	17	36.7	38.3	37.7	36.6	0.91	43.5	45.5	39.0	38.5	1.32
	18	30.0	32.2	30.9	30.5	1.14	35.0	36.7	35.7	34.5	1.35
Range		19.1 – 36.7	24 – 39.1	24.4 – 37.9	21.9 – 40.9		26.0 – 44.0	21.5 – 45.5	27.0 – 50.0	25.5 – 52.5	

Table 15 Silicon in rice straw and grain of check pots, check yield, maximum yield, yield increase and relative yield

Location	Sl No	Straw Si in check pot <------(%)----->	Grain Si in check pot <------(%)----->	Check yield <------(g pot ⁻¹)----->	Maximum yield <------(g pot ⁻¹)----->	Yield increase	Relative yield (%)
MANGALORE	1	2.32	0.72	24.9	40.9	16.0	35.8
	2	2.49	0.60	21.1	36.7	15.5	26.6
	3	2.73	1.04	28.0	38.0	10.0	64.4
	4	3.04	1.11	21.8	30.2	8.4	61.6
	5	2.98	1.15	25.9	32.1	6.2	75.8
	6	2.81	0.82	26.3	31.5	5.2	80.4
MUDIGERE	7	2.68	1.09	20.5	27.4	6.9	66.5
	8	2.48	1.15	20.3	26.7	6.4	68.3
	9	2.66	1.34	20.9	30.6	9.8	53.2
	10	2.84	1.32	25.4	38.9	13.5	46.7
	11	2.99	1.70	33.1	35.6	2.4	92.6
	12	3.41	1.41	29.5	30.6	1.1	96.4
PONNAMPET	13	2.22	1.01	19.1	25.4	6.3	67.1
	14	2.46	1.08	22.0	37.1	15.2	30.9
	15	2.71	1.11	23.8	29.1	5.3	77.8
	16	2.66	1.08	32.0	39.1	7.1	77.7
	17	3.01	1.39	36.7	38.3	1.6	95.7
	18	3.20	1.35	30.0	32.2	2.2	92.8

Check yield- Control yield, **Yield increase**= Maximum yield – Check yield; **Maximum yield**= Yield obtained due to application of Si
Relative yield (%) = [1- {(Maximum yield – Check yield)/ (Check yield)* 100}]

The grain and straw yield of rice in check pots were ranged from 19.1 to 36.7 mg pot⁻¹ and 29.5 to 44.0 g pot⁻¹ respectively. The per cent Si content of grain and straw were ranged from 0.72 to 1.70 and 2.22 to 3.41 respectively. Similarly, Si uptake in grain and straw ranges from 127.6 to 561.6 mg pot⁻¹ and 644.3 to 1309.0 mg pot⁻¹, respectively for different soils. Among the soils studied, the lowest and the highest plant Si uptake was observed in soils of Ponnampet. Whereas, highest and the lowest per cent Si content was noticed in soils of Mudigere. In general, grain and straw yield, per cent Si and its uptake were generally increased with increasing available Si content (Table 14). The maximum yield obtained due to supplement of varied levels of CaSiO₃ as Si source for different soils was ranged from 25.4 to 40.9 g pot⁻¹ and yield increase was ranged from 1.1 to 16.0 g pot⁻¹. The relative yield is the yields achieved on the unfertilized soil relative to the maximum yield achieved on the Si fertilized soil were ranged from 35.8 to 96.4 per cent (Table 15).

The critical limits of plant available soil Si for different extractants were presented in the Table 16 and Fig 6A - F and revealed that the critical limit of soil Si for 0.5M acetic acid-1, 0.5M acetic acid-2, 0.5M acetic acid-3, 0.01M CaCl₂, distilled water-1, distilled water- 4, 0.5M NH₄OAc, N NaOAc-1, N NaOAc-2, 0.1M citric acid and 0.005M H₂SO₄ were 54, 54, 87, 43, 30, 14, 32, 75, 85, 185 and 207 ppm respectively. The highest and lowest critical limits of available Si were noticed in 0.005M H₂SO₄ and distilled water-1, respectively.

The available Si was categorized into low (L), medium (M) and high (H) based on the per cent relative yield for different extractants. Data presented in Table 16 (Fig. 7A - F) indicated < 44 ppm was considered to be low, 44 - 116 ppm to be medium and > 116 ppm as high for 0.5 M acetic acid-1 extractable soil Si. According to 0.5M acetic acid extractable Si, < 47 ppm was considered as low, 47-102 ppm as medium and > 102 ppm as high. The categorization of plant available Si for rest of the extractants are as follows:

Table 16 Critical levels and categorization of plant available silicon (ppm) for different extractants for rice growing soils and rice straw and grain

Sl No	Extractants	Critical limit	Categorization		
			Low	Medium	High
<u>Soils (ppm)</u>					
1	0.5 M acetic acid-1	54	<44	44 - 116	>116
2	0.5 M acetic acid-2	54	<47	47 - 102	>102
3	0.5 M acetic acid-3	87	-	-	-
4	0.01 M CaCl ₂	43	<42	42 - 65	>65
5	Distilled water-1	14	<13	13 - 21	>21
6	Distilled water-4	30	<30	30 - 45	>45
7	0.5M NH ₄ OAc	32	<29	29 - 57	>57
8	N NaOAc-1	75	<67	67 - 95	>95
9	N NaOAc-2	85	<80	80 - 110	>110
10	0.1M Citric acid	185	<174	-	-
11	0.005M H ₂ SO ₄	207	<235	-	-
<u>Rice</u>					
1	Straw Si (%)	2.9	<2.85	2.85 - 3.4	>3.4
2	Grain Si (%)	1.2	-	-	-

0.01M CaCl_2 (< 42, 42- 65 and > 65 ppm :: L : M : H respectively)
 Distilled water-1 (<13, 13 - 21 and >21 ppm :: L : M : H respectively)
 Distilled water-4 (< 30, 30 - 45 and >45ppm for L : M : H respectively)
 0.5M NH_4OAc (< 29, 29 - 57 and >57 ppm for L : M : H respectively)
 N NaOAc-1 (<67, 67 - 95 and >95 ppm for L : M : H respectively)
 N NaOAc-2 (<80, 80 - 110 and >110 ppm for L : M : H respectively)
 0.1M citric acid (<174 ppm as low)
 0.005M H_2SO_4 (< 235 ppm as low).

The available Si as extracted by 0.5 M acetic acid-3, 0.1M citric acid and 0.005 M H_2SO_4 extractants did not show linear relationship in calibration curve and hence could not able to categorize into all three categories by these methods (Table 15 and Fig. 7B, 7E and 7F).

The data depicted in the Table 16 (Fig. 8 and 9) indicated that 2.9 and 1.2 per cent Si as critical limits for straw and grains respectively. The per cent straw Si lower than 2.85 was considered to be low, 2.85 to 3.4 per cent as medium and more than 3.4 per cent straw Si as high.

5.4 Evaluation of genotypic difference in relation to Si accumulation under different moisture regimes

Four different rice genotypes (BI-33, BI-43, Rasi and IRRI-49) were evaluated in two different soils (Mangalore and Mudigere) to know the Si accumulation under two moisture regimes (aerobic and submergence) with and without application of calcium silicate ($\text{S0- } 0 \text{ kg Si ha}^{-1}$ and $\text{S1- } 966 \text{ kg Si ha}^{-1}$) as Si source at three growth stages viz., MT- maximum tillering, FS- flowering stage and HS- harvesting stage. The data pertaining to plant height, number of tillers, straw yield, grain yield, per cent Si in straw, per cent Si in grain, Si uptake in straw, Si uptake in grain and total uptake are given in Table 17, 18, 19, 20, 21, 22, 23, 24, and 25 respectively and Fig. 10 and 11.

Table 17 Effect of silicon (as calcium silicate) on plant height (cm) of different rice genotypes at different growth stages

Si (kg ha ⁻¹)	Genotype	<u>MANGALORE</u>						<u>MUDIGERE</u>					
		<u>Submergence</u>			<u>Aerobic</u>			<u>Submergence</u>			<u>Aerobic</u>		
		MT	FS	HS	MT	FS	HS	MT	FS	HS	MT	FS	HS
S0 (0 kg ha ⁻¹)	BI-33	51.5	74.0	77.5	43.5	49.0	50.0	57.3	72.0	75.0	38.5	50.0	51.0
	BI-43	57.4	74.5	74.5	38.0	42.5	42.5	54.4	74.2	74.8	38.0	43.5	44.0
	Rasi	54.2	74.0	77.0	39.6	52.0	52.5	52.5	76.0	76.5	33.3	51.5	52.0
	IRRI-49	54.5	67.5	67.5	38.6	45.0	46.0	50.4	71.5	71.0	34.9	48.5	49.0
S1 (966 kg ha ⁻¹)	BI-33	52.0	77.5	78.0	33.0	49.7	51.0	58.9	74.8	75.5	40.2	51.0	51.5
	BI-43	59.9	76.0	76.0	38.0	45.5	46.0	55.5	73.0	74.5	35.7	42.5	44.0
	Rasi	54.3	75.5	77.5	38.2	52.5	54.0	54.5	76.8	77.0	34.0	52.5	53.0
	IRRI-49	54.7	68.3	68.5	33.3	46.0	48.0	52.2	71.5	72.5	35.4	52.0	52.0
SEM±		1.60	1.48	0.95	1.70	1.49	1.53	1.50	0.77	1.60	3.63	2.98	1.60
CD (0.05%)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

MT- Maximum tillering stage; **FS** – Flowering stage; **HS**- Harvesting stage

Table18 Effect of silicon (as calcium silicate) on number of tillers of different rice genotypes at different growth stages

Si (kg ha ⁻¹)	Genotype	<u>MANGALORE</u>						<u>MUDIGERE</u>					
		<u>Submergence</u>			<u>Aerobic</u>			<u>Submergence</u>			<u>Aerobic</u>		
		MT	FS	HS	MT	FS	HS	MT	FS	HS	MT	FS	HS
S0 (0 kg ha ⁻¹)	BI-33	12.5	15.0	15.5	13.5	19.5	20.0	11.0	12.5	13.0	11.5	18.0	19.0
	BI-43	16.0	13.0	14.0	15.0	19.5	19.5	9.5	9.5	10.0	11.5	17.0	17.5
	Rasi	11.0	14.5	16.0	12.0	18.0	18.0	12.0	12.0	13.0	10.0	17.5	18.5
	IRRI-49	16.5	13.5	15.0	10.0	15.0	15.5	12.0	12.0	12.0	12.0	16.0	17.0
S1 (966 kg ha ⁻¹)	BI-33	14.5	14.5	16.5	11.5	18.0	20.5	11.5	12.5	13.2	11.0	18.5	19.5
	BI-43	15.0	15.5	15.0	12.0	18.0	20.0	10.0	11.5	12.0	12.5	17.5	18.5
	Rasi	15.5	15.0	17.0	9.5	19.5	20.0	13.0	12.5	13.5	9.5	18.0	18.5
	IRRI-49	13.5	15.0	16.0	10.5	16.5	17.0	12.5	12.5	12.5	14.5	17.5	18.0
SEM±		1.59	0.85	0.79	0.80	1.27	1.62	1.03	0.47	0.75	1.19	0.97	1.15
CD (0.05%)		4.18	NS	NS	2.58	NS	5.30	NS	1.53	NS	NS	NS	NS

MT- Maximum tillering stage; **FS** – Flowering stage; **HS-** Harvesting stage

4.4.1 Plant height: The data indicated no significant difference among the rice genotypes at all the growth stages even with the application of Si in both the soils under both aerobic and submerged conditions (Table 17). However, plant height was 1.5 times higher in submergence condition than in the aerobic condition.

4.4.2 Number of tillers: The number of tillers increased with the application of calcium silicate in both the soils under aerobic as well as submerged conditions (Table 18). However, there was no significant difference in number of tillers with the Si application in both the soils. In general, the number of tillers were highest in aerobic than in submerged condition in both the soils.

4.4.3 Straw Yield: The data indicated that increase in straw yield was recorded in all genotypes at all the stages in wetland soils of Mangalore and Mudigere with the application of 966 kg Si ha⁻¹ (Table 19). But increase was significant only with BI-33 (31.5 g pot⁻¹) and Rasi (35.5 g pot⁻¹) with the application of 966 kg Si ha⁻¹ in Mangalore soil at harvesting stage. Whereas, in aerobic condition, decrement in straw yield was observed at maximum tillering due to application of 966 kg Si ha⁻¹ in both the soils and significant increase in straw yield was observed at flowering and harvesting stage in all the genotypes in soils of Mangalore. But increase was significant only in BI-33 and Rasi at harvesting stage in soils of Mudigere. In general, Rasi (13.0, 31.0, and 35.5 g pot⁻¹ at maximum tillering stage, flowering stage and harvesting stage, respectively) and BI-33 (11.5, 25.5 and 30.5 g pot⁻¹ at maximum tillering stage, flowering stage and harvesting stage respectively) in Mangalore and Mudigere soils due to the application of 966 kg Si ha⁻¹ under submerged condition. In aerobic condition, both Rasi and BI-33 were recorded highest straw yield due to the application of Si.

4.4.4 Grain yield: Data pertaining to the grain yield of four genotypes are presented in the Table 20 showed that the grain yield was increased in all the

Table 19 Effect of silicon (as calcium silicate) on straw yield (g pot⁻¹) of different rice genotypes at different growth stages

Si (kg ha ⁻¹)	Genotype	<u>MANGALORE</u>						<u>MUDIGERE</u>					
		<u>Submergence</u>			<u>Aerobic</u>			<u>Submergence</u>			<u>Aerobic</u>		
		MT	FS	HS	MT	FS	HS	MT	FS	HS	MT	FS	HS
S0 (0 kg ha ⁻¹)	BI-33	12.0	30.5	29.0	4.5	12.3	14.4	10.5	25.0	28.5	5.5	14.2	14.6
	BI-43	12.0	27.0	26.0	4.0	13.2	13.5	7.5	19.0	26.3	5.0	13.0	13.7
	Rasi	9.5	26.3	32.8	4.0	13.3	12.6	7.0	23.5	29.3	3.5	12.1	12.7
	IRRI-49	10.5	27.0	26.5	3.5	10.8	11.3	10.0	21.5	30.5	4.5	11.2	11.3
S1 (966 kg ha ⁻¹)	BI-33	13.0	31.0	31.5	4.5	16.0	16.5	11.5	25.5	30.5	5.5	14.5	15.8
	BI-43	12.5	30.5	27.5	3.5	15.9	16.0	10.5	20.5	26.5	4.5	13.3	13.8
	Rasi	11.0	28.3	35.5	3.5	15.8	16.9	11.0	24.0	29.5	4.5	12.9	13.9
	IRRI-49	11.0	28.5	27.0	3.5	13.6	12.2	12.0	22.5	26.5	3.5	11.9	12.5
SEM±		1.20	0.80	0.70	0.43	0.66	0.40	0.61	0.60	1.10	0.66	0.45	0.38
CD (0.05%)		NS	NS	2.30	NS	2.10	1.30	2.00	NS	3.70	2.15	NS	1.20

- **MT**- Maximum tillering stage; **FS** – Flowering stage; **HS**- Harvesting stage

Table 20 Effect of silicon (as calcium silicate) on grain yield (g pot⁻¹) of different rice genotypes at different growth stages

Si (kg ha ⁻¹)	Genotype	<u>MANGALORE</u>				<u>MUDIGERE</u>			
		<u>Submergence</u>		<u>Aerobic</u>		<u>Submergence</u>		<u>Aerobic</u>	
		FS	HS	FS	HS	FS	HS	FS	HS
S0 (0 kg ha ⁻¹)	BI-33	9.8	14.8	3.0	6.0	9.0	20.0	3.2	6.1
	BI-43	9.8	12.5	2.5	5.8	8.5	19.5	2.7	6.0
	Rasi	10.7	12.5	2.8	6.2	8.5	17.5	3.2	6.3
	IRRI-49	9.5	12.5	2.7	5.6	9.5	15.5	2.5	5.8
S1 (966 kg ha ⁻¹)	BI-33	10.3	15.7	3.2	6.5	8.5	20.5	3.3	6.3
	BI-43	9.5	13.5	2.7	6.0	10.0	20.5	2.8	6.2
	Rasi	10.0	14.0	3.0	6.8	10.5	19.9	3.3	6.8
	IRRI-49	10.3	14.0	2.8	5.8	11.5	16.3	2.6	5.8
SEM±		0.52	0.43	0.06	0.15	0.90	0.62	0.71	0.11
CD (0.05%)		1.70	1.41	0.20	0.50	2.94	2.02	0.23	0.36

* FS – Flowering stage; HS- Harvesting stage

genotypes due to the application of 966 kg Si ha⁻¹ under submerged condition in both the soils. But the increase was significant only in Rasi genotype at harvesting stage in both Mangalore (14.0 g pot⁻¹) and Mudigere (19.9 g pot⁻¹) under submerged condition. In aerobic system, significant increase in grain yield was observed in BI-33 (6.5 g pot⁻¹) and Rasi (6.8 g pot⁻¹) in Mangalore soil and Rasi (6.8 g pot⁻¹) in Mudigere soil. Among the genotypes studied, BI-33 and Rasi recorded highest grain yield in submerged and aerobic conditions, respectively due to the application of 966 kg Si ha⁻¹ in both the soils.

4.4.5 Per cent Si in straw: Results pertaining to the per cent Si in straw of different rice genotypes are presented in Table 21. It was found that per cent Si content increased significantly in all the four genotypes with the application of 966 kg Si ha⁻¹ under submerged condition in both the soils. Higher per cent Si in straw was recorded at flowering and harvesting stages compared to maximum tillering stage in Si applied pots. No specific trend was observed in control pots. The highest per cent Si was noticed in BI-33 (2.82 %) and Rasi (3.60%) at Mangalore and Mudigere soils, respectively under submerged condition. Similarly in aerobic condition, the per cent Si content increased significantly in all the genotypes due to application of 966 kg Si per hectare over non applied pots and it was higher at harvesting stage followed by flowering stage and least at maximum tillering stage in both Mangalore and Mudigere soils. The per cent Si in straw recorded was highest in Rasi genotypes in both Mangalore (2.50 %) and Mudigere (2.72 %) followed by BI-33 in both the studied soils. In general, Rasi/ BI-33 genotype recorded highest Si accumulation in straw in control as well as Si treated pots and Si accumulation was slightly higher under submerged condition than in aerobic condition.

4.4.6 Per cent Si in grains: The per cent Si in grains increased in all the rice genotypes with the supplement of CaSiO₃ as Si source over control under submerged condition in both Mudigere and Mangalore soils (Table 22). The

Table 21 Effect of silicon (as calcium silicate) on percent straw Si of different rice genotypes at different growth stages

Si (kg ha ⁻¹)	Genotype	<u>MANGALORE</u>						<u>MUDIGERE</u>					
		<u>Submergence</u>			<u>Aerobic</u>			<u>Submergence</u>			<u>Aerobic</u>		
		MT	FS	HS	MT	FS	HS	MT	FS	HS	MT	FS	HS
S0 (0 kg ha ⁻¹)	BI-33	1.51	1.34	1.91	1.32	1.69	1.30	1.56	2.06	2.04	1.29	1.75	1.66
	BI-43	1.46	1.31	1.91	1.13	1.52	1.21	1.75	2.00	1.85	1.12	1.59	1.63
	Rasi	1.56	1.60	2.08	1.09	1.60	1.51	1.82	2.13	2.13	1.35	1.64	2.03
	IRRI-49	1.71	1.35	1.92	1.12	1.52	1.46	1.67	1.95	1.53	1.34	1.72	1.75
S1 (966 kg ha ⁻¹)	BI-33	1.74	1.79	2.82	1.62	2.16	2.18	2.24	3.25	2.97	1.60	1.90	2.66
	BI-43	1.97	1.52	2.29	1.35	2.00	1.97	1.96	2.50	2.39	1.32	2.17	1.95
	Rasi	1.85	2.00	2.69	1.42	2.24	2.50	1.99	3.46	3.60	1.46	2.55	2.72
	IRRI-49	1.81	1.58	2.50	1.54	1.83	2.25	1.89	2.60	2.98	1.61	1.90	2.14
SEM±		0.03	0.03	0.15	0.03	0.09	0.16	0.07	0.06	0.10	0.06	0.07	0.10
CD (0.05%)		0.10	0.10	0.48	0.10	0.30	0.53	0.22	0.19	0.34	0.20	0.25	0.53

• **MT**- Maximum tillering stage; **FS** – Flowering stage; **HS**- Harvesting stage

Table 22 Effect of silicon (as calcium silicate) on percent grain Si of different rice genotypes at different growth stages

Si (kg ha ⁻¹)	Genotype	<u>MANGALORE</u>				<u>MUDIGERE</u>			
		<u>Submergence</u>		<u>Aerobic</u>		<u>Submergence</u>		<u>Aerobic</u>	
		FS	HS	FS	HS	FS	HS	FS	HS
S0 (0 kg ha ⁻¹)	BI-33	0.91	0.99	0.94	1.26	1.16	1.37	1.02	1.29
	BI-43	0.74	0.84	0.74	1.06	1.30	1.22	0.86	1.09
	Rasi	0.77	1.18	0.97	1.34	1.05	1.63	1.14	1.36
	IRRI-49	0.74	0.71	0.70	1.13	1.10	1.38	0.82	1.17
S1 (966 kg ha ⁻¹)	BI-33	0.94	1.23	1.18	1.38	1.56	1.57	1.31	1.40
	BI-43	0.99	1.21	1.06	1.19	1.40	1.32	1.02	1.21
	Rasi	1.02	1.62	1.31	1.44	1.65	1.82	1.37	1.46
	IRRI-49	0.86	1.13	1.07	1.26	1.15	1.49	1.05	1.26
SEM±		0.04	0.08	0.04	0.04	0.07	0.19	0.04	0.03
CD (0.05%)		0.12	0.26	0.14	0.13	0.24	0.60	0.14	0.09

FS – Flowering stage; **HS**- Harvesting stage

Table 23 Effect of silicon (as calcium silicate) on straw silicon uptake (mg pot⁻¹) by different genotypes at different growth stages

Si (kg ha ⁻¹)	Genotype	<u>MANGALORE</u>						<u>MUDIGERE</u>					
		<u>Submergence</u>			<u>Aerobic</u>			<u>Submergence</u>			<u>Aerobic</u>		
		MT	FS	HS	MT	FS	HS	MT	FS	HS	MT	FS	HS
S0 (0 kg ha ⁻¹)	BI-33	181.3	408.1	552.1	59.3	205.8	187.1	163.7	514.4	581.7	71.0	215.0	241.5
	BI-43	175.6	353.7	496.6	45.2	199.3	162.7	130.8	380.0	485.7	56.5	206.1	222.8
	Rasi	147.1	420.8	681.1	43.8	212.2	190.4	127.5	499.0	622.4	47.3	197.5	256.9
	IRRI-49	179.8	364.5	507.6	38.9	163.7	161.4	167.0	419.5	462.5	60.3	191.3	198.0
S1 (966 kg ha ⁻¹)	BI-33	225.5	517.2	885.6	72.6	345.5	359.7	257.2	828.5	901.7	87.9	275.8	418.5
	BI-43	245.6	463.4	628.1	47.3	315.5	315.2	205.8	512.5	633.7	59.8	288.6	269.1
	Rasi	202.4	565.2	952.9	49.8	352.1	421.7	217.8	830.2	1059.7	65.3	328.3	354.4
	IRRI-49	198.7	449.3	675.0	54.2	246.7	274.0	227.2	585.0	788.0	64.3	225.6	265.8
SEM±		8.51	16.90	10.60	6.21	11.70	18.10	10.20	12.50	18.00	9.10	11.70	14.60
CD (0.05%)		28.00	55.00	34.40	20.30	38.00	59.10	33.40	40.00	58.80	29.50	38.00	47.60

• **MT**- Maximum tillering stage; **FS** – Flowering stage; **HS**- Harvesting stage

Table 24 Effect of silicon (as calcium silicate) on grain Si uptake (mg pot⁻¹) of different rice genotypes at different growth stages

Si (kg ha ⁻¹)	Genotype	MANGALORE				MUDIGERE			
		<u>Submergence</u>		<u>Aerobic</u>		<u>Submergence</u>		<u>Aerobic</u>	
		FS	HS	FS	HS	FS	HS	FS	HS
S0 (0 kg ha ⁻¹)	BI-33	88.3	145.9	27.8	74.8	103.5	279.5	32.5	78.3
	BI-43	71.7	105.3	18.4	61.2	89.5	238.0	22.7	64.6
	Rasi	90.9	147.2	26.8	82.4	98.9	285.4	36.2	85.0
	IRRI-49	79.5	88.5	18.5	63.6	88.2	213.2	20.4	67.3
S1 (966 kg ha ⁻¹)	BI-33	95.9	192.3	37.7	89.7	150.3	320.5	43.2	87.7
	BI-43	92.7	162.4	29.0	71.4	131.3	263.0	28.4	74.7
	Rasi	102.1	226.8	39.2	97.9	156.8	344.5	45.1	99.3
	IRRI-49	87.8	157.5	29.7	72.6	129.6	241.1	27.6	74.3
SEM±		2.50	10.40	1.20	3.70	3.00	9.40	1.10	2.50
CD (0.05%)		8.10	34.00	3.80	11.90	9.73	30.60	3.40	3.60

FS – Flowering stage; **HS**- Harvesting stage

Table 25 Effect of silicon (as calcium silicate) on total Si uptake (mg pot⁻¹) of different genotypes at different growth stages

Si (kg ha ⁻¹)	Genotype	<u>MANGALORE</u>						<u>MUDIGERE</u>					
		<u>Submergence</u>			<u>Aerobic</u>			<u>Submergence</u>			<u>Aerobic</u>		
		MT	FS	HS	MT	FS	HS	MT	FS	HS	MT	FS	HS
S0 (0 kg ha ⁻¹)	BI-33	181.3	497.0	698.0	59.3	233.6	261.9	163.7	617.9	861.2	71.0	247.4	319.8
	BI-43	175.6	425.4	601.9	45.2	217.7	223.8	130.8	469.5	723.6	56.5	228.8	287.3
	Rasi	147.1	511.7	828.3	43.8	239.0	272.7	127.5	597.9	907.8	47.3	233.7	341.9
	IRRI-49	179.8	444.0	596.1	38.9	182.2	225.0	167.0	507.7	675.7	60.3	211.7	265.3
S1 (966 kg ha ⁻¹)	BI-33	225.5	613.1	1077.9	72.6	383.2	449.4	257.2	978.8	1222.2	87.9	319.0	506.2
	BI-43	245.6	556.1	790.5	47.3	344.5	386.6	205.8	643.8	896.7	59.8	317.0	343.8
	Rasi	202.4	667.2	1179.7	49.8	391.3	519.6	217.8	987.0	1404.2	65.3	373.4	453.7
	IRRI-49	198.7	537.1	832.5	54.2	276.4	346.6	227.2	714.6	1029.1	64.3	253.1	340.1
SEM±		8.5	16.2	13.0	6.2	15.1	18.7	10.2	12.9	20.1	9.10	11.5	28.0
CD (0.05%)		28.00	52.7	42.3	20.3	51.0	61.0	33.40	41.9	65.6	29.5	37.7	92.0

MT- Maximum tillering stage; **FS** – Flowering stage; **HS**- Harvesting stage

higher per cent Si in grains was noticed at harvesting stage followed by flowering stage. The per cent Si in the grains recorded highest in Rasi in both Mangalore (1.62 % and 1.18%) and Mudigere (1.82 % and 1.63%) soils under submerged condition in Si treated and non treated pots respectively followed by BI 33. Similar trend as observed in submerged condition was also noticed in aerobic condition. The highest per cent Si was recorded in Rasi in both Mangalore (1.44% and 1.34%) and Mudigere (1.46% and 1.36%) soils in Si treated and non treated pots respectively. In general, per cent Si accumulation in grains was higher in submerged condition than aerobic condition and different genotypes follow the order: Rasi > BI-33 >IRRI-49~BI-43.

4.4.7 Straw Si uptake: Data pertaining to the straw Si uptake are presented in the Table 23 and results revealed that the Si uptake increased with the addition of calcium silicate as Si source over control in submerged condition. It was highest in Rasi at harvesting stage in both Mangalore (952.9 and 681.1 mg pot⁻¹) and Mudigere (1059.7 and 901.7 mg pot⁻¹) soil under submerged condition of Si treated and non treated pots. This was followed by BI-33, IRRI-49 and BI-43. In aerobic system, the Si uptake was found to increase with the supplement of calcium silicate as Si source and recorded highest in Rasi (421.7 mg pot⁻¹) in Mangalore and BI-33 (418.5 mg pot⁻¹) in Mudigere soil. In general Si uptake by different genotypes followed the order of Rasi > BI-33 > IRRI 49 > BI-43 under submerged condition and Rasi/Bi-33>BI-43>IRRI-49 in aerobic condition. The Si uptake was highest at harvesting stage followed by flowering stage and lowest was observed at maximum tillering stage in both the soils under aerobic as well as submerged condition.

4.4.8 Grain Si Uptake: The Si uptake by all the genotypes was highest under Si treated pots (Table 24) in both soils under submerged condition. It was highest in Rasi at harvesting stage in Mangalore (226.8 and 147.2 mg pot⁻¹) and Mudigere (344.5 and 285.4 mg pot⁻¹) soils under submerged condition in Si treated and non treated pots respectively. Similar observations were also

Table 26 Effect of Si and N and their interaction on biometrical observations at different locations

Si /N levels (kg ha ⁻¹)	<u>Mudigere</u>												
	<u>Plant height (cm)</u>				<u>Number of tillers per hill</u>				<u>Days to 50 % flowering</u>				
	N1	N2	N3	Mean	N1	N2	N3	Mean	N1	N2	N3	Mean	
S0	88.3	89.3	89.3	89.0	6.9	7.6	6.8	7.1	105.3	105.7	105.3	105.4	
S1	89.6	89.6	89.9	89.7	7.7	7.7	8.7	8.0	106.3	106.7	109.0	107.3	
S2	85.8	87.9	90.7	88.1	7.3	6.8	7.9	7.3	105.7	107.0	107.0	106.6	
Mean	87.9	88.9	90.0		7.3	7.4	7.8		105.8	106.4	107.1		
Effect of Si/ N	SEM±		CD (0.05%)		SEM±		CD (0.05%)		SEM±		CD (0.05%)		
	0.78		2.32		0.19		0.56		0.62		1.87		
	Si x N		1.34		NS		0.32		0.97		1.08		3.23
Si /N levels	<u>Ponnampet</u>												
	N1	N2	N3	Mean	N1	N2	N3	Mean	N1	N2	N3	Mean	
	S0	75.6	77.2	76.0	76.3	6.3	7.3	8.1	7.2	106.3	106.3	106.6	106.4
S1	76.5	78.9	79.6	77.9	8.4	8.3	8.5	8.4	107.0	107.6	107.0	107.2	
S2	76.7	76.7	79.5	78.4	7.9	7.9	8.1	8.0	107.0	108.0	107.0	107.3	
	76.2	78.7	77.7		7.5	7.8	8.2		106.8	107.3	106.9		
Effect of Si/ N	SEM±		CD (0.05%)		SEM±		CD (0.05%)		SEM±		CD (0.05%)		
	0.73		2.17		0.15		0.45		0.47		NS		
	Si x N		1.26		3.77		0.26		0.79		0.82		2.44

S0: 0 kg Si ha⁻¹, S1: 117 kg Si ha⁻¹, S2: 234 kg Si ha⁻¹,N1: 50 kg N ha⁻¹, N2: 100 kg N ha⁻¹, N3: 150 kg N ha⁻¹

Table 27 Effect of Si and N and their interaction on percent spikelet sterility

Si/ N levels (kg ha ⁻¹)	Blank spikelets <------(kg ha ⁻¹)----->				Spikelet sterility <------(%)----->		
	N1	N2	N3	Mean	N1	N2	N3
	<u>MUDIGERE</u>						
S0	376.7	516.7	500.0	464.4	6.63	7.92	9.24
S1	283.3	353.3	456.7	364.4	4.44	5.03	5.81
S2	306.7	373.3	363.3	347.8	4.65	4.94	5.98
Mean	322.2	414.4	440.0		5.24	5.97	7.01
	SEM±		CD (0.05 %)				
Effect of Si/N	22.7		55.8				
Si x N	36.5		86.7				
	<u>PONNAMPET</u>						
Si/ N levels (kg ha ⁻¹)	N1	N2	N3	Mean	N1	N2	N3
S0	240.0	310.0	305.0	285.0	6.42	6.67	6.42
S1	270.0	195.0	385.0	283.0	5.67	3.48	5.93
S2	200.0	305.0	375.0	293.0	4.62	6.47	6.14
Mean	237	270	355		5.57	5.54	6.16
	SEM±		CD (0.05 %)				
Effect of Si/ N	20.5		51.0				
Si x N	30.6		79.0				
S0: 0 kg Si ha ⁻¹ , S1: 117 kg Si ha ⁻¹ , S2: 234 kg Si ha ⁻¹ , N1: 50 kg N ha ⁻¹ , N2: 100 kg N ha ⁻¹ , N3: 150 kg N ha ⁻¹							

4.5.1 Plant height:

The data pertaining to the effect of Si and N on plant height (cm) at Mudigere and Ponnampet are presented in Table 26 and there was no significant difference in plant height due to the effect of Si and N in both Mudigere and Ponnampet locations.

4.5.2. Number of tillers

The effect of Si and N and their interaction on number of tillers was found to be statistically significant in both the studied locations (Table 26). There was significant increase in number of tillers per hill with the application of 117 kg Si ha⁻¹(S1) over control in Mudigere (8.0) and Ponnampet (8.4). The application of Si along with increased levels of N (up to 150 kg ha⁻¹) increased the number of tillers and highest number of tillers was noticed with 117 kg Si (S1) and 150 kg N ha⁻¹ (N3) in both Mudigere (8.7) and Ponnampet (8.5).

4.5.3 Per cent spikelet sterility

The results pertaining to the effect of Si and N and their interaction on per cent spikelet sterility in soils of Mudigere and Ponnampet are presented in Table 27 and Fig. 14. There was significant increase in spikelet sterility with the application of higher doses of N (N3) at Mudigere (440 kg ha⁻¹) and Ponnampet (355 kg ha⁻¹) locations. A significant reduction in per cent spikelet sterility was observed due to combined application of Si along with higher doses of N.

4.5.4 Grain yield of rice

Results of the grain yield obtained due to the combined application of different levels of Si and N are presented in Table 28 and Fig. 13. There was a significant difference with respect to grain yield of KRH-2 in both the studied locations. The highest grain yield was recorded with the application of 100kg N and further application decreased the grain yield at Mudigere but not in Ponnampet. Similarly, application of 117 kg Si ha⁻¹ (S1) recorded highest grain

Table 28 Effect of Si and N and their interaction on grain and straw yield of rice

Si/N levels (kg ha ⁻¹)	Grain Yield <----- kg ha ⁻¹ ----->				Straw yield <----- -- kg ha ⁻¹ ----->				Grain harvest index <----->			
	N1	N2	N3	Mean	N1	N2	N3	Mean	N1	N2	N3	Mean
<u>Mudigere</u>												
S0	5680	6520	5410	5870	6367	7880	8587	7611	0.47	0.45	0.39	0.44
S1	6377	7023	7860	7087	6840	8000	8497	7779	0.48	0.49	0.48	0.49
S2	6600	7553	6073	6742	6987	8100	6927	7338	0.49	0.47	0.47	0.48
Mean	6219	7032	6448		6731	7993	8006		0.48	0.47	0.45	
	SEM±		CD (0.05 %)		SEM±		CD (0.05 %)		SEM±		CD (0.05 %)	
Effect of Si/N	266		89		362		121		0.004		0.013	
Si x N	460		154		626		209		0.007		0.022	
<u>Ponnampet</u>												
Si/N levels	N1	N2	N3	Mean	N1	N2	N3	Mean	N1	N2	N3	Mean
S0	3740	4645	4750	4378	3780	4720	4990	4497	0.50	0.50	0.49	0.49
S1	4760	5600	6490	5617	4815	5695	6600	5703	0.50	0.50	0.50	0.50
S2	4325	4715	6110	5050	4485	4620	6270	5125	0.49	0.51	0.49	0.50
Mean	4275	4787	5783		4360	5012	5953		0.50	0.50	0.49	
	SEM±		CD (0.05 %)		SEM±		CD (0.05 %)		SEM±		CD (0.05 %)	
Effect of Si/N	108		352		147		479		0.003		0.008	
Si x N	187		610		254S		829		0.004		0.014	

S0: 0 kg Si ha⁻¹, **S1:** 117 kg Si ha⁻¹, **S2:** 234 kg Si ha⁻¹, **N1:** 50 kg N ha⁻¹, **N2:** 100 kg N ha⁻¹, **N3:** 150 kg N ha⁻¹

yield in both Mudigere (7087 kg ha⁻¹) and Ponnampet (6490 kg ha⁻¹) and further application decreased the grain yield in both the locations. However, combined application of 117 kg Si ha⁻¹ (S1) along with 150 kg N (N3) recorded highest grain yield in both Mudigere (7860 kg ha⁻¹) and Ponnampet (6490 kg ha⁻¹). In general, application of higher doses of N alone decreased the grain yield. But combined application of higher doses of N along with 117 kg Si ha⁻¹ (S1) increased the grain yield in both locations.

4.5.5 Straw yield of rice

It was observed that increased application of N alone significantly increased the straw yield to an extent of 8006 kg ha⁻¹ (N3) at Mudigere and 5953 kg ha⁻¹ (N3) at Ponnampet. Application of 117 kg Si ha⁻¹ (S1) at Ponnampet significantly increased the straw yield (5703 kg ha⁻¹) but it was on par at Mudigere over control. However combined application of 150 kg N (N3) along with 117 kg Si ha⁻¹ (S1) at Ponnampet recorded highest straw yield of 6600 kg ha⁻¹ and similar trend was also observed at Mudigere. In general, application of Si along with higher doses of nitrogen (up to N3) significantly increased the straw yield.

4.5.6 Grain harvest index of rice

The data pertaining to the grain harvest index of KRH-2 rice significantly decreased with the increased application of N alone (Table 29). Whereas application of Si significantly increased the grain harvest index and the highest grain harvest index (0.485) was noticed with the application of 117 kg Si ha⁻¹ (S1) at Mudigere. However, there was no significant difference observed with the application of Si or N alone. The interaction between Si and N on grain harvest index was found to be significant at Mudigere but not at Ponnampet.

4.5.7 Per cent Si and N in Straw and grain

Table 29 Effect of Si and N and their interaction on Si and N content (%) in straw and grains at Mudigere

Si/N levels (kg ha ⁻¹)	<u>Si (%)</u>				<u>N (%)</u>			
	<u>Straw</u>							
	N1	N2	N3	Mean	N1	N2	N3	Mean
S0	3.15	3.20	2.70	3.02	0.21	0.38	0.34	0.31
S1	5.24	4.50	4.22	4.65	0.27	0.33	0.46	0.36
S2	5.59	4.90	4.51	5.00	0.24	0.35	0.39	0.33
Mean	4.66	4.20	3.81		0.24	0.35	0.40	
	SEM±		CD (0.05%)		SEM±		CD (0.05%)	
Effect of Si/ N	0.16		0.48		0.03		0.10	
Si x N	0.28		0.830		0.05		0.18	

Si / N levels	<u>Grains</u>							
	N1	N2	N3	Mean	N1	N2	N3	Mean
S0	2.51	2.53	2.43	2.49	1.07	1.19	1.20	1.15
S1	3.61	3.37	3.08	3.35	1.13	1.16	1.18	1.16
S2	3.50	3.45	3.27	3.41	1.09	1.15	1.16	1.13
Mean	3.21	3.11	2.93		1.10	1.16	1.18	
	SEM±		CD (0.05%)		SEM±		CD (0.05%)	
Effect of Si/N	0.12		0.35		0.02		0.05	
Si x N	0.20		0.60		0.03		0.09	

S0: 0 kg Si ha⁻¹, **S1:** 117 kg Si ha⁻¹, **S2:** 234 kg Si ha⁻¹, **N1:** 50 kg N ha⁻¹, **N2:** 100 kg N ha⁻¹, **N3:** 150 kg N ha⁻¹

Table 30 Effect of Si and N and their interaction on Si and N uptake in grain and straw in rice at Mudigere

Si /N levels (kg ha ⁻¹)	Si uptake (kg ha ⁻¹)				N uptake (kg ha ⁻¹)			
	N1	N2	N3	Mean	N1	N2	N3	Mean
<u>Straw</u>								
S0	200.7	252.4	232.2	228.4	13.9	29.7	29.5	24.3
S1	359.3	327.2	357.1	347.9	18.8	24.4	39.0	27.4
S2	389.7	414.4	310.3	371.4	16.4	29.0	27.6	24.3
Mean	316.6	331.3	299.8		16.3	27.7	32.0	
SEM±		CD (0.05%)		SEM±		CD (0.05%)		
Effect of Si/N	14.3	42.9		2.10		6.3		
Si x N	24.8	74.3		3.62		10.8		
Si /N levels (kg ha ⁻¹)	<u>Grains</u>							
	N1	N2	N3	Mean	N1	N2	N3	Mean
S0	142.4	165.8	131.3	146.5	61.3	75.5	61.9	66.2
S1	229.2	235.5	242.0	235.5	68.2	79.4	91.7	79.7
S2	230.5	259.0	197.2	228.9	70.8	83.8	67.8	74.1
Mean	200.7	220.1	190.1		66.7	79.6	73.8	
SEM±		CD (0.05%)		SEM±		CD (0.05%)		
Effect of Si/N	7.6	22.7		0.7		2.2		
Si x N	13.1	39.3		1.3		3.8		

S0: 0 kg Si ha⁻¹, **S1:** 117 kg Si ha⁻¹, **S2:** 234 kg Si ha⁻¹, **N1:** 50 kg N ha⁻¹, **N2:** 100 kg N ha⁻¹, **N3:** 150 kg N ha⁻¹

Table 31 Effect of Si and N and their interaction on Si and N content (%) in rice at Ponnampet

Si / N levels (kg ha ⁻¹)	Si (%)				N (%)			
	N1	N2	N3	Mean	N1	N2	N3	Mean
				Straw				
S0	2.14	2.57	2.39	2.36	0.56	0.75	0.74	0.68
S1	3.35	4.46	3.35	3.72	0.63	0.72	0.78	0.71
S2	3.51	3.60	2.91	3.34	0.48	0.75	0.75	0.66
Mean	3.00	3.54	2.88		0.56	0.74	0.76	
	SEM±		CD (0.05%)		SEM±		CD (0.05%)	
Effect of Si/N	0.06		0.19		0.09		0.29	
Si x N	0.10		0.32		0.15		0.49	
				Grains				
Si / N levels	N1	N2	N3	Mean	N1	N2	N3	Mean
S0	1.01	1.19	1.11	1.10	1.01	1.23	1.07	1.10
S1	1.87	2.03	1.28	1.72	1.01	1.12	1.40	1.18
S2	1.32	1.38	1.10	1.26	1.08	1.20	1.44	1.24
Mean	1.40	1.53	1.16		1.03	1.18	1.30	
	SEM±		CD (0.05%)		SEM±		CD (0.05%)	
Effect of Si/N	0.04		0.12		0.02		0.07	
Si x N	0.06		0.21		0.04		0.12	

S0: 0 kg SiO₂ ha⁻¹, **S1:** 117 kg Si ha⁻¹, **S2:** 234 kg Si ha⁻¹,

N1: 50 kg N ha⁻¹, **N2:** 100 kg N ha⁻¹, **N3:** 150 kg N ha⁻¹

Table 32 Effect of Si and N and their interaction on Si and N uptake at Ponnampet

Si / N levels (kg ha ⁻¹)	Si uptake (kg ha ⁻¹)				N uptake (kg ha ⁻¹)			
	N1	N2	N3	Mean	N1	N2	N3	Mean
Straw								
S0	80.8	121.3	119.0	107.0	21.2	35.4	36.7	31.1
S1	161.4	254.1	221.3	212.2	30.7	41.1	51.3	41.0
S2	157.3	165.6	182.3	168.4	21.2	33.9	47.2	34.1
Mean	133.1	180.3	174.2		24.4	36.8	45.1	
	SEM±		CD (0.05%)		SEM±		CD (0.05%)	
Effect of Si/N	3.6		11.7		3.1		10.0	
Si x N	6.2		20.1		5.3		17.3	
Grains								
Si / N levels	N1	N2	N3	Mean	N1	N2	N3	Mean
S0	37.8	55.3	52.5	48.6	37.6	57.3	50.7	48.5
S1	88.7	113.7	83.0	95.1	48.3	62.5	90.8	67.2
S2	57.0	64.9	67.1	63.0	46.9	56.5	88.3	63.9
Mean	61.2	78.0	67.6		44.2	58.8	76.6	
	SEM±		CD (0.05%)		SEM±		CD (0.05%)	
Effect of Si/N	2.2		7.3		1.7		5.6	
Si x N	3.9		12.7		3.0		9.6	

S0: 0 kg Si ha⁻¹, **S1:** 117 kg Si ha⁻¹, **S2:** 234 kg Si ha⁻¹,

N1: 50 kg N ha⁻¹, **N2:** 100 kg N ha⁻¹, **N3:** 150 kg N ha⁻¹

The effect of Si and N and their interaction on per cent Si and N in straw and grain at Mudigere and Ponnampet are presented in the Table 29 and 31 respectively. Increased application of N alone significantly decreased the per cent Si in both straw and grain at both locations. Whereas, application of higher levels of Si alone increased the accumulation of Si in straw as well as grain at both locations. The interaction between Si and N was found to be statistically significant.

The per cent N in straw and grain significantly increased with increased application of N alone at both locations. Application of higher levels (S2) of Si decreased the per cent N in both straw as well as grain at Mudigere location and increasing trend was observed at Ponnampet location (Table 32). The interaction effect of Si and N on per cent N was found to be significant in both grain as well as straw at both locations.

4.5.8 Si and N uptake in grain and straw

The data pertaining to Si and N uptake in grain and straw at Mudigere and Ponnampet are presented in Table 30 and 32 respectively. Increased application of Si alone significantly increased Si uptake in both grain and straw at both locations. However, increased application of N alone significantly increased the grain and straw Si uptake only at Ponnampet but not at Mudigere. The interactions between Si and N on Si uptake by both grain as well as straw were found to be statistically significant.

The N uptake in straw and grain increased significantly due to supplement of higher doses (up to N3) of N alone at both locations. Increased N uptake in straw was noticed with the application of 117 kg Si ha⁻¹ (S1) alone and then showed a declining trend. A significant increase in grain N was noticed with the application of 117 kg Si ha⁻¹ (S1) and then showed a declining trend in both locations. The interaction effect of Si and N was found to be statistically significant.

Table 33 Effect of Si and N and their interaction on the incidence of insect pests and diseases in rice at Mudigere

Si / N levels (kg ha ⁻¹)	<u>Leaf blast</u>				<u>Brown leaf spot</u>				<u>Bacterial leaf blight</u>			
	N1	N2	N3	Mean	N1	N2	N3	Mean	N1	N2	N3	Mean
S0	3	3	4	3.3	1.7	2.0	2.3	2.0	2.3	2.7	3.0	2.7
S1	1	1	1	1.0	0.7	0.8	1.3	0.9	1.3	1.7	0.8	1.3
S2	1	2	2	1.7	0.7	0.8	1.0	0.8	1.7	2.3	1.3	1.8
Mean	2	2	3		1.0	1.2	1.6		1.8	2.2	1.7	
	SEM±		CD (0.05%)		SEM±		CD (0.05%)		SEM±		CD (0.05%)	
Effect of Si/N	0.24		0.56		0.15		0.44		0.26		0.79	
Si x N	0.42		1.12		0.26		0.77		0.45		1.36	

Si / N levels	<u>Leaf roller</u>				<u>Blue beetle</u>				<u>Hispa</u>			
	N1	N2	N3	Mean	N1	N2	N3	Mean	N1	N2	N3	Mean
S0	2.7	3.3	4.0	3.3	0.7	1.0	1.3	1.0	1.3	1.7	2.0	1.7
S1	1.3	1.7	2.0	2.2	0.3	0.3	0.7	0.4	0.7	1.0	0.7	0.8
S2	1.0	1.7	2.3	2.8	0.3	0.7	0.3	0.4	0.3	0.7	1.0	0.7
Mean	1.7	2.2	2.8		0.4	0.7	0.8		0.8	1.1	1.2	
	SEM±		CD (0.05%)		SEM±		CD (0.05%)		SEM±		CD (0.05%)	
Effect of Si/N	0.21		0.63		0.26		0.78		0.22		0.66	
Si x N	0.37		1.09		0.45		1.20		0.38		1.14	

S0: 0 kg Si ha⁻¹, **S1:** 117 kg Si ha⁻¹, **S2:** 234 kg Si ha⁻¹

N1: 50 kg N ha⁻¹, **N2:** 100 kg N ha⁻¹, **N3:** 150 kg N ha⁻¹

Table 34 Effect of Si and N and their interaction on the incidence of insect pests and diseases in rice at Ponnampet

Si / N levels (kg ha ⁻¹)	<u>Leaf blast</u>				<u>Udabatta</u>			
	N1	N2	N3	Mean	N1	N2	N3	Mean
S0	1.0	1.3	3.0	1.2	1.3	1.0	2.0	1.4
S1	0.5	0.5	0.2	0.4	0.3	0.0	0.0	0.1
S2	0.6	0.1	0.4	0.4	0.0	0.7	0.0	0.2
Mean	0.7	0.6	1.2		0.6	0.6	0.7	
	SEM±		CD (0.05%)		SEM±		CD (0.05%)	
Effect of Si/N	0.1		0.2		0.2		0.6	
Si x N	0.1		0.3		0.3		1.0	

S0: 0 kg Si ha⁻¹, **S1:** 117 kg Si ha⁻¹, **S2:** 234 kg Si ha⁻¹

N1: 50 kg N ha⁻¹, **N2:** 100 kg N ha⁻¹, **N3:** 150 kg N ha⁻¹

4.5.9 Incidence of insect pests and disease

The data pertaining to Si and N and its interaction effect on disease and insect pest incidence at Mudigere and Ponnampet are presented in Table 33 and 34 respectively. There was a significant increase in leaf blast, brown leaf spot and leaf roller due to the increased application of N alone. However, significant reduction in diseases (leaf blast, brown leaf spot and bacterial leaf spot) and insect pests (leaf roller, case worm and hispa) were noticed due to the application of Si over control. The interaction effect of Si and N on control of insect pests and diseases was found to be statistically significant at Mudigere (Table 33).

There was increasing incidence of leaf blast and *Udabatta* diseases with increased application of N alone at Ponnampet. However significant reduction in both the diseases was observed due to the application of Si. The interaction between Si and N was found to be significant in controlling the leaf blast and *udabatta* diseases at Ponnampet (Table 34).

Discussion

V. DISCUSSION

The results of the investigation on various aspects of available Si viz., available Si status, evaluation of suitable soil test method for available Si, critical limits for soil and plant Si, evaluation of genotypic variation for Si accumulation under different moisture regimes, interaction effect of Si and N on growth and yield of rice in soils of Karnataka are discussed under the following headings:

- 5.1 Plant available Si status in rice growing soils of Karnataka.
- 5.2 Evaluation of different extractants for available Si in soils
- 5.3 Critical limits of soil and plant Si in rice
- 5.4 Evaluation of genotypic difference in relation to Si accumulation under different moisture regimes
- 5.5 Interaction effect of Si and N on growth and yield of rice

5.1 Plant available Si status in different rice growing soils of Karnataka

The available Si content extracted by ammonium acetate and acetic acid ranged from 7.1 to 64.6 and 15.9 to 78.4 ppm, respectively (Table 6, 7 and 8). In Mangalore soils, the Si content extracted by 0.5M ammonium acetate and 0.5M acetic acid were highest in Kalmanja-3 (46.3 ppm) and Gurupur-2 (78.4 ppm) and lowest in Kankanadi-4 (8.1 ppm) and Kankanadi-3 (18.2 ppm) respectively. In Mudigere soil, the lowest Si content as extracted by 0.5 M ammonium acetate and acetic acid in Bijuvalli-2 (9.2 ppm) and Gonibeedu-2 (15.9 ppm), and highest Si content in Dundige-4 (64.6 ppm) and Halase (72.2 ppm), respectively. In Ponnampet soils, the lowest and the highest available Si were noticed in Kunda-3 (7.3 and 16.8 ppm) and B. Guntahalli-1(54.9 and 74.2 ppm) respectively for 0.5 M ammonium acetate and acetic acid extractants. The variation among the available Si was mainly attributed to the cultivation practices followed, cropping system, organic carbon content of the soils, soil

reaction, rainfall, parent materials, topography of the land, soil type and type and nature of the crop residues incorporated etc.

The available Si extracted by different extractants in soils of Kerala ranged from 8 to 435 ppm (Nair and Aiyer., 1968, Sadanandan and Vergeese., 1968, Nayar *et al.*, 1982a). Similarly the available Si in soils of Tamil nadu ranged from 29 to 80 ppm (Subramanian and Gopalaswamy., 1990 and 1991). Nayar *et al.*, (1977) reported that the available Si extracted by N NaOAc ranged from 8 to 278 ppm in soils of Orissa. The results are also in agreement with the findings of Matichenkov *et al.*, (2000) in soils of south Florida and Korndorfer *et al.*, (2001) in soils of Brazil.

In general, soils of Ponnampet recorded lowest available Si followed by Mangalore and highest available Si was recorded at Mudigere soils. There was wide variation in available Si content among the soils studied. This was mainly attributed to the clay content, amount of rainfall and organic matter content of the particular location (Korndorfer *et al.*, 2001). Among the locations, soils of ponnampet recorded lowest organic carbon, clay content and comparatively lower rainfall compared to other locations. Extractable available Si values increases with soil clay content (Meyer, 2001). Gontijo (2000) observed that soil Si values decreased with increased content of sand in the soil. Soils with high percentage of sand tend to show low Si contents due to their poor capacity to supply Si to plants. Sand consists basically of quartz minerals and in spite of having high SiO₂ content in its composition, has a low Si release potential in the short and medium term. Thus sand fraction of a soil is practically inert. Sandy soils normally show good drainage, which prevents Si accumulation.

In general, 0.5M acetic acid extractable available Si was higher than the ammonium acetate extractable Si (Table 9). This was mainly attributed to the extracting power of the individual extractant, soil to solution ratio taken for analysis, pH of the extractant and forms of Si which extracts (Nayar *et al.*, 1977).

The sodium acetate buffer extracted the greatest amounts of Si (0 to 509 ppm), followed by acetic acid (1 to 239 ppm) and calcium chloride (3 to 109 ppm) in organic and mineral soils of Florida respectively (Rodrigues *et al.*, 2003). Similar results were also noticed by Filho *et al.* (2001) in some soils of Brazil.

Among the soils studied from two different agro climatic zones of Karnataka, 75 to 90 per cent of soils were low to medium in available Si as extracted by both the methods (Table 9). This could be attributed to the depletion of available Si due to continuous rice cultivation, low solubility and / or slow dissolution kinetics of soil Si (Lindsay, 1979 and Drees *et al.*, 1989), high uptake of Si by rice crops to an extent of 250 kg ha⁻¹ for producing grain yield of 5 t ha⁻¹ (Savant *et al.*, 1997), limited attempts by farmers to recycle Si in crop residues and / or apply balanced fertilizer that include Si sources (Savant *et al.*, 1997).

5.2 Evaluation of different extractants for plant available silicon in rice soils

5.2.1 Available silicon by different extractants

Different extractants were used to select suitable extractants for diagnosing plant available Si status of rice soils by growing rice as the test crop. The available Si extracted by different extractants viz., 0.5M acetic acid-1, 0.5M acetic acid-2, 0.5M acetic acid-3, 0.01M CaCl₂, distilled water-1, distilled water-4, 0.5M NH₄OAc, N NaOAc-1, N NaOAc-2, 0.1M citric acid and 0.005M H₂SO₄ were ranged from 11.3 to 73.8 ppm, 13.2 to 60.2 ppm, 22.1 to 102.5 ppm, 22.4 to 55.9 ppm, 6.1 to 16.9 ppm, 12.7 to 37.1 ppm, 10.9 to 42.3 ppm, 38.5 to 86.7 ppm, 47.8 to 97.9 ppm, 44.1 to 317.7 ppm and 118 to 263.2 ppm respectively (Table 10 and Fig. 3). The available Si extracted by various extractants irrespective of the soils used for the study was in the order of 0.005M H₂SO₄ > 0.1M citric acid > N NaOAc-2 > N NaOAc-1 > 0.5M acetic acid-3 > 0.5M acetic acid-2 > 0.5M acetic acid-1 > 0.01M CaCl₂ > 0.5M NH₄OAc > distilled water-4 > distilled water-1 (Fig. 3). This variation may be attributed to dissolution of soluble, exchangeable and specifically adsorbed Si

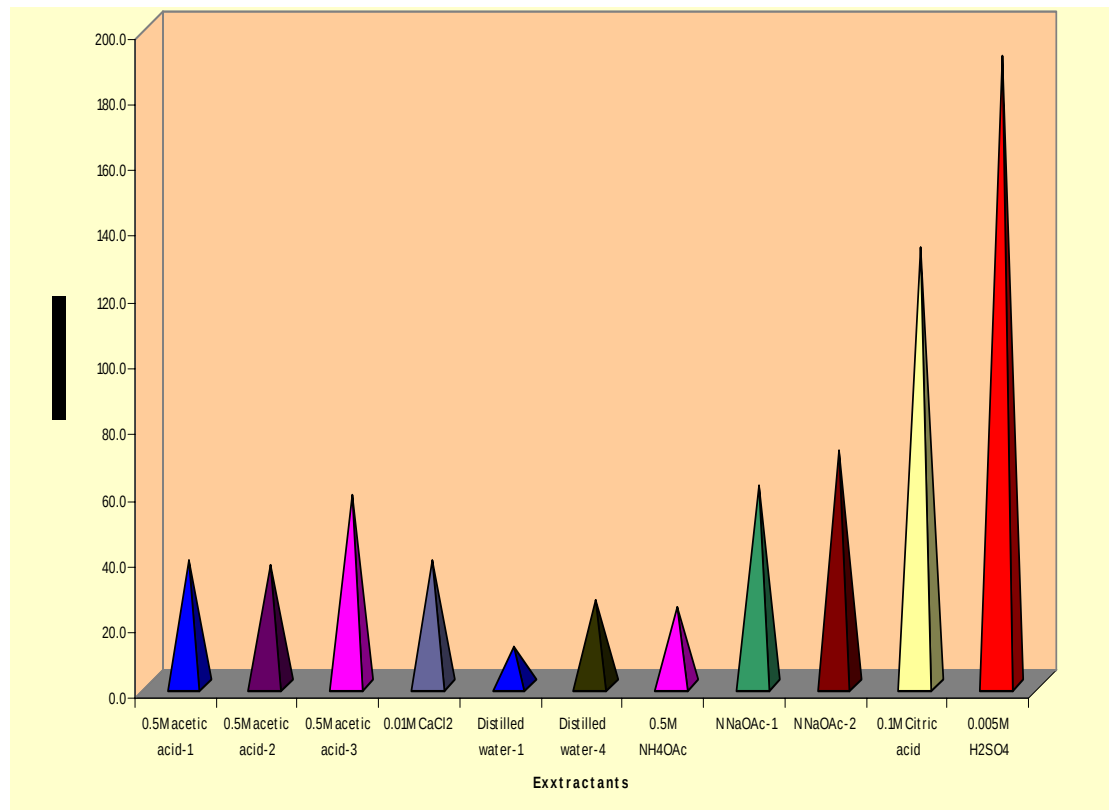


Fig. 2 The available Si as extracted by different extractants

and also dissolution of some unavailable forms of Si present in the soils, based on the kind and nature of the extractant used, its soil to solution ratio, pH of the extractant used, shaking period, etc. The longer the contact times of the extractant, higher the extraction of available Si. It must be assumed that, with a continuous shaking of 16 hrs, silicate clay minerals were attacked by both chemically and mechanically and there by overestimating available Si by citric and sulphuric acid as extractants (Hurney, 1973).

Daniela *et al*, (2006) reported that the different extractants showed different capabilities to desorb silicic acid and greater extraction potential with H_2SO_4 and citric acid and least with distilled water. Similar results were also noticed by Fox *et al* (1967) and reported that acetic acid, sulphuric acid and calcium dihydrogen phosphates had greater Si extraction potential than extraction with water and CaCl_2 . Berthelsen *et al*. (2001) compared six extraction methods viz., CaCl_2 , sodium acetate, acetic acid, phosphate buffer, citric acid, sulphuric acid for sugarcane soils of Southern Australia and noticed that ammonium acetate, acetic acid and phosphate buffer extracted 1, 1.5 and 3 times more Si from soils than distilled water and CaCl_2 . Diluted sulphuric acid and citric acid dissolved 12 and 16 times, respectively more Si than CaCl_2 and distilled water. They suggested that CaCl_2 and distilled water extracts easily soluble Si and sodium acetate, acetic acid and phosphate buffer dissolve some exchangeable Si also, while citric acid and sulphuric acid extract specifically adsorbed Si. In general, lower the pH of the extractant, higher the Si extraction power of the soil. Hence citric acid and sulphuric acid extracted higher available Si in all the soils compared to other extractants. Similar results were also noticed by Hurney, (1973).

5.2.2 Plant growth indices for evaluation of different extractants

The growth indices considered in soil test evaluation for available Si were per cent Si content in straw and grain and its uptake in check pots (Table 11). The grain and straw yield of rice in check pots ranged from 19.1 to 36.7

mg pot⁻¹ and 29.5 to 44.0 g pot⁻¹, respectively. The per cent Si content of grain and straw were ranged from 0.72 to 1.70 and 2.22 to 3.41 respectively. Similarly, Si uptake in grain and straw and total uptake ranged from 127.6 to 561.6 mg pot⁻¹, 644.3 to 1309.0 mg pot⁻¹ and 847.5 to 1820.4 mg pot⁻¹ respectively for different soils. The grain and straw yield, per cent Si and its uptake in grain increased with increasing soil Si levels and yield increase was negligible, when soil Si levels were high. The higher grain and straw yield in Si treated pots were mainly attributed to higher photosynthetic activity, control of pest and diseases and there by increased dry matter production (Agarie *et al.*, 1992). Similar results were also reported by Takahashi *et al* (1990) in soils of Sreelanka, Singh *et al.* (2006) in soils of India and Snyder *et al.* (1986) and Korndorfer *et al.* (2001) in some soils of Florida.

5.2.3 Relationship between soil test values extracted by different methods and crop growth parameters

Among all the eleven extractants studied, ten extractants showed significantly positive correlation between contents and uptake of Si by straw and grain and available Si. However, the highest degree of significant correlation was noticed between available Si extracted by N NaOAc-1, 0.5 M acetic acid-2 and N NaOAc-2 and per cent Si in straw, grain, Si uptake by straw, grain and total uptake in check pots (Table 12 and Table 13 and Fig. 3A-F and 4A-F). The soils were sandy loam to sandy clay loam in texture, contained enough quantities of available Si and hence had a good Si supplying power. Hence these methods were considered to be the suitable methods for evaluating the Si supplying power of rice growing soils of Karnataka.

The available Si extracted by water, CaCl₂ and NH₄OAc dissolves only water soluble fraction present in the soils. While diluted 0.005M sulphuric acid, citric acid and acetic acid-3 dissolves some of the non available Si fraction in soil such as amorphous (phytoliths, silica cutans, etc), microcrystalline (allophone, imogolite and opal) and crystalline (primary and secondary silicate)

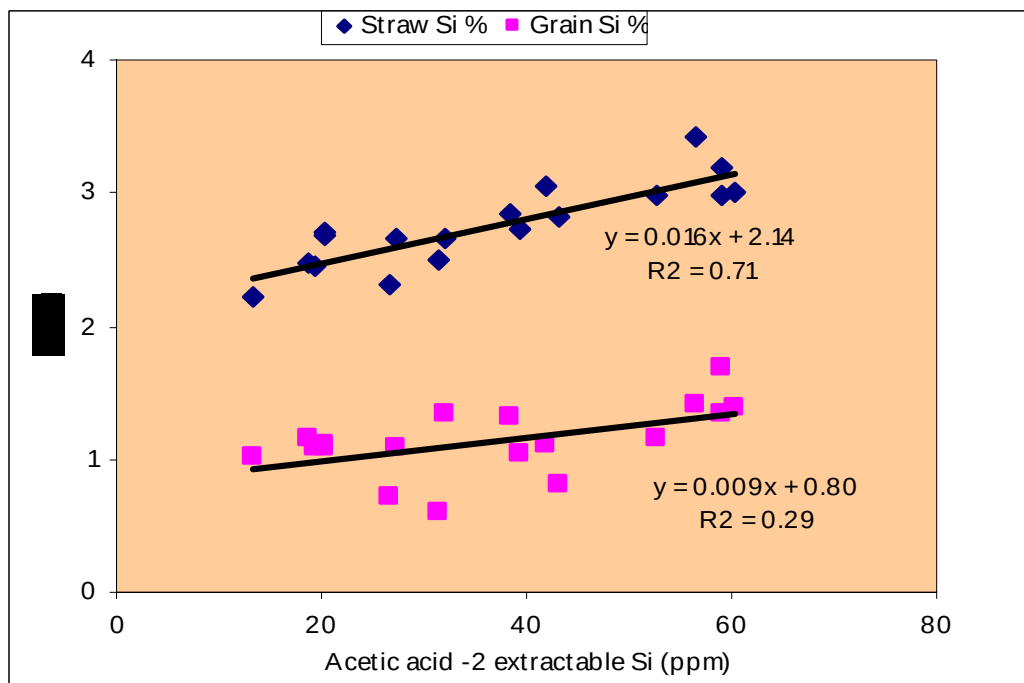
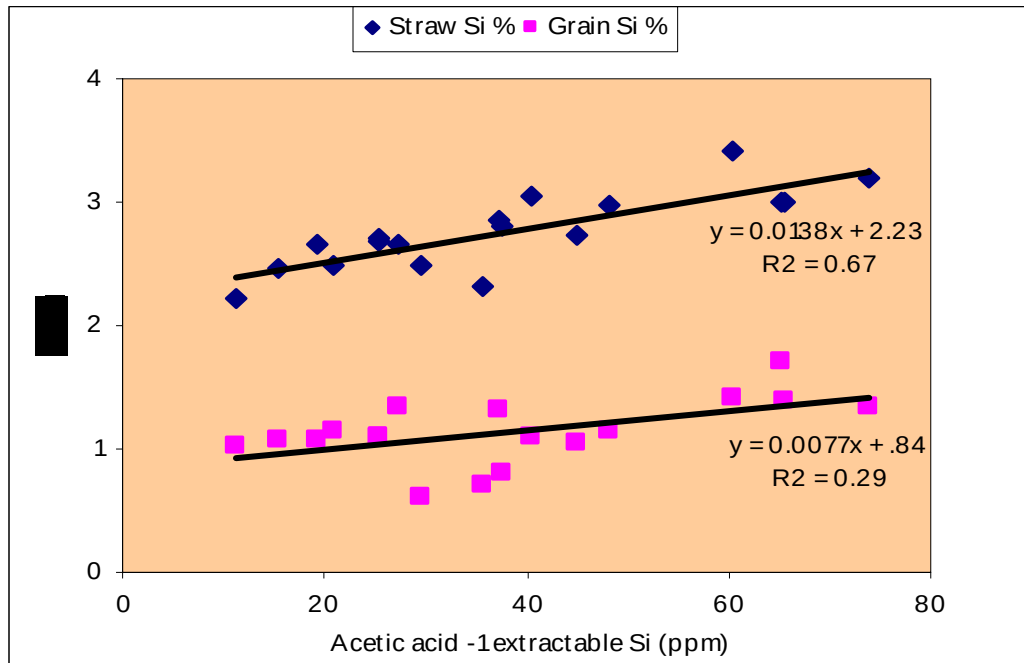


Fig. 3A Relationship between percent Si in straw and grain and plant available soil Si extracted by (a) Acetic acid-1 and (b) Acetic acid-2 extractants

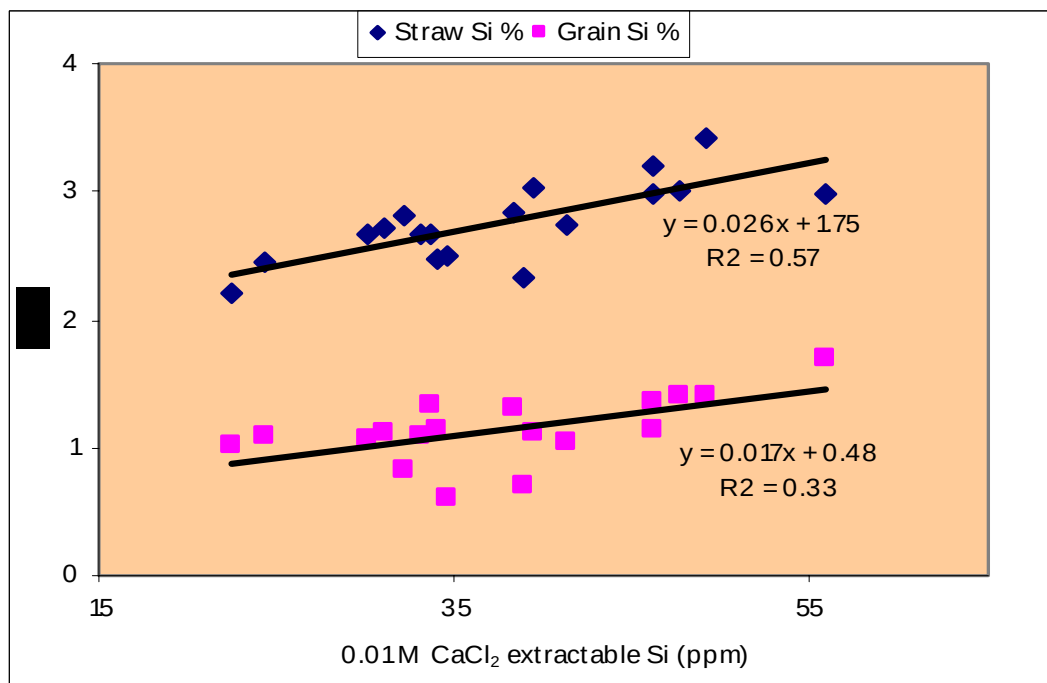
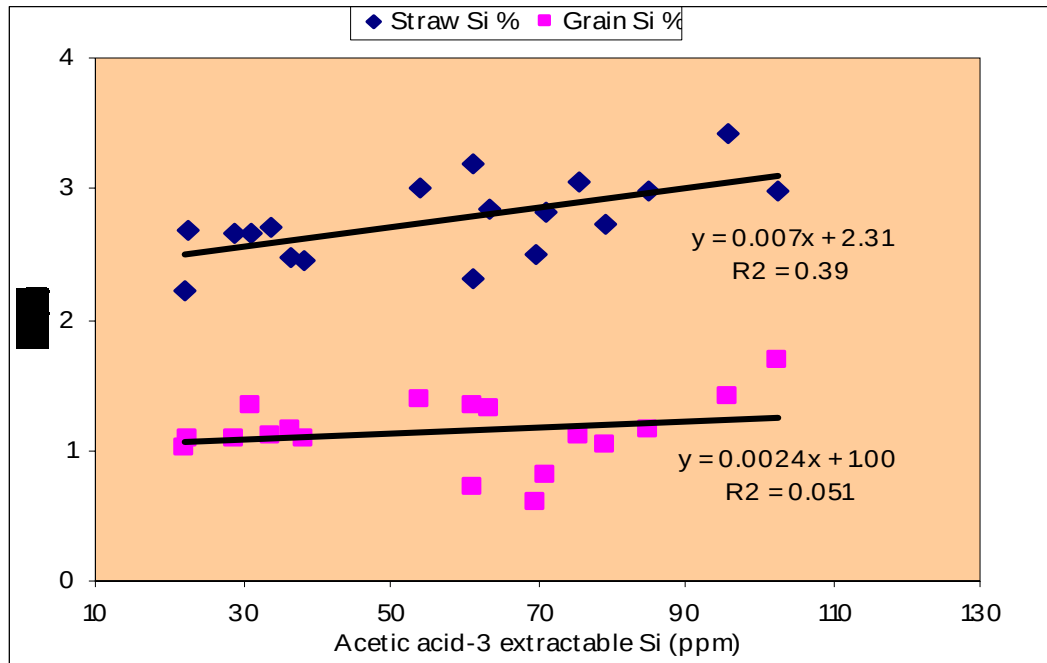


Fig. 3B Relationship between percent Si in straw and grain and plant available soil Si extracted by (a) Acetic acid-3 and (b) 0.01M CaCl₂ extractants

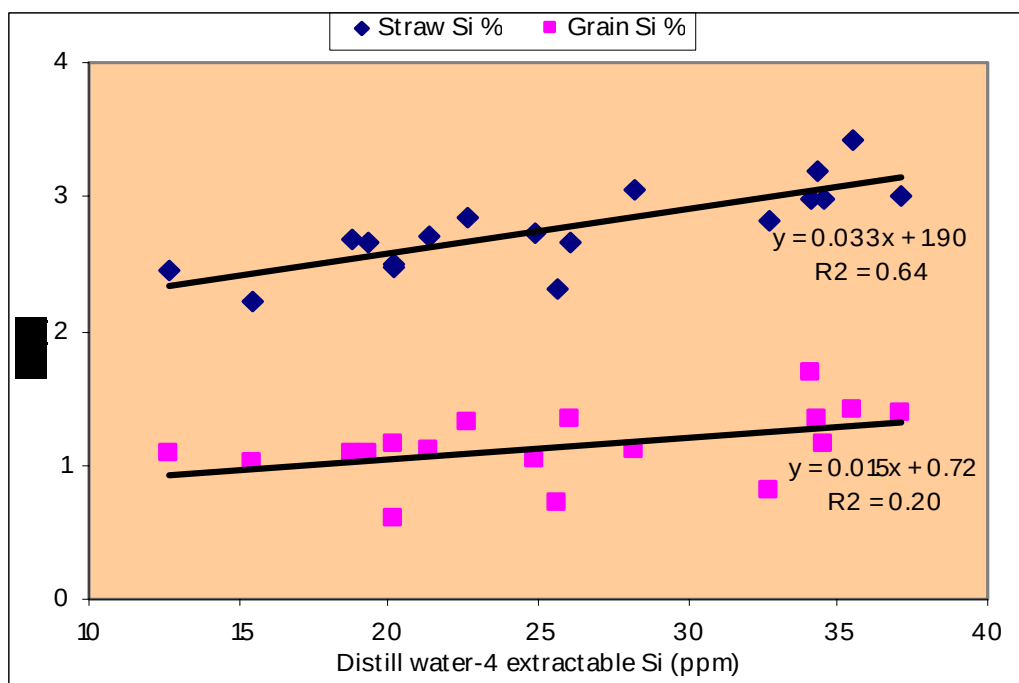
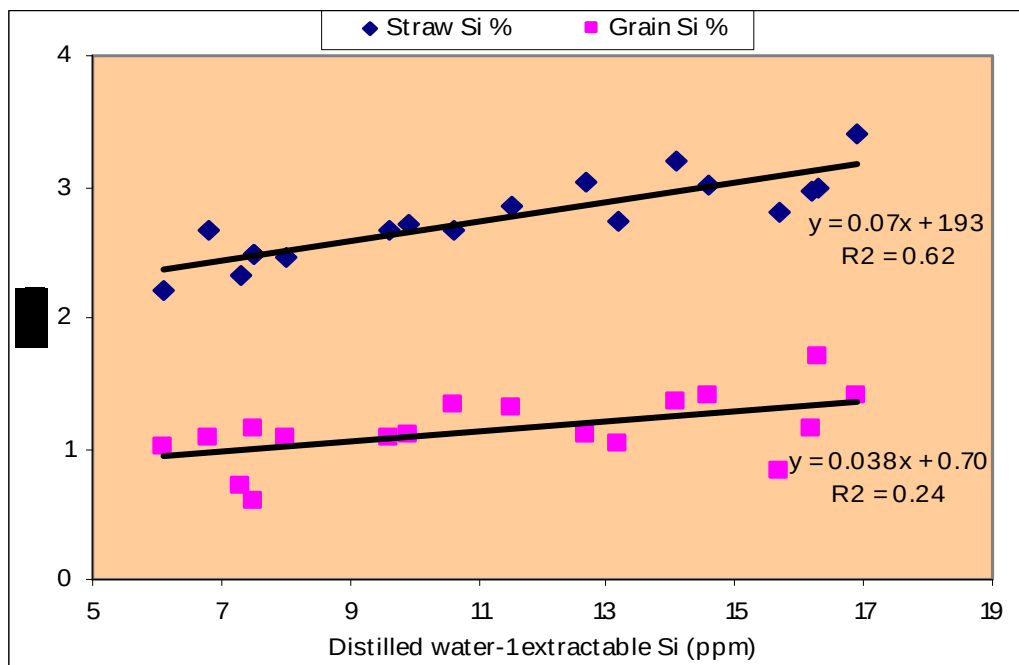


Fig. 3C Relationship between percent Si in straw and grain and plant available soil Si extracted by (a) Distilled water-1 and (b) Distilled water-4 extractants

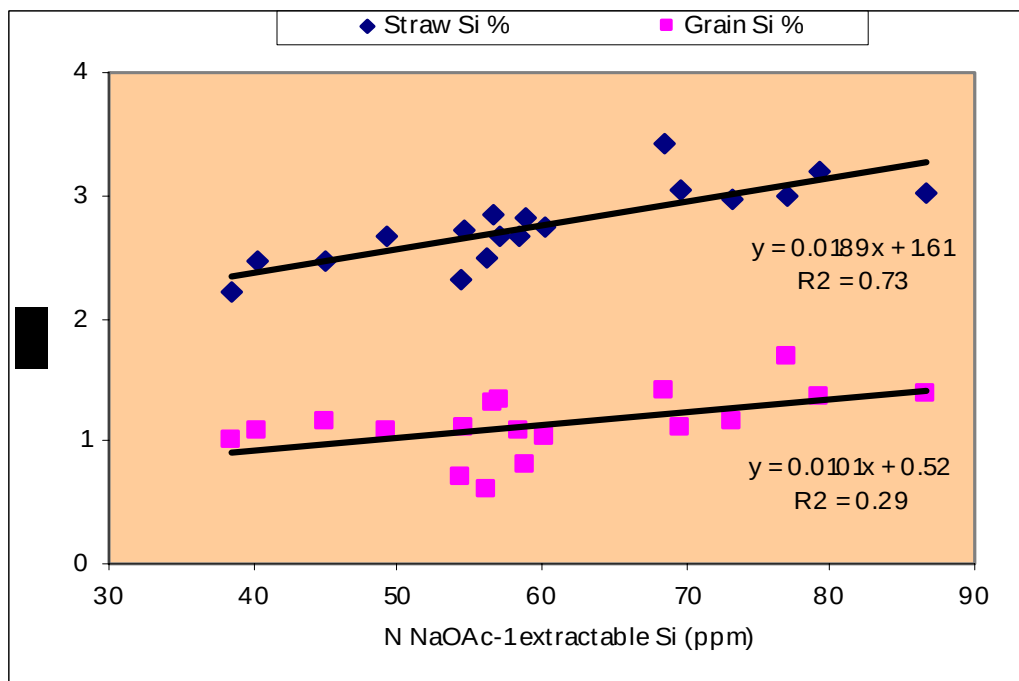
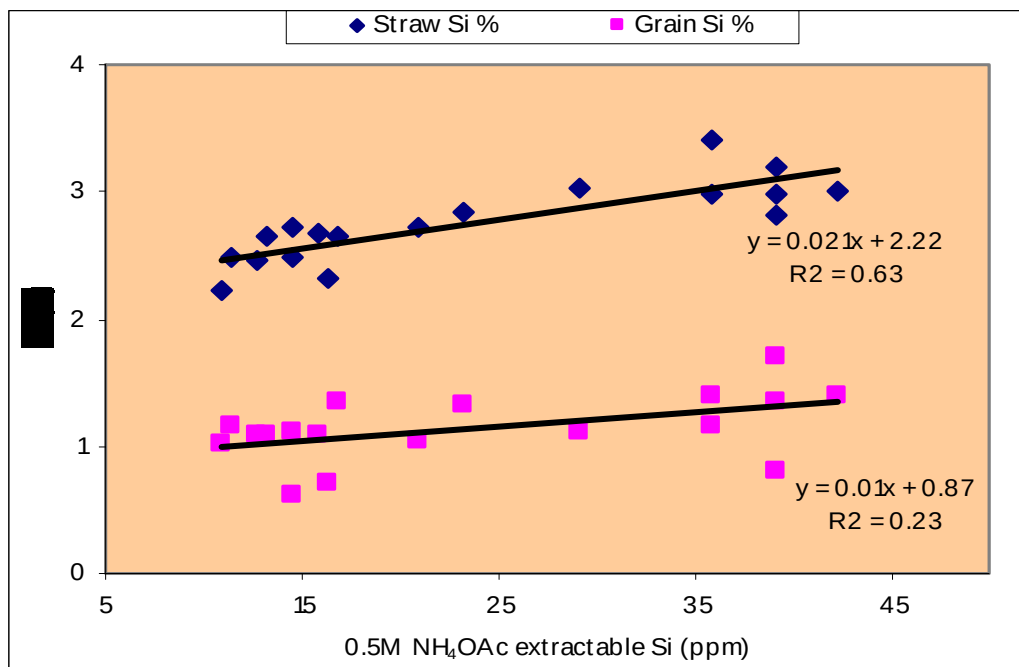


Fig. 3D Relationship between percent Si in straw and grain and plant available soil Si extracted by (a) 0.5M NH_4OAc and (b) N NaOAc-1extractants

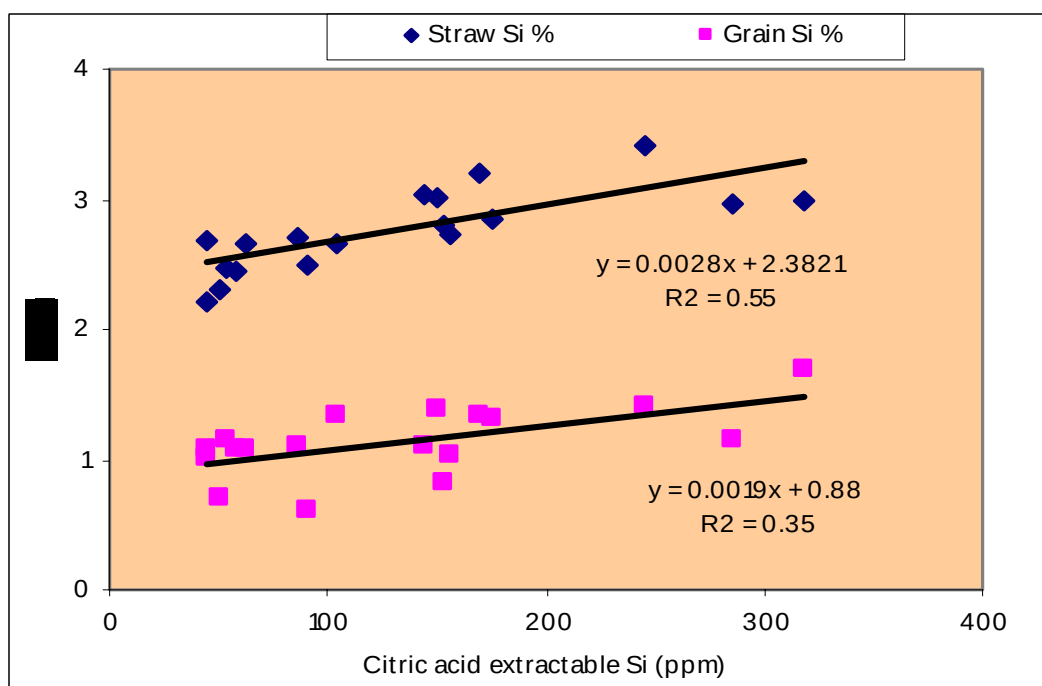
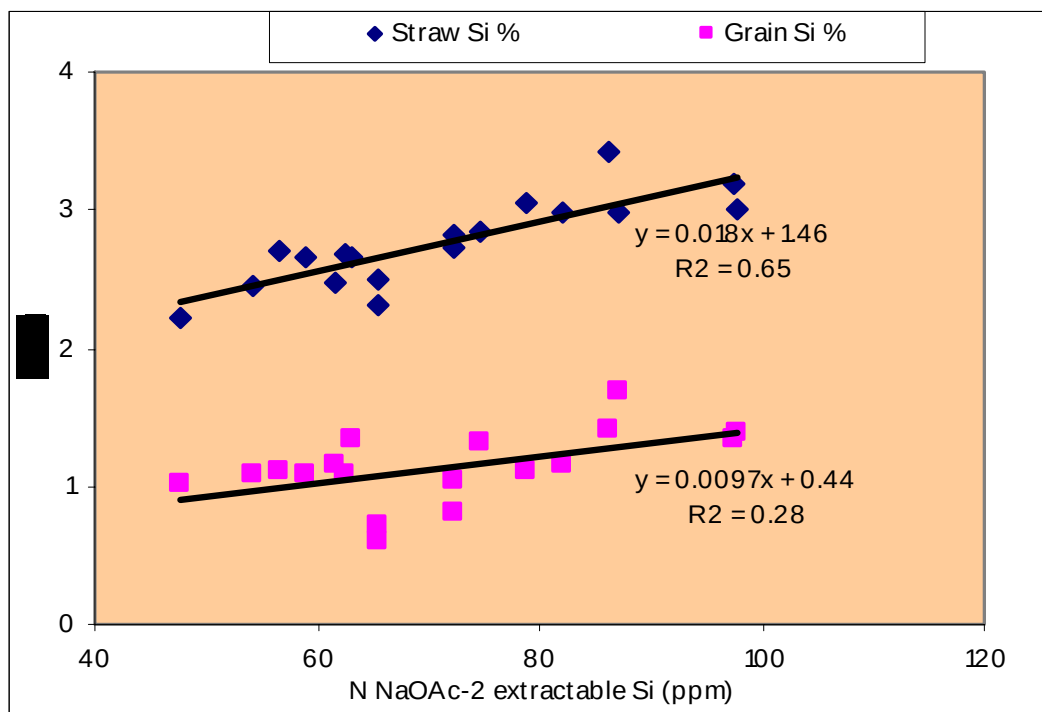


Fig. 3E Relationship between percent Si in straw and grain and plant available soil Si extracted by (a) N NaOAc-2 and (b) Citric acid extractants

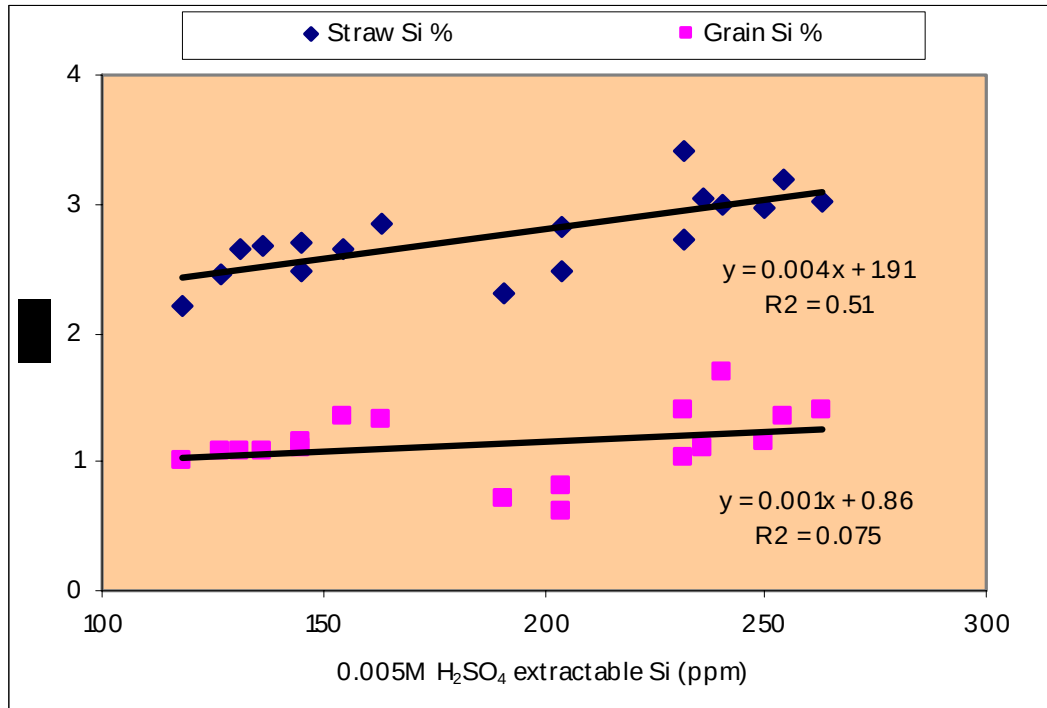


Fig. 3F Relationship between percent Si in straw and grain and plant available soil Si extracted by (a) 0.005M H₂SO₄ extractant

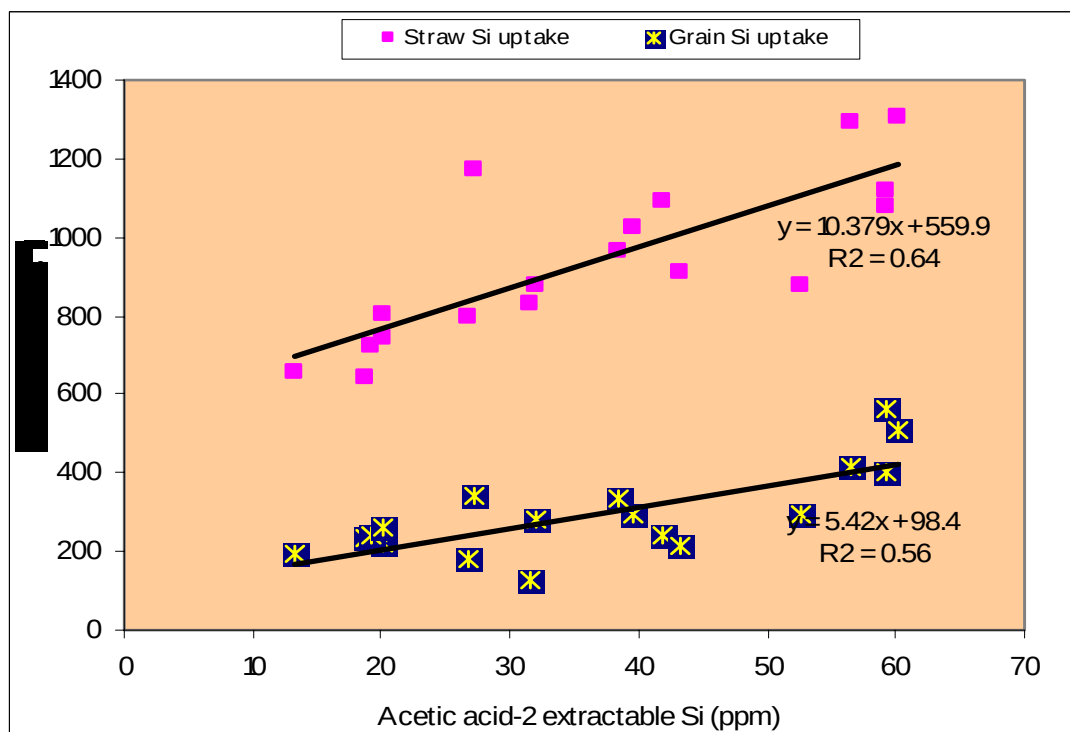
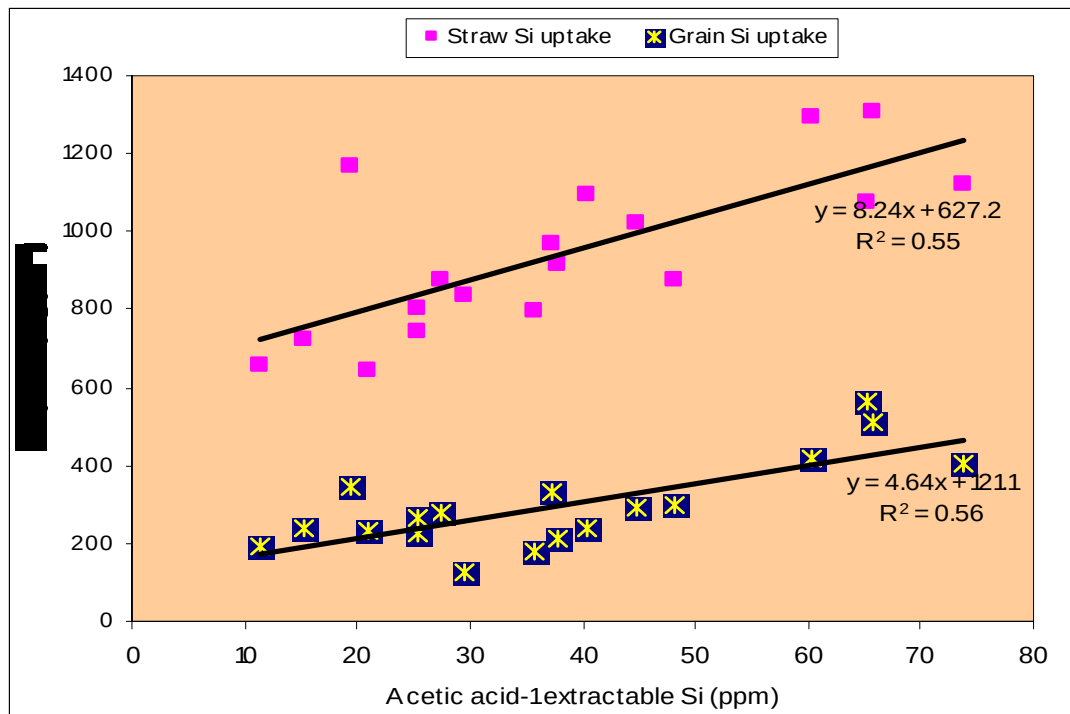


Fig. 4A Relationship between Si uptake in straw and grain and plant available soil Si extracted by (a) Acetic acid-1 and (b) Acetic acid-2 extractants

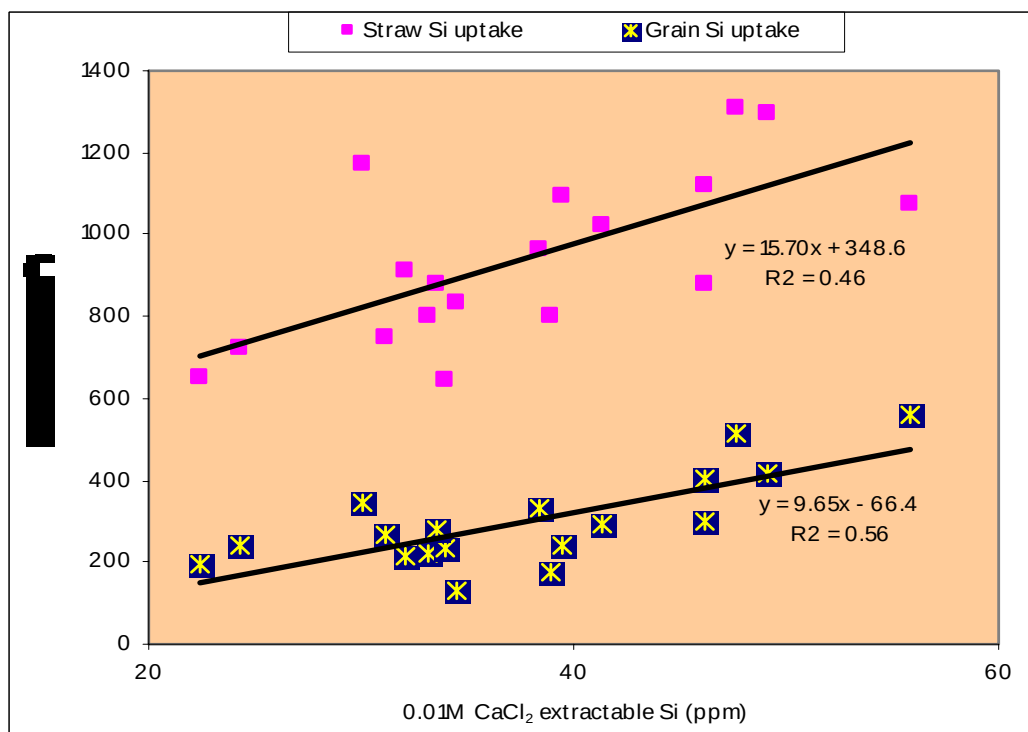
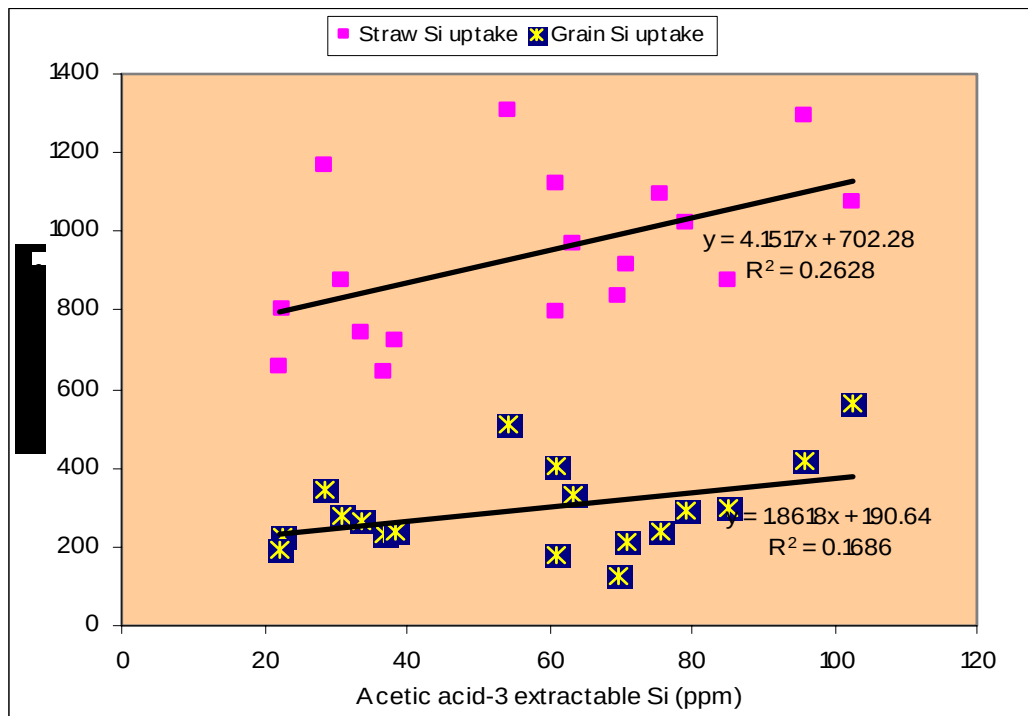


Fig. 4B Relationship between Si uptake in straw and grain and plant available soil Si extracted by (a) Acetic acid-3 and (b) 0.01M CaCl_2 extractants

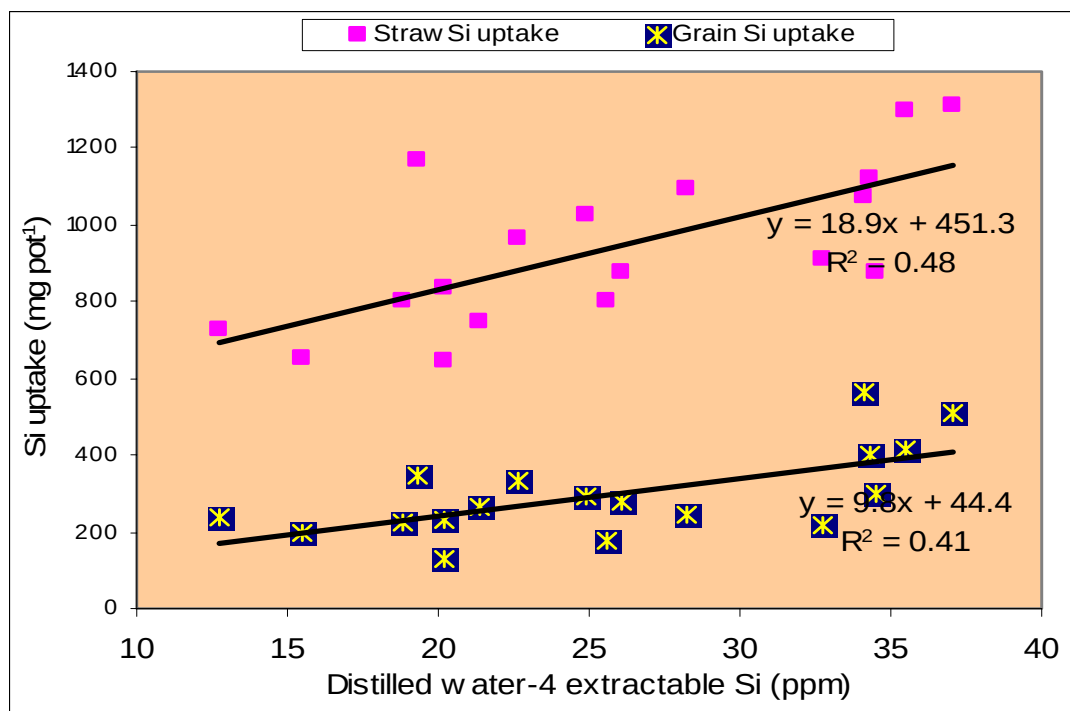
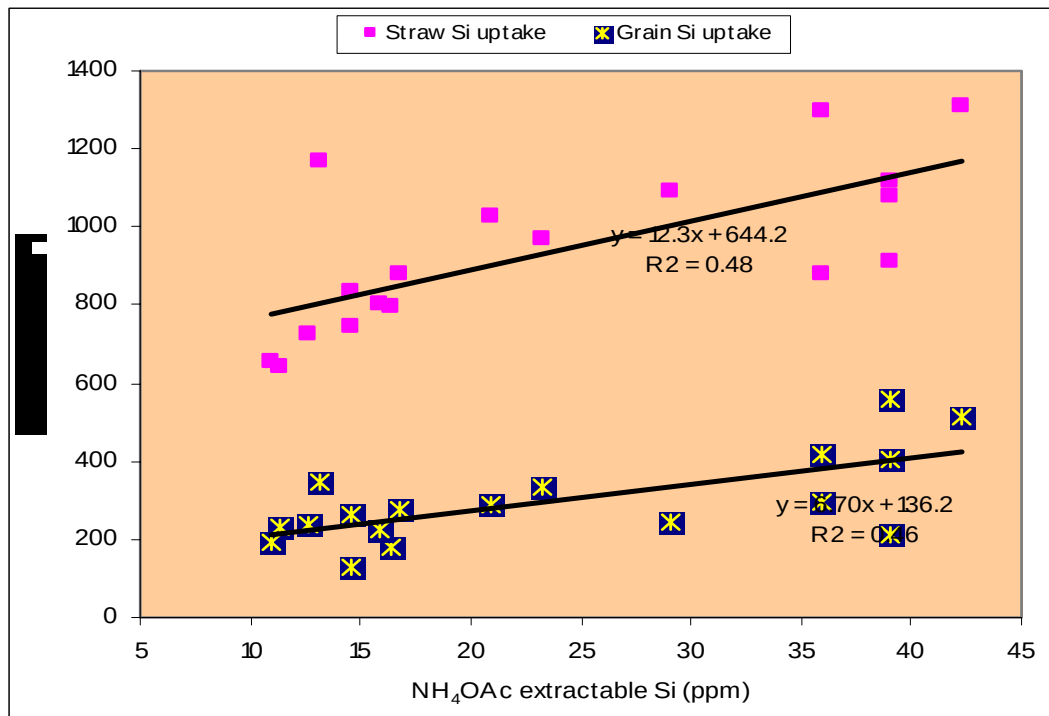


Fig. 4C Relationship between Si uptake in straw and grain and plant available soil Si extracted by (a) Distilled water-1 and (b) Distilled water-4 extractants

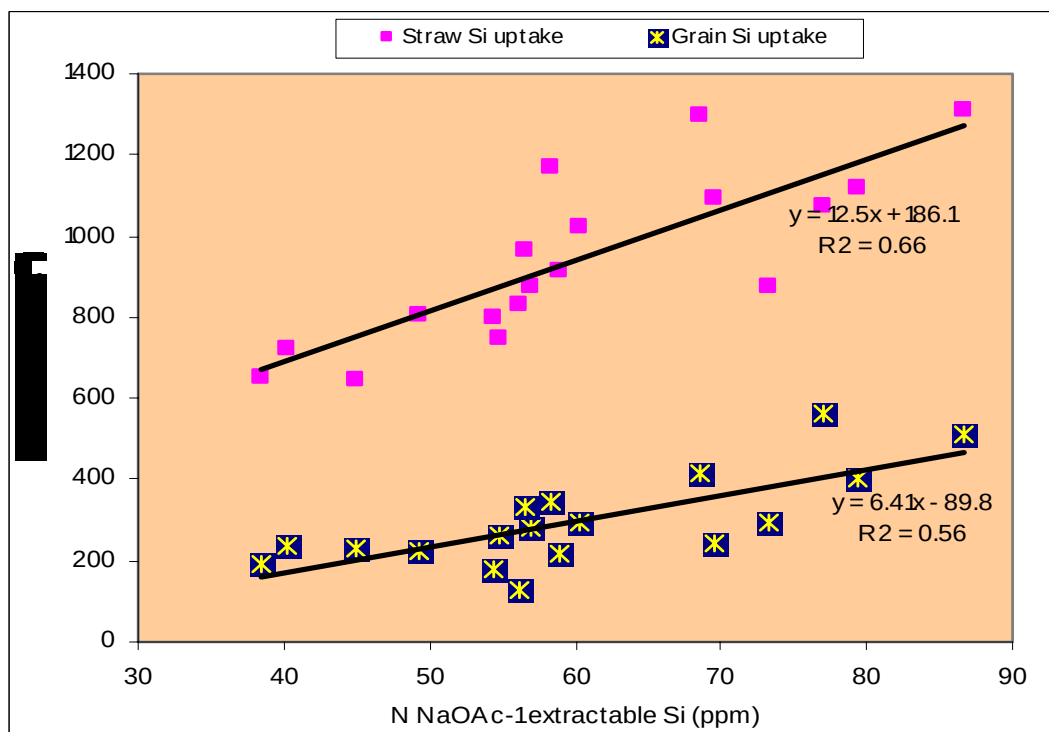
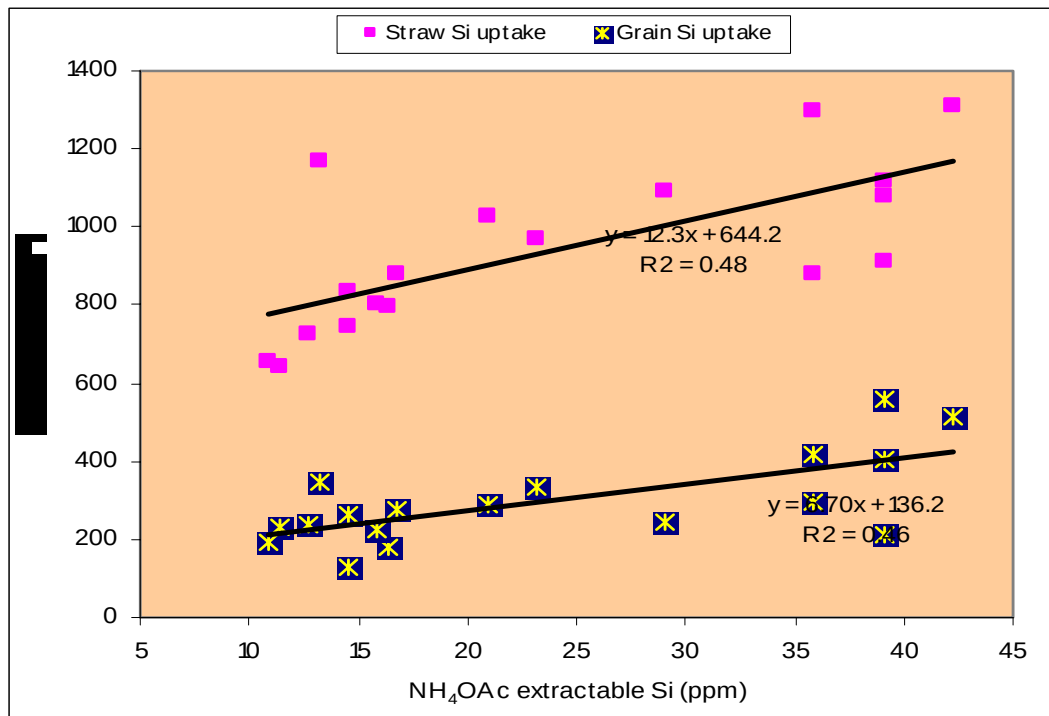


Fig. 4D Relationship between Si uptake in straw and grain and plant available soil Si extracted by (a) NH₄OAc and (b) N NaOAc-1 extractants

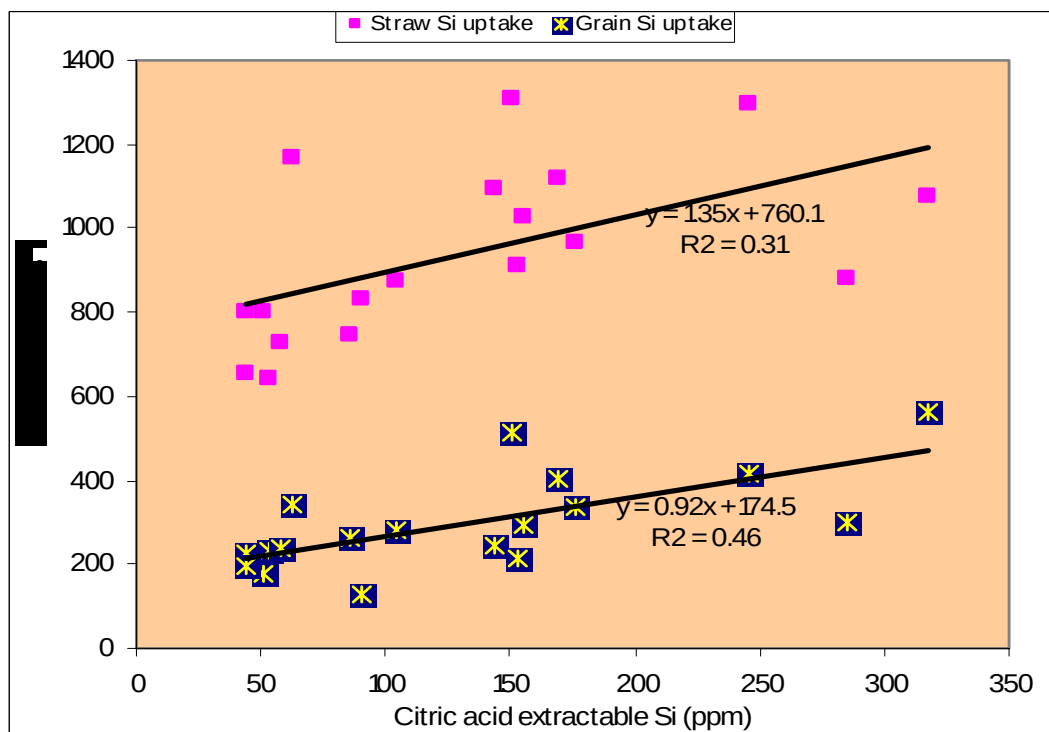
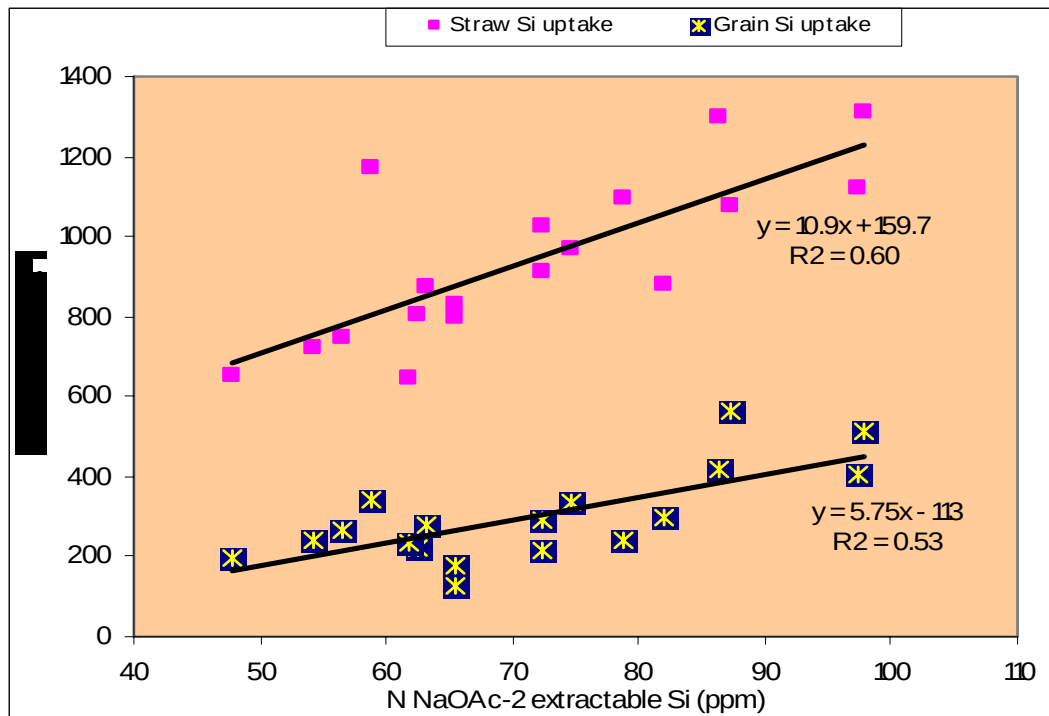


Fig. 4E Relationship between Si uptake in straw and grain and plant available soil Si extracted by (a) N NaOAc-2 and (b) Citric acid extractants

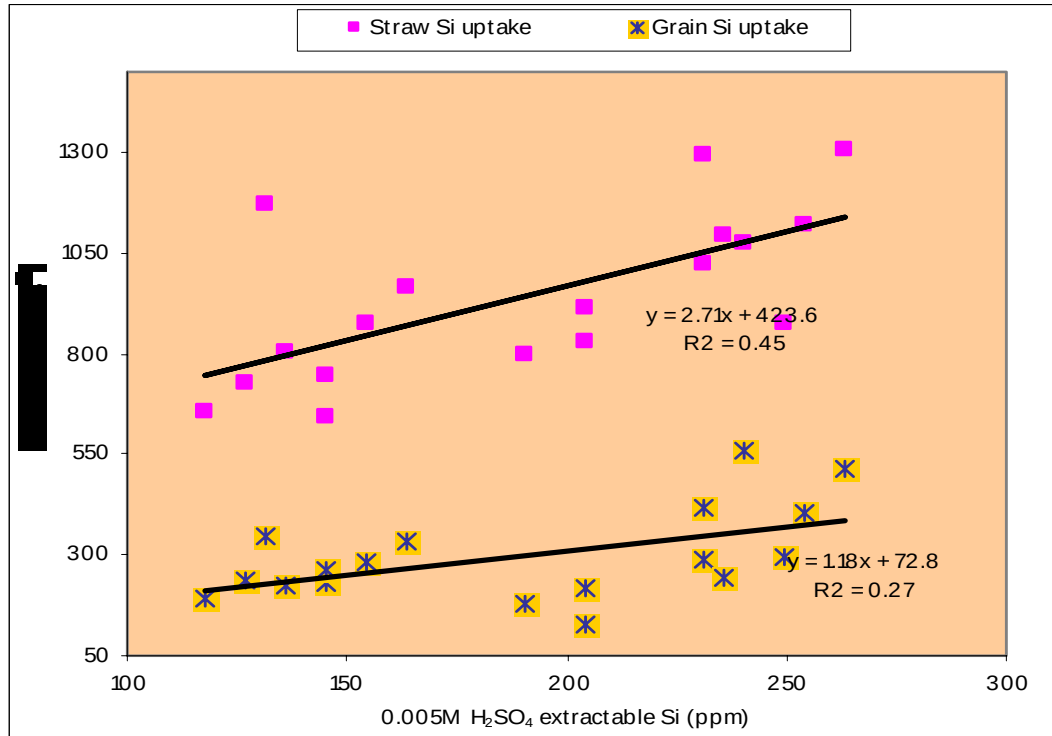


Fig. 4F Relationship between Si uptake in straw and grain and plant available soil Si extracted by (a) 0.005M H₂SO₄ extractant

forms and hence could be possible reason for over estimating the available Si. Similar observations were also noticed by Daniela *et al.* (2006). The N NaOAc-1, 2 and acetic acid-1, 2 dissolves water soluble and Si present on the adsorbed phase. Haysom and Chapman (1975) compared 0.01 M CaCl_2 , 0.5M NH_4OAc , and 0.005 M H_2SO_4 for their ability to extract plant available Si from soils and found that Si extracted by CaCl_2 showed highest correlation ($r^2 = 0.82$) with sugarcane yields.

Acetic acid and some acetates (NH_4OAc and CH_3COONa), were used to remove soluble Si and some of the exchangeable Si from soil. Imaizumi and Yoshida (1958) and Ayres (1966) used buffered acetate solutions to extract available Si. Snyder (2001) used acetic acid extraction in their soil testing laboratory at the University of Florida as a standardized method to analyze plant available Si in rice growing soils.

Highest coefficient of determination of plant Si with 0.5 M acetic acid ($R^2 = 0.88$), followed by water ($R^2=0.84$), CaCl_2 ($R^2 = 0.70$) and N NaOAc ($R^2 = 0.69$) were noticed in soils of Brazil (Korndorfer *et al.*, 1999). Filho *et al.* (2001) noticed that 0.5 M acetic acid noticed highest correlation with rice straw ($R^2 = 0.90$) and grain Si ($R^2= 0.77$), followed by 1 % citric acid. Kato (1998) reported that combination method and phosphate buffer method were found to be the best methods for determination of available Si in soils of Japan.

In the present investigation, the highest degree of significant correlation was noticed between available Si extracted by N NaOAc-1, 0.5 M acetic acid-2 and N NaOAc-2 with the plant growth indices. These methods extract water soluble Si plus Si present on adsorbed phase. The procedure adopted for these extractants involves less time for extraction. However, acetic acid-1, 3, CaCl_2 , sulphuric acid, citric acid extracts relatively higher amount of available Si mainly because of longer contact hours and usually extracts non available Si also (amorphous, crystalline, microcrystalline forms of Si). Hence N NaOAc-1,

0.5M acetic acid - 2 and N NaOAc -2 were considered as suitable extractants for extracting available Si in rice soils of Karnataka.

5.3 Critical limits of plant and soil silicon in rice

The data pertaining to grain and straw yield, relative yield, critical levels of available Si for different extractants and straw / tissue Si are presented in Table 14, 15 and 16 respectively and Fig. 5, 6A - F and 7A - F.

5.3.1 Effect of calcium silicate as a Si source on grain and straw yield in rice soils

The data in Table 14 and Fig. 5 indicated that the application of calcium silicate as Si source significantly increased the grain and straw yield in all the soils. Among the soils studied, 1, 3, 4 and 14 have responded to the applied Si even up to 1448 kg ha⁻¹ in achieving higher grain yield over control. Similarly, soils of 2, 5, 6, 9, 10 and 13 have recorded higher grain yield with the application of 966 kg Si ha⁻¹ and then showed a declining trend. Few soils (7, 8, 11, 12, 15, 16, 17 and 18) responded to the application of only 483 kg Si ha⁻¹ and further application neither increased nor decreased the grain yield. This can be mainly attributed to native available Si content. Soils having low to medium in available Si responded to applied Si fertilizers to greater extent than the soils having higher levels of available Si. Similar results were also noticed by Korndorfer *et al.* (2001) in soils of Florida. After transplanting, Si fertilization increases the number of tillers and grains (Liang *et al.*, 1994). Increase in rice yields under flooded condition was noticed with Si fertilization in Srilanka (Takjima *et al.*, 1970), Thailand (Takahashi *et al.*, 1990), India (Singh *et al.*, 2006) and Florida (Datnoff *et al.*, 1992). Snyder *et al.*, (1986) showed that application of calcium silicate increased the rice yields in histosols mainly due to the supply of available Si and not due to supply of other nutrients. The effect of Si on reducing diseases unquestionably contributes to increase yields, but Si has also been shown to increase yield in the absence of disease (Datnoff *et al.*, 1992).

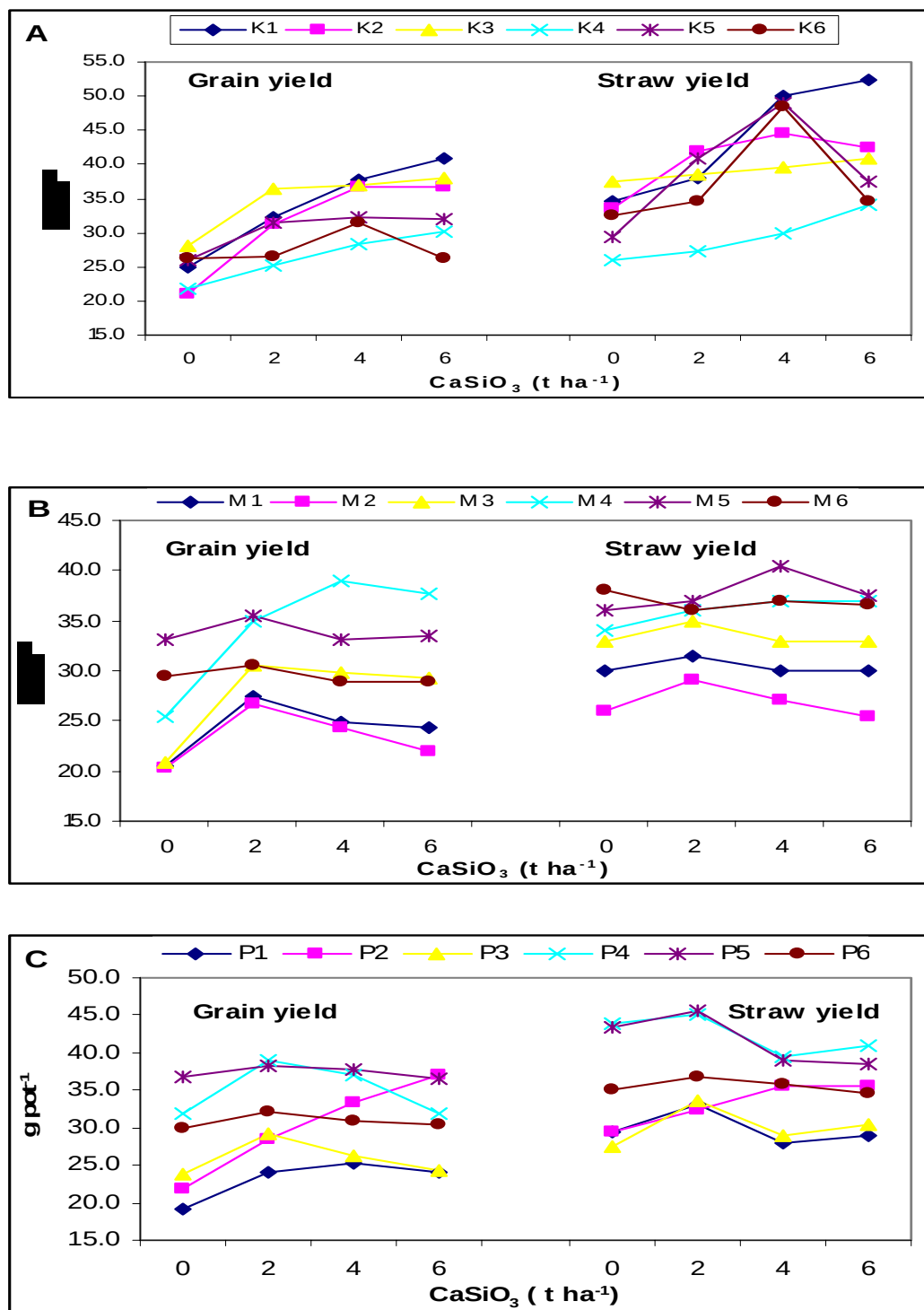


Fig 5 Effect of varied levels of calcium silicate (CaSiO_3) on grain and straw yield of rice in different soils of Karnataka A. Mangalore, B. Mudigere and C. Ponnampet



Plate 3 Effect of graded levels of Si on growth of wetland rice

The maximum yield obtained due to supplement of varied levels of Si in different soils ranged from 25.4 to 40.9 g pot⁻¹ and yield increase ranged from 1.1 to 16.0 g pot⁻¹. The relative yield is the yield achieved on the unfertilized soil relative to the maximum yield achieved on the Si fertilized soil and ranged from 35.8 to 96.4 per cent (Table 15). This variation may be attributed to native available Si content and response to the additional Si fertilizer. In general, relative yield was higher for the soils having higher native Si and lower relative yield for the soils having lower native Si. Similar observations were also noticed by Korndorfer *et al.* (2001) in different soils of Florida.

The critical level for Si in the soil (level below which response to the added Si fertilizer is expected) calculated by Cate and Nelson (1965 and 1971) procedure was different for different extractants and plant nutrient elements. The critical limit for soil Si as extracted by 0.5M acetic acid -1, 0.5M acetic acid -2, 0.5M acetic acid -3, 0.01M CaCl₂, distilled water -1, distilled water -4, 0.5M NH₄OAc, N NaOAc -1, N NaOAc -2, 0.1M citric acid and 0.005M H₂SO₄ were 54, 54, 87, 43, 30, 14, 32, 75, 85, 185 and 207 ppm respectively (Fig 6A-F). The highest critical limit was noticed in 0.005M H₂SO₄ and 0.1M citric acid and the least was noticed in distilled water -1. There was wide variation in critical levels of soil Si extracted by different extractants and it was mainly attributed to the extracting power of extractants, pH of the extracting solution, shaking period, soil to solution ratio as well as nature of different extractants used. Similar results were also noticed by Korndorfer *et al.* (2001) in soils of Florida and Fox *et al.* (1967) for calcium phosphate, acetic acid and sulphuric acid extractants. Imaizumi and Yoshida (1958) noticed the critical limit of soil Si extracted by N NaOAc as 49 ppm and it was widely used in Japan and Taiwan. In spite of higher Si content (71-181 ppm) in calcareous soils of China, as extracted by sodium acetate buffer rice yields were continued to respond to the application of Si fertilizers (Liang *et al.*, 1994).

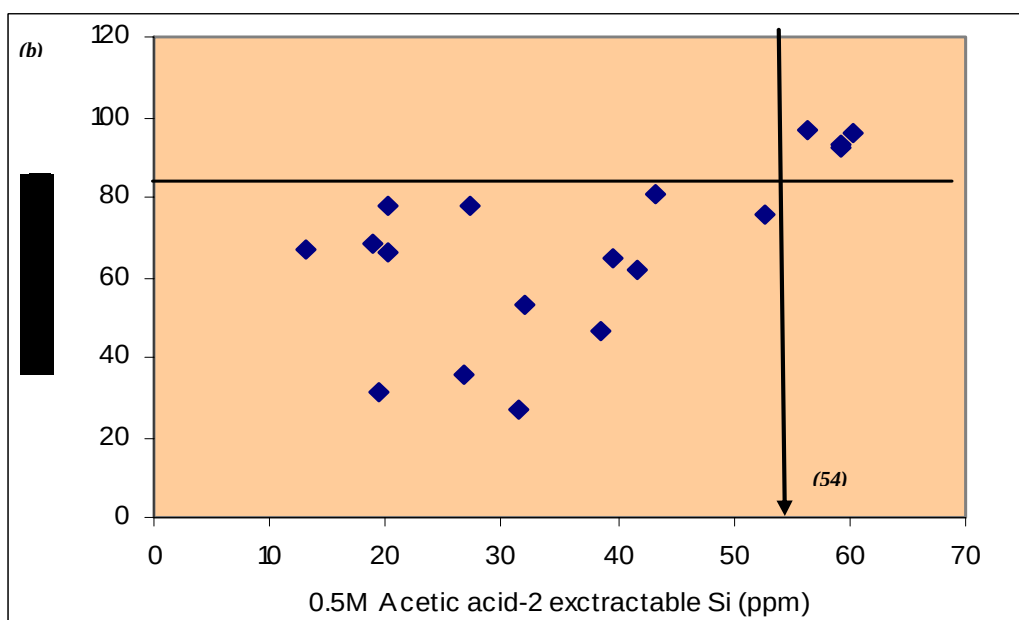
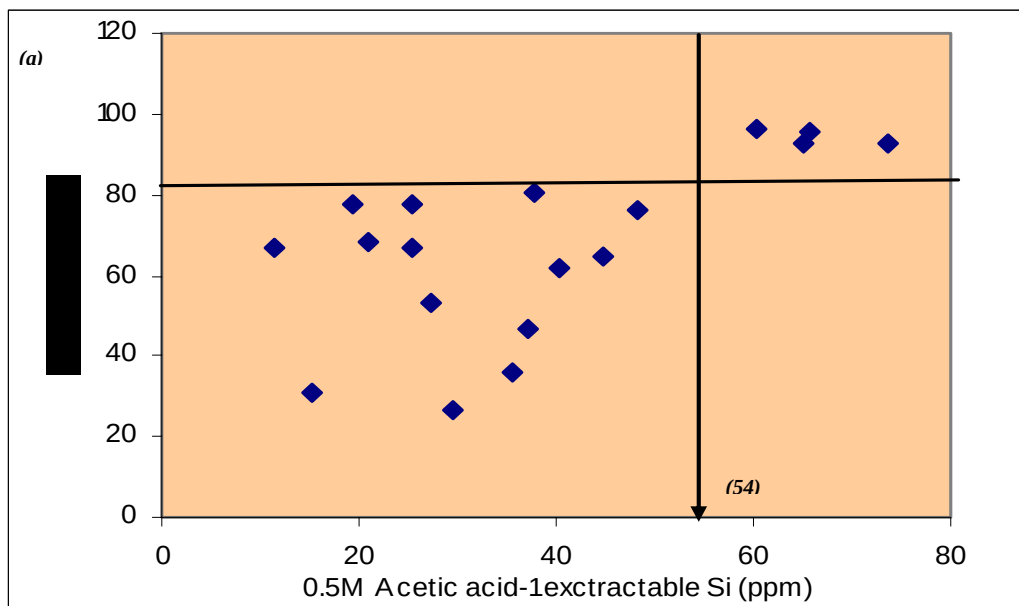


Fig. 6A Critical levels of plant available soil Si extracted by (a) Acetic acid-1 and (b) Acetic acid-2 extractants

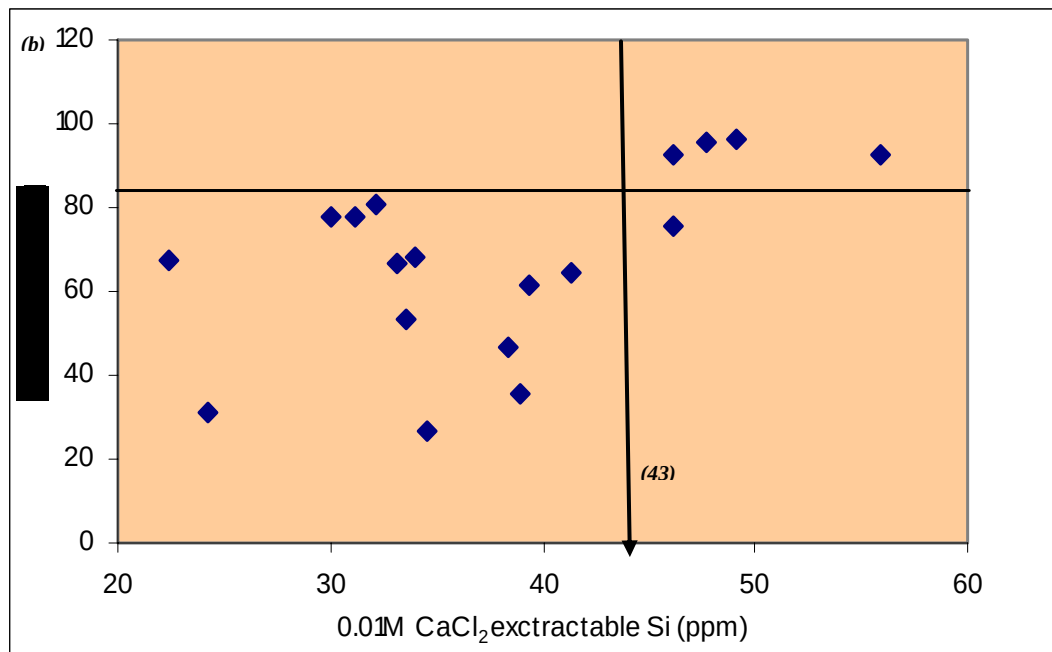
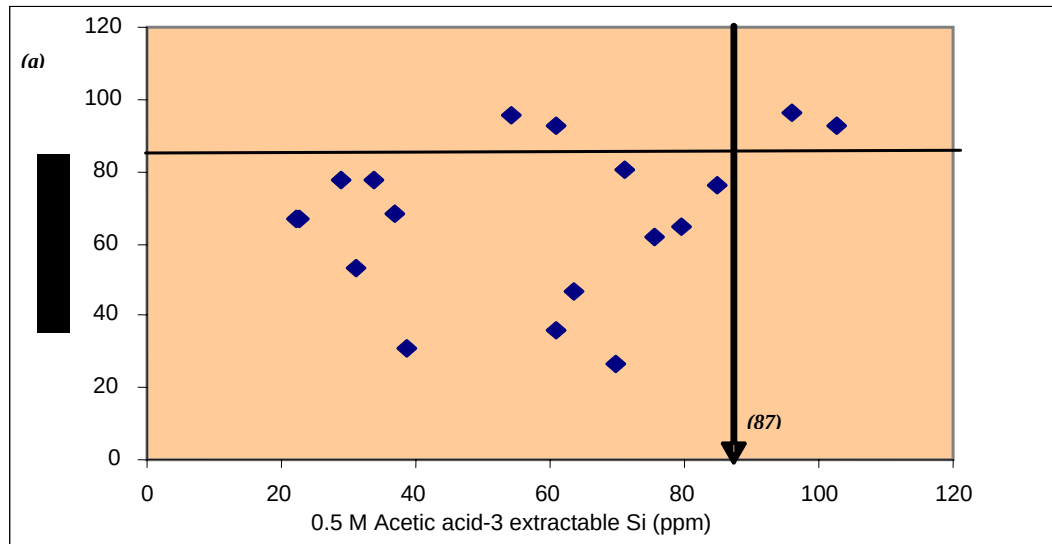


Fig. 6B Critical levels of plant available soil Si extracted by (a) acetic acid-3 and (b) 0.01M CaCl₂ extractants

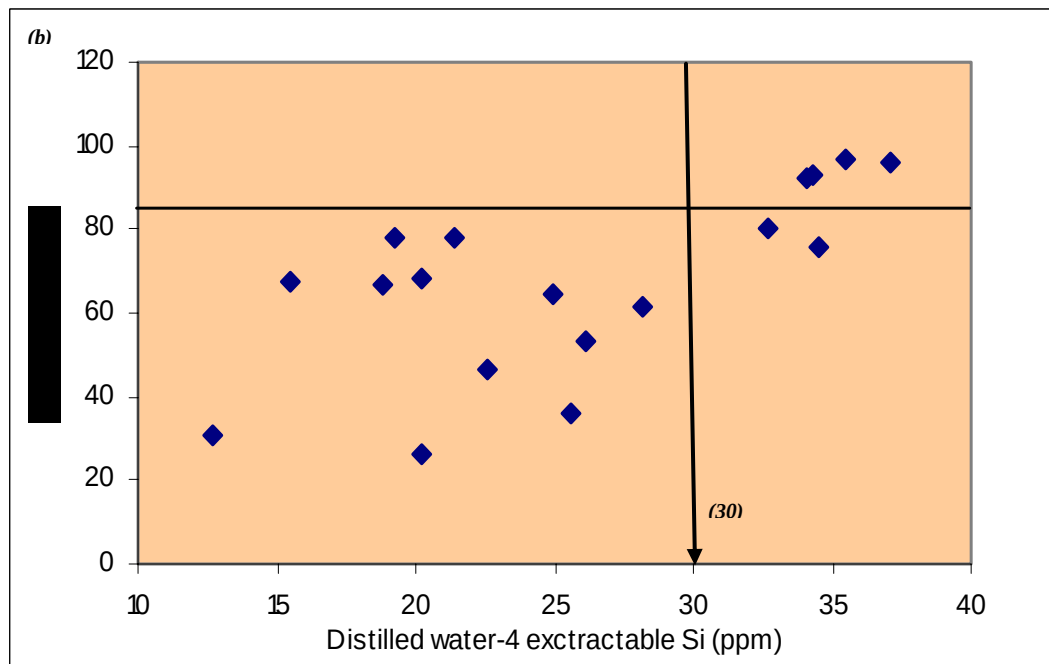
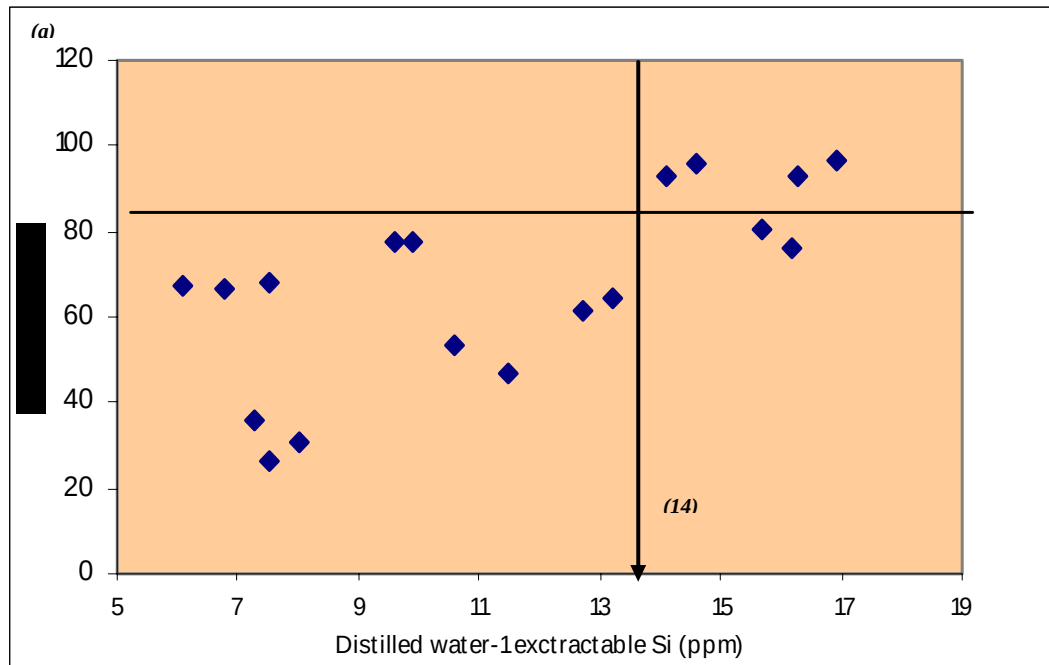


Fig. 6C Critical levels of plant available soil Si extracted by (a) Distilled water-1 and (b) Distilled water-4 extractants

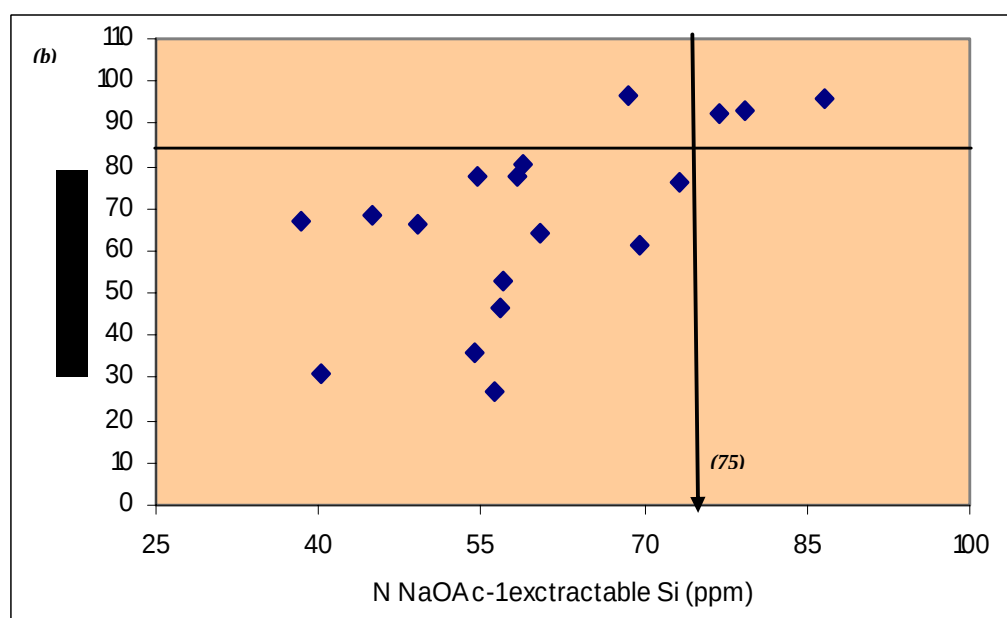
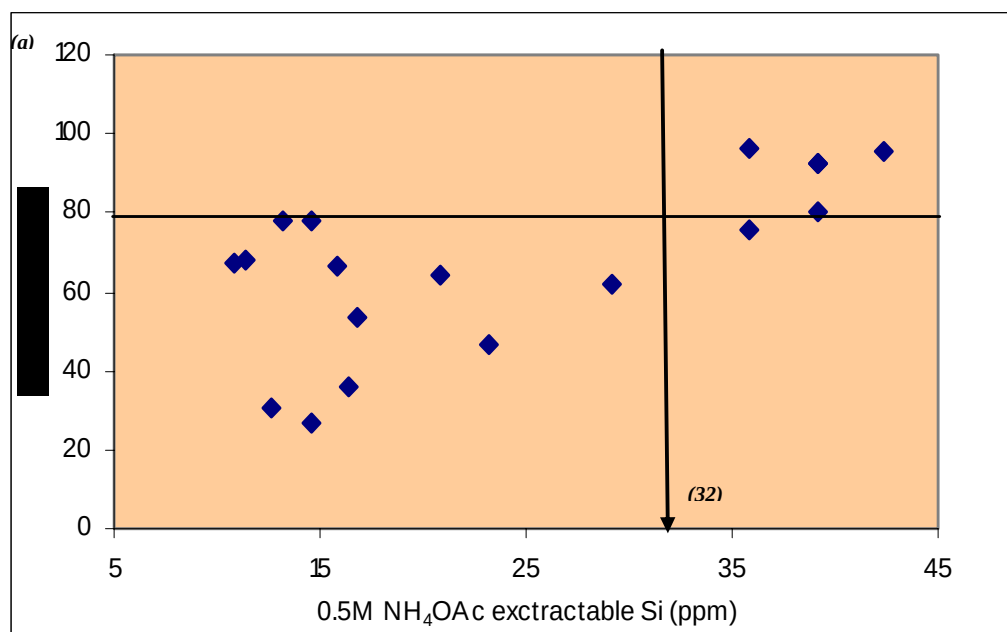


Fig. 6D Critical levels of plant available soil Si extracted by (a) 0.5M NH₄OAc and (b) N NaOAc-1 extractants

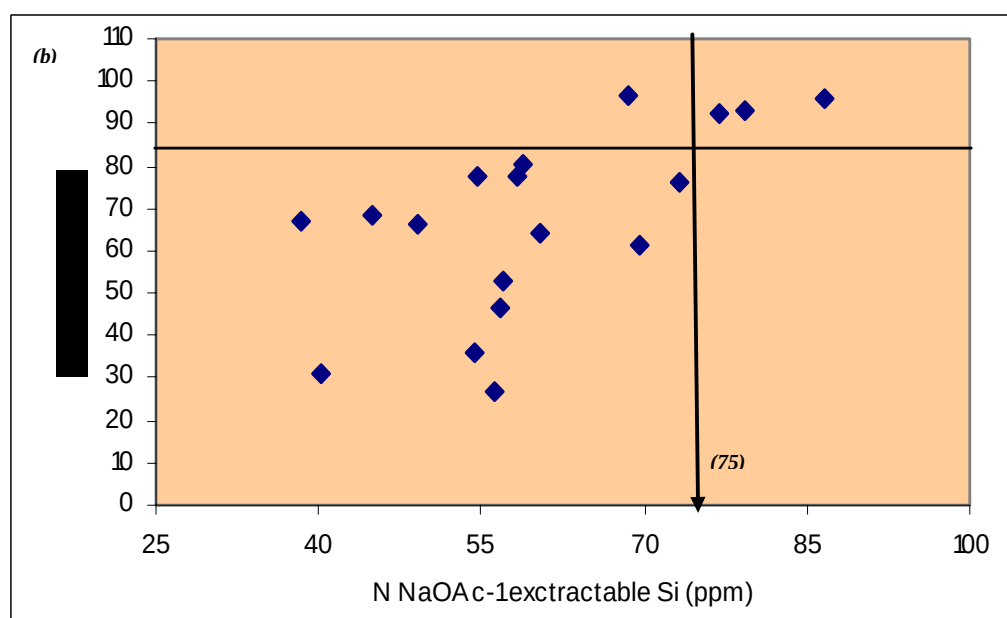
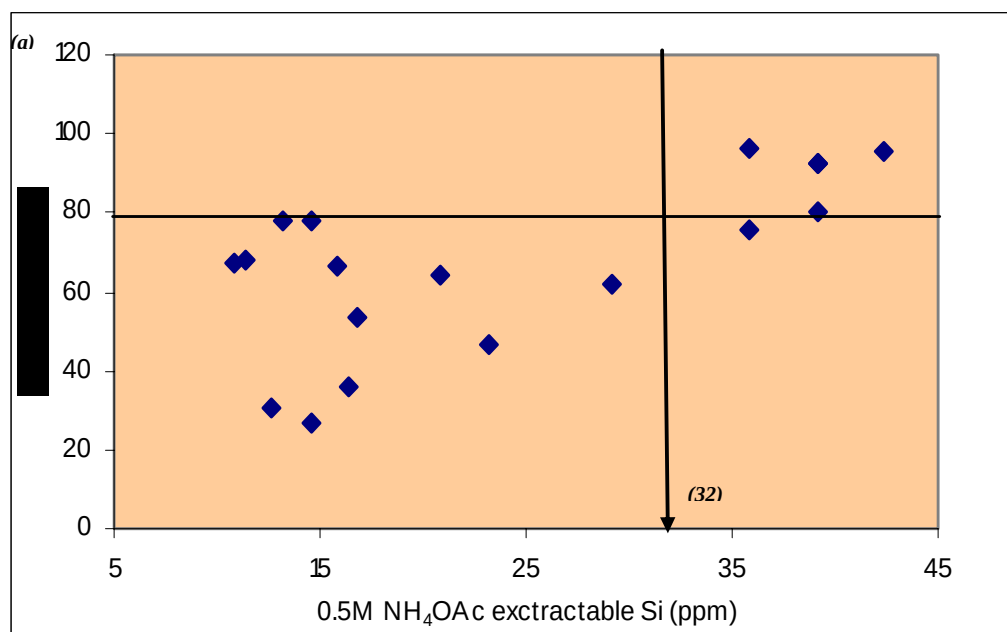


Fig. 6D Critical levels of plant available soil Si extracted by (a) 0.5M NH₄OAc and (b) N NaOAc-1 extractants

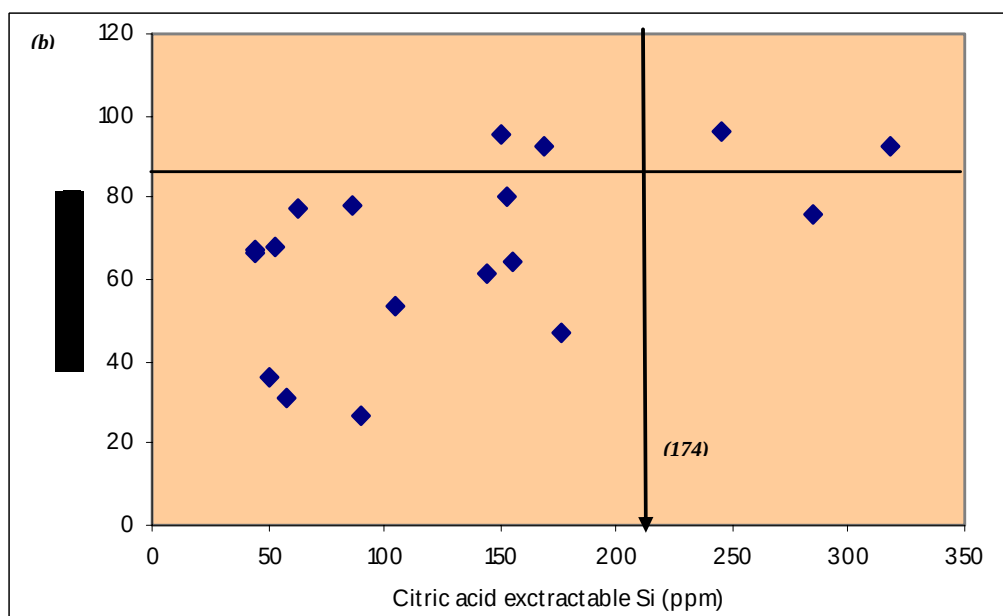
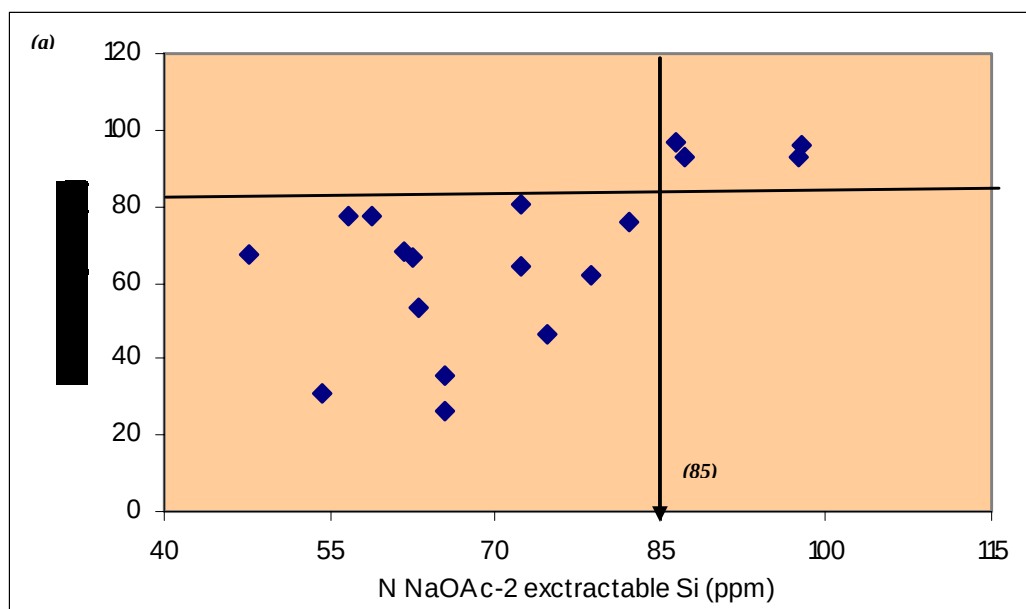


Fig. 6E Critical levels of plant available soil Si extracted by (a) N NaOAc-2 and (b) Citric acid extractants

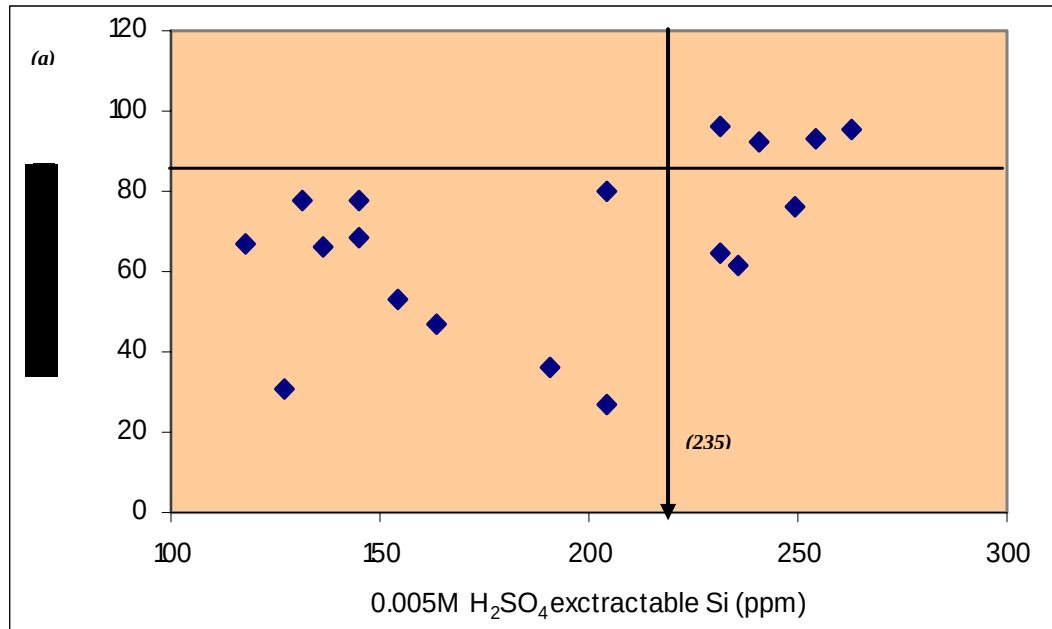


Fig. 6F Critical levels of plant available soil Si extracted by (a) 0.05 H₂SO₄ extractant

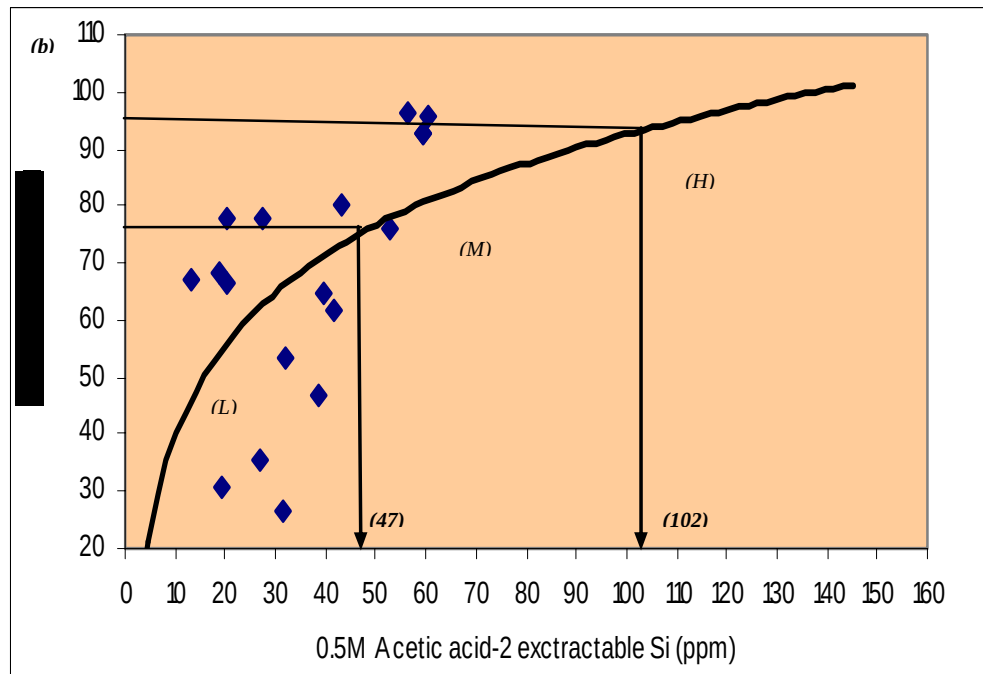
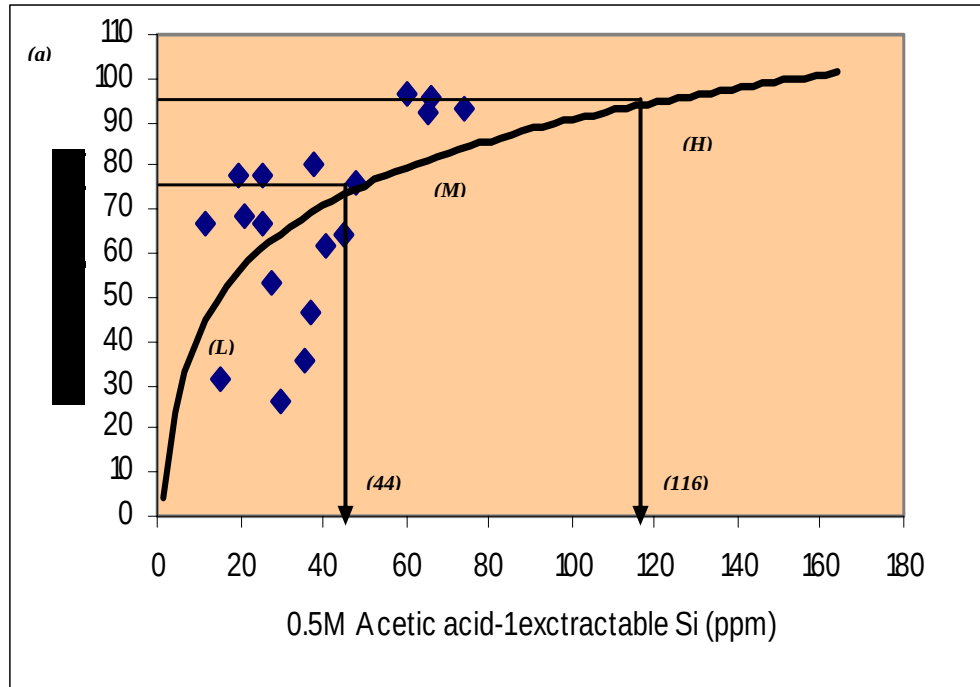


Fig. 7A Categorization of plant available soil Si into low, medium and high
For (a) Acetic acid-1 and (b) Acetic acid-2 extractants

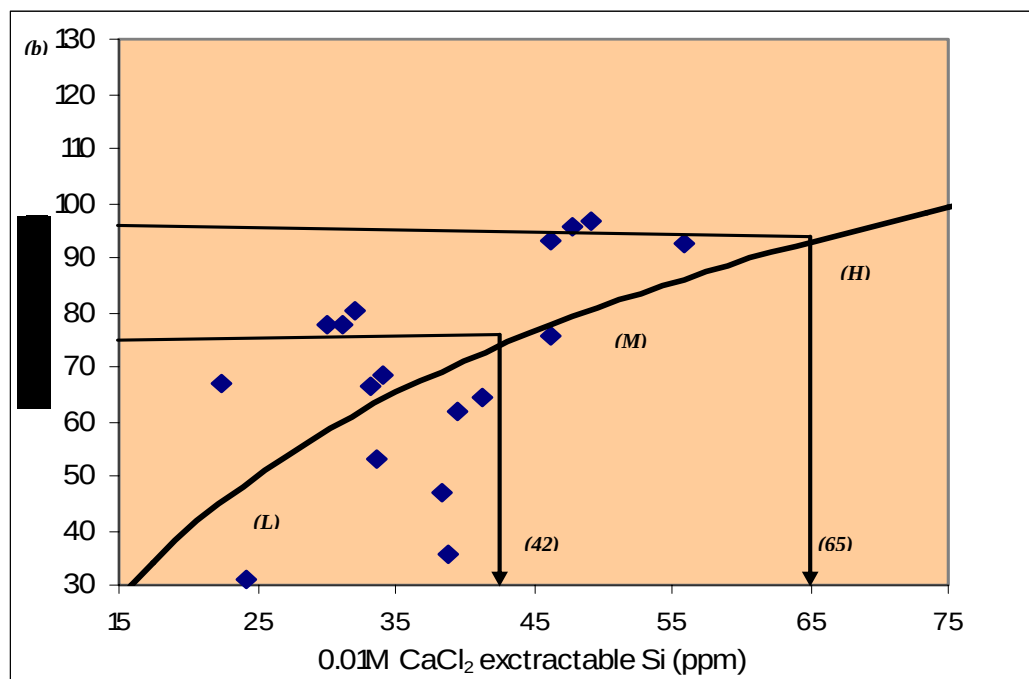
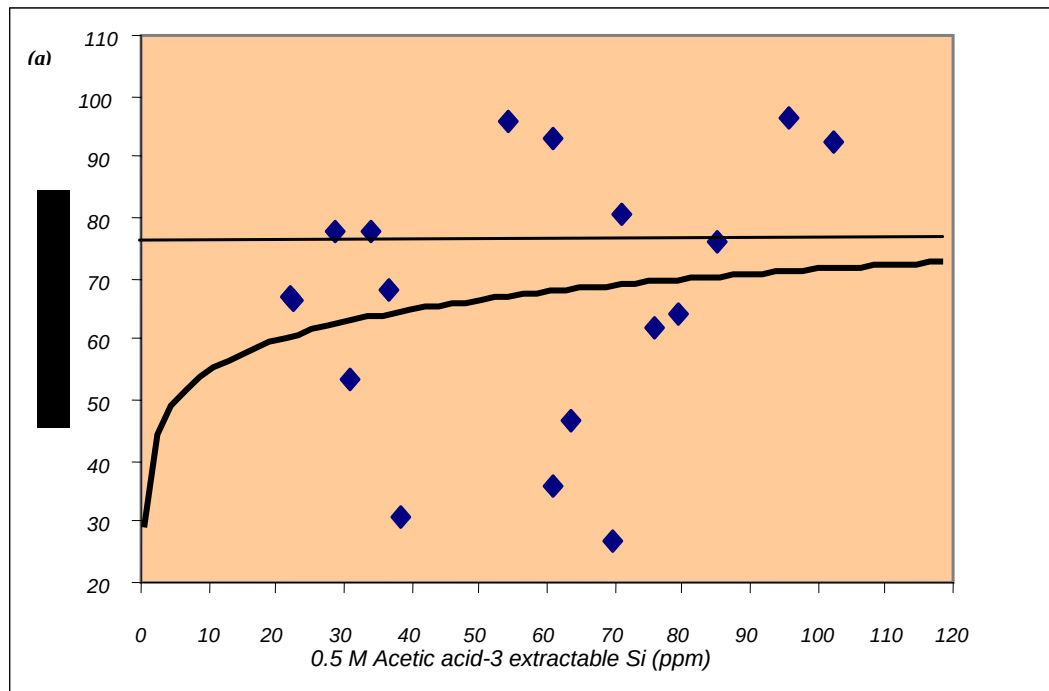


Fig. 7B Categorization of plant available soil Si into low, medium and high for
(a) Acetic acid-3 and (b) 0.01M CaCl₂ extractants

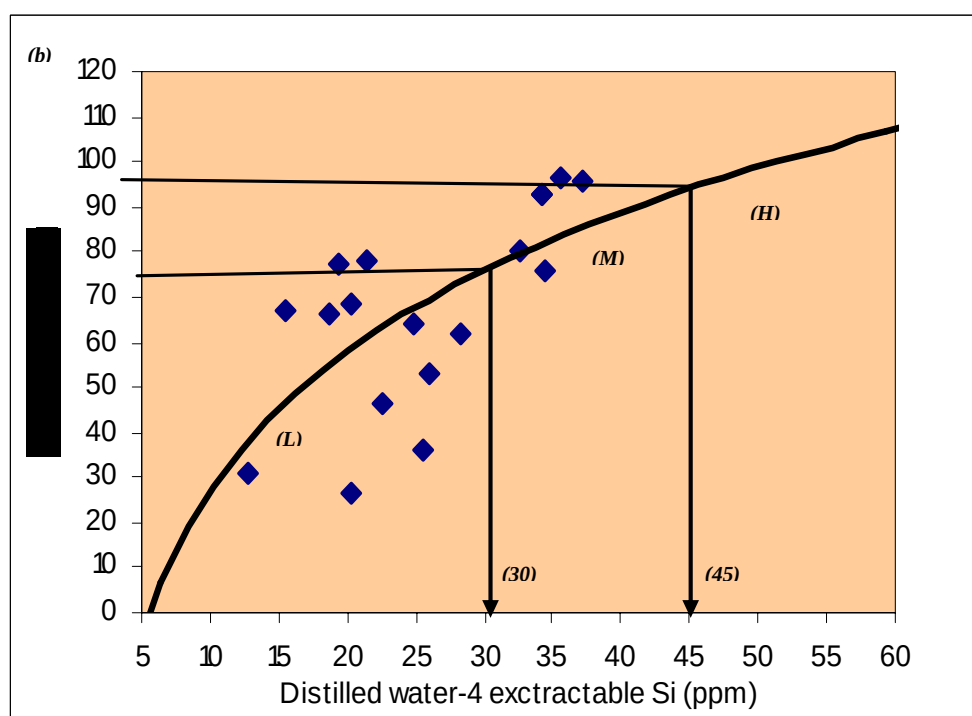
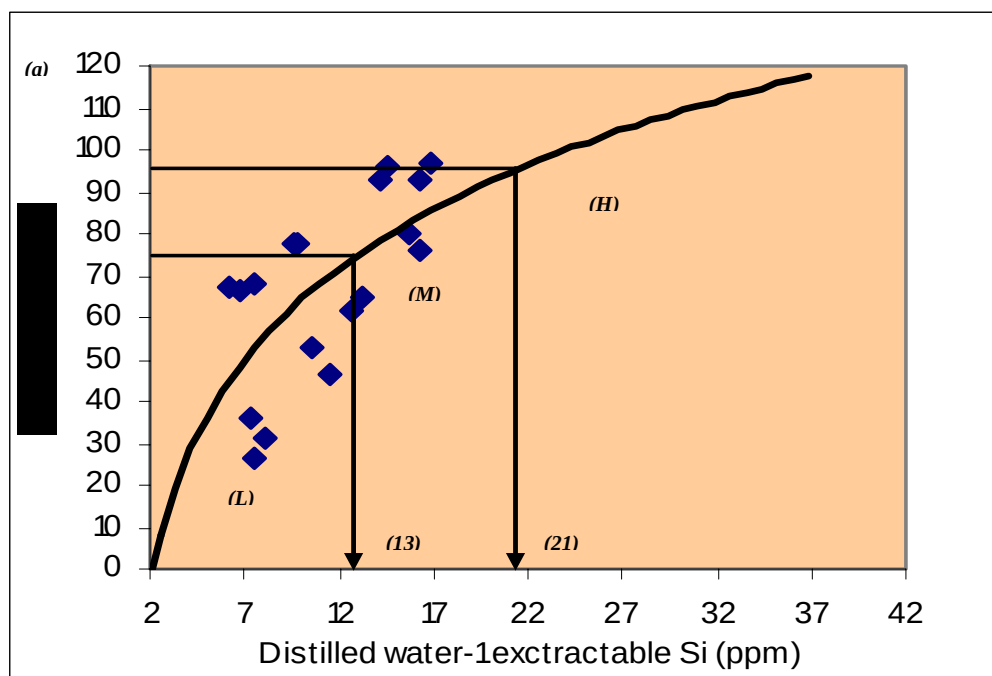


Fig. 7C Categorization of plant available soil Si into low, medium and high for (a) Distilled water-1 and (b) Distilled water-4 extractants

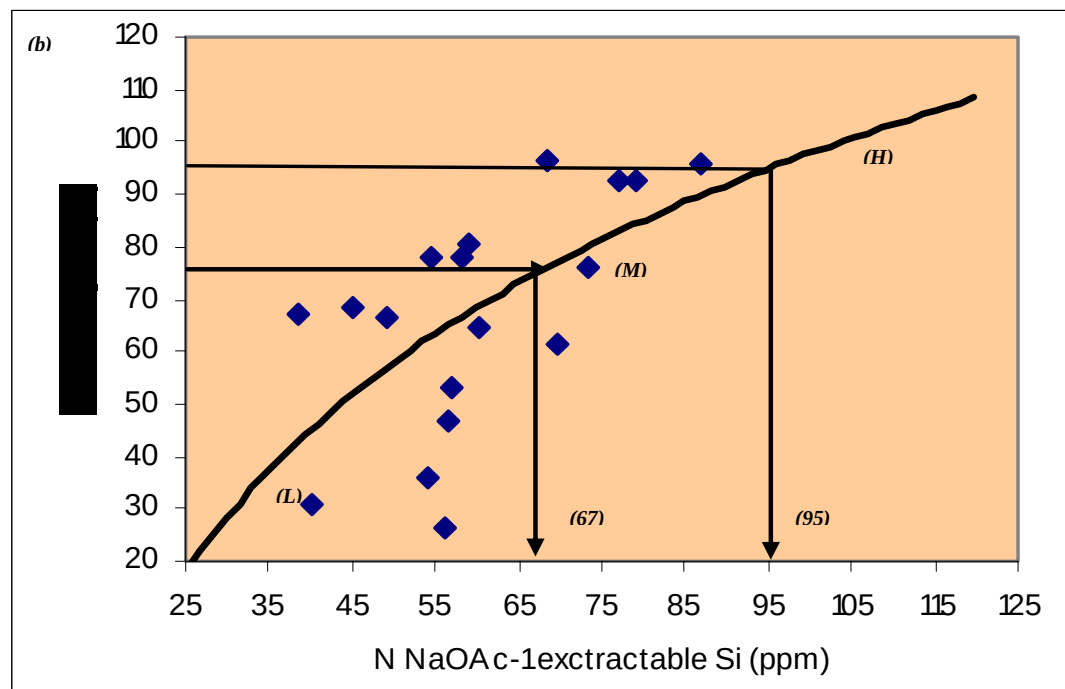
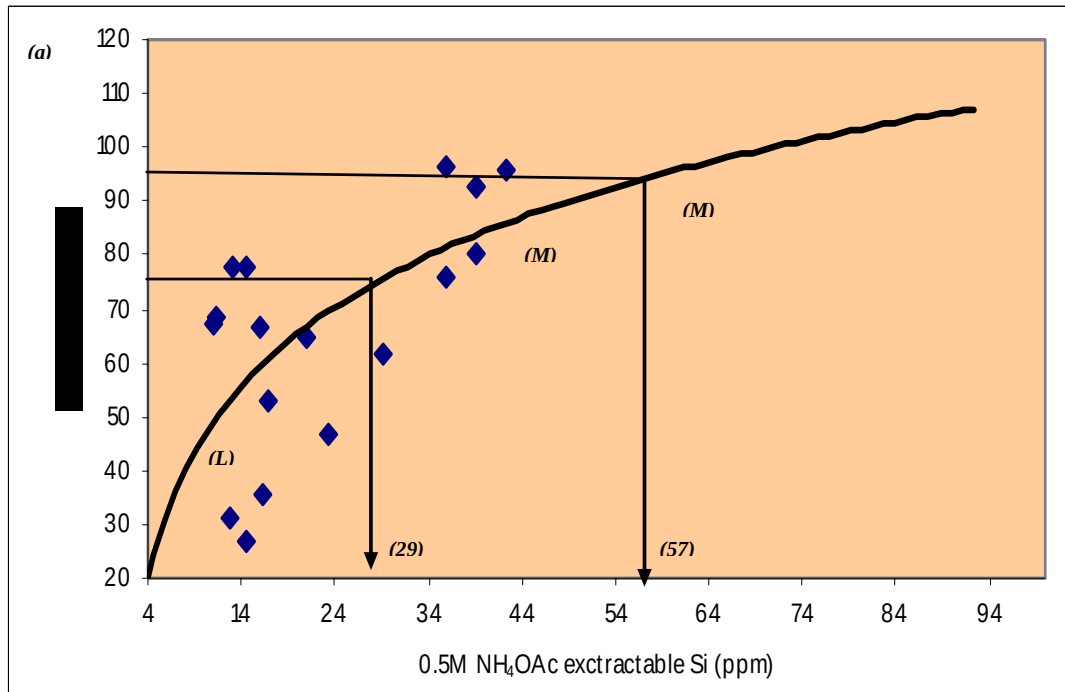


Fig. 7D Categorization of plant available soil Si into low, medium and high for (a) 0.5M NH_4OAc and (b) N NaOAc-1 extractants

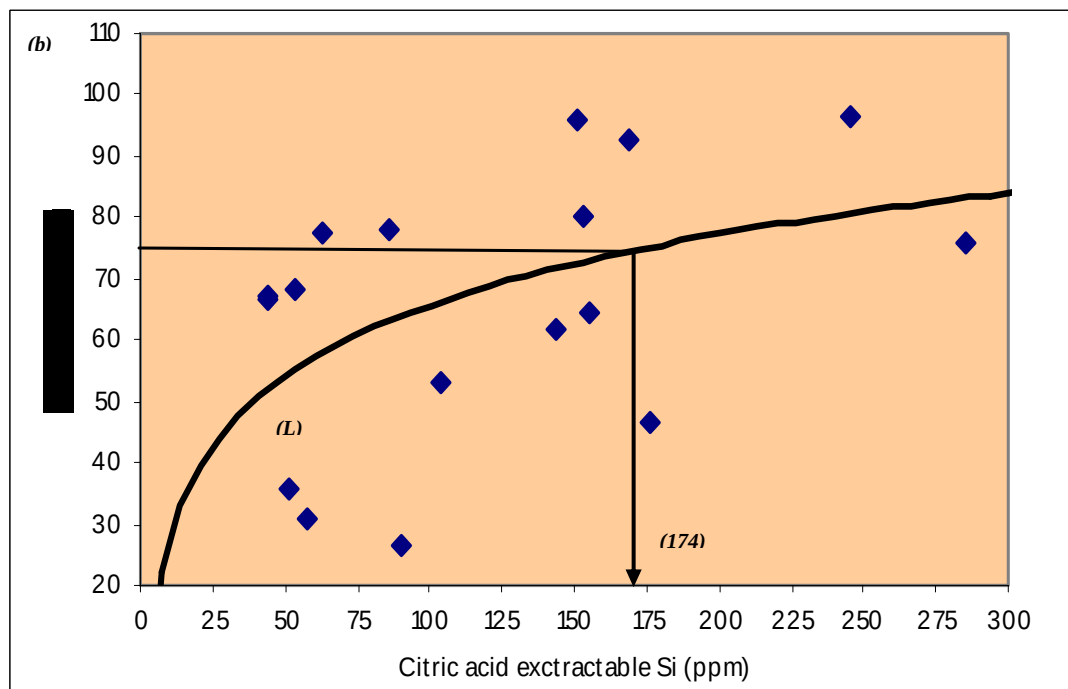
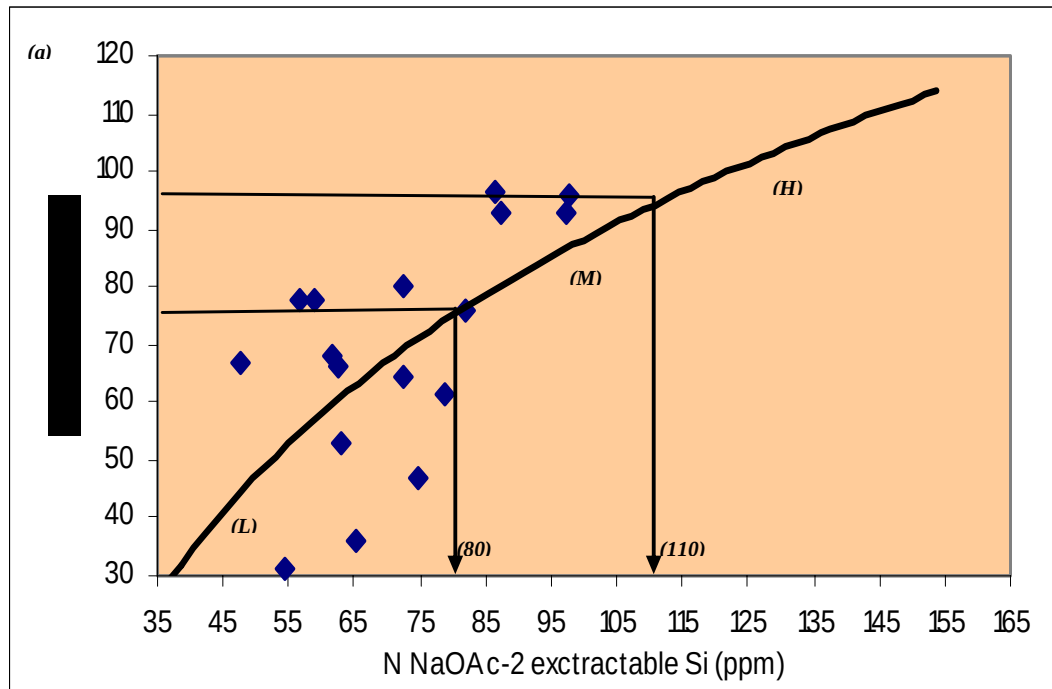


Fig. 7E Categorization of plant available soil Si into low, medium and high for (a) N NaOAc-2 and (b) Citric acid extractants

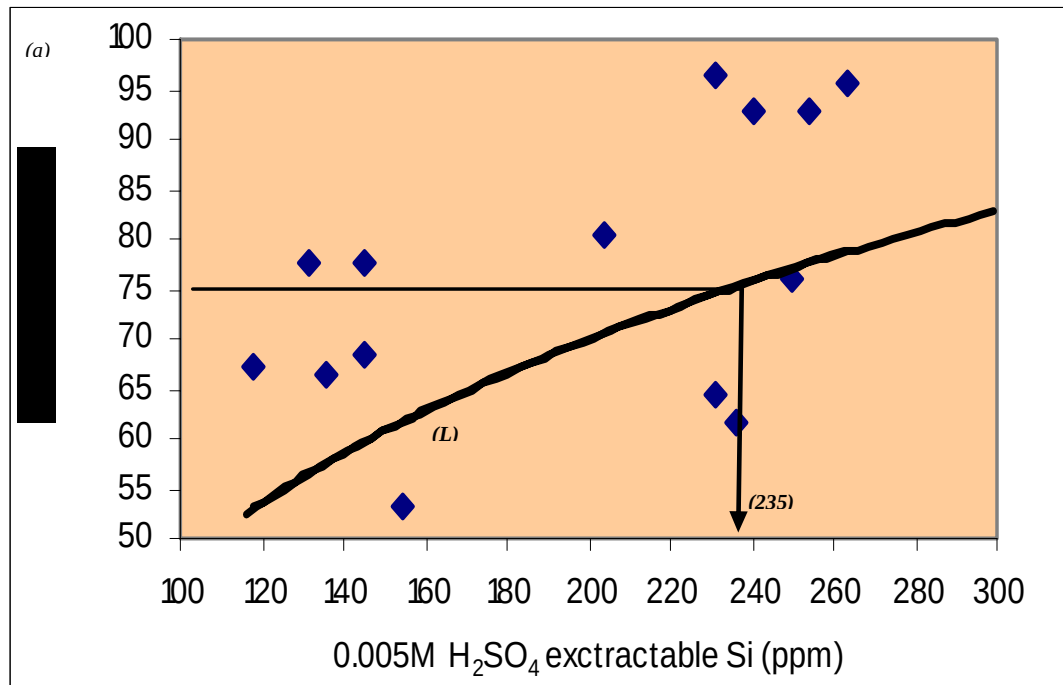


Fig. 7F Categorization of plant available soil Si into low, medium and high for 0.005M H₂SO₄ extractant

Based on the calibration curve for available Si extracted by different methods, three categories were established for the soil test values: low (L), medium (M) and high (H) (Fig. 7A - F)). The upper and lower values for each category were determined based on relative yield (%) according to Cope and Rouse (1973). The relative yield refers to the yield achieved on the unfertilized soil relative to the maximum yield achieved on the Si fertilized soil. The lower third (75% relative yield) of the response zone was arbitrarily called the low category. The upper zone (75-95 % relative yield) was called as medium and more than 95 per cent relative yield zone was called as high in available Si. The different extractants showed different range of values for each category of soil Si (Table 16). For 0.5M acetic acid -2 the extractable Si <47 ppm was considered to be low, 47 - 102 ppm was considered to be medium and >102 ppm was considered to be high in available Si. The categorization of available Si into L, M, and H for N NaOAc -1 was <67, 67 - 95 and >95 ppm respectively and for N NaOAc -2, it was <80, 80 - 110 and >110 ppm for L: M: H respectively. Wide variation in low, medium and high categories of available Si may be attributed to the type and nature of the extractant, pH of the respective extractant, shaking period, soil to solution ratio used and temperature, which contribute to the dissolution of different forms of Si present in the soil. Some extractants (citric acid, H₂SO₄) dissolve unavailable forms of Si from the soil resulting in higher critical values with wider variation in low, medium and high categories of available Si. Similarly, some extractants (water, ammonium acetate) do not extract all available Si forms and hence underestimate the available Si in the soil.

The extractants like N NaOAc-1, 0.5M acetic acid-2 and N NaOAc-2 were found to be the suitable extractants in the present investigation and the soils which falls under higher category have less response to the applied silicate fertilizers. Those soils having low to medium contents of available Si showed good response to the added fertilizers. These results were also in agreement with the findings of Korndorfer *et al.* (2001) and suggested that the soil test

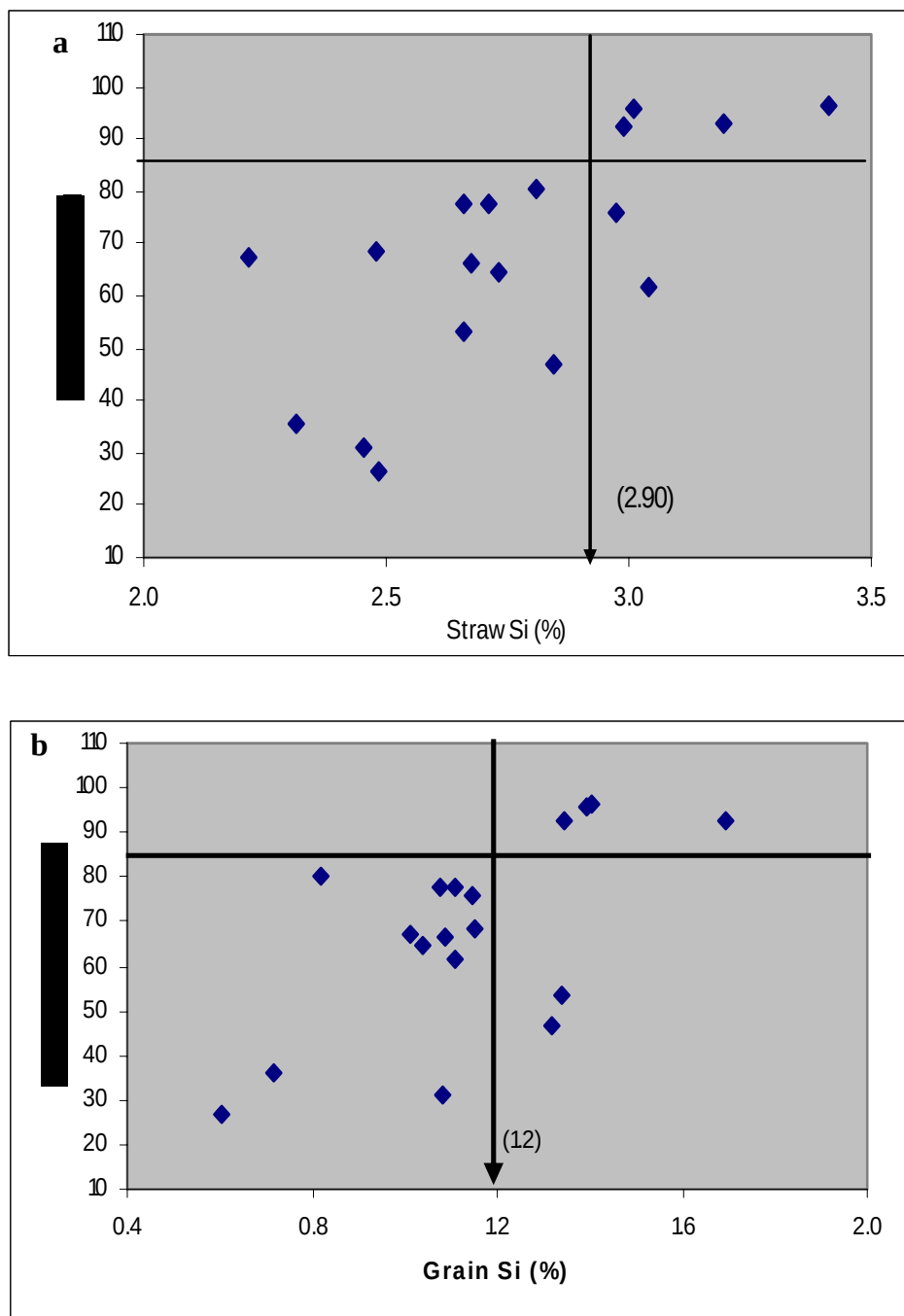


Fig. 8 Critical level of (a) Straw and (b) Grain Si for rice

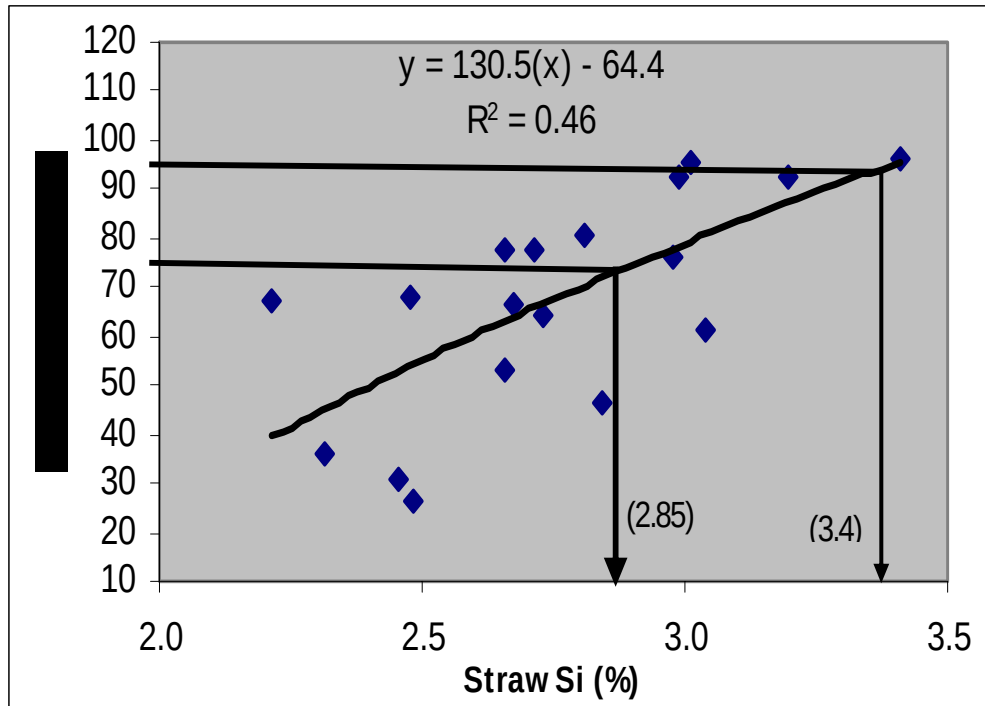


Fig. 9 Categorization of straw Si into low, medium and high for rice

ratings of Si for 0.5 M acetic acid were 0 to 6.4 ppm (low), 6.5 to 24 ppm (medium) and > 24 ppm (high) for some soils of Florida.

Critical limits of Si for straw and grains were 2.9 and 1.2 per cent respectively (Table 16). Per cent straw Si less than 2.85 (<75 % relative yield) was considered to be low, 2.85 to 3.4 per cent (75 – 95 % relative yield) was considered to be medium and more than 3.4 per cent (>95 % relative yield) straw Si was considered to be high (Table 16 and Figures 8 and 9). The lower straw Si concentrations were associated with the lower relative yield. These results corroborate with the findings of Korndorfer *et al.* (2001) in Florida. The critical per centage of Si in straw for no yield response to Si fertilization was 6.1 per cent in Japan and Korea and 5.1 per cent in Taiwan (Lian, 1976). In tropical eco regions of Srilanka and India, indica rice varieties may respond to Si application if Si content in straw is lower than 3.7 per cent (Nair and Ayer., 1968 and Takjima *et al.*, 1970).

5.4 Evaluation of genotypic difference in relation to Si accumulation under different moisture regimes

Four different rice genotypes (G) viz., G₁- BI-33, G₂- BI-43, G₃- Rasi and G₄- IRRI-49 were used to evaluate the Si accumulation at different growth stages (MT- maximum tillering, FS- flowering stage and HS- harvesting stage) under different moisture regimes (aerobic and submergence) in two different soils (Mangalore and Mudigere) of Karnataka with (S1- 966 kg Si ha⁻¹) and without addition of Si. The data pertaining to plant height, number of tillers, straw yield, grain yield, per cent Si in straw, per cent Si in grain, Si uptake in straw, Si uptake in grain and total uptake of the four different rice genotypes are given in Table 17, 18, 19, 20, 21, 22, 23, 24, and 25, respectively and Fig. 10 and 11.

The biometrical plant growth parameters such as plant height, number of tillers, straw weight and grain weight were highest in Rasi and BI-33 followed

by B1-43 and IRRI-49. The straw and grain yields were significantly higher due to the addition of 966 kg Si ha⁻¹. This may be attributed to the positive effect of adequate supply of Si on leaf erectness and thereby enhancing the photosynthetic activity. The results were also in agreement with the findings of Yoshida *et al.* (1959). According to Agarie *et al.* (1992), the maintenance of photosynthetic activity due to Si fertilization could be one of the reasons for the increased dry matter production. They also observed increased water use efficiency in Si amended rice plants probably due to prevention of excessive transpiration. Increased number of tillers due to application of Si was also noticed by Liang *et al.* (1994).

The per cent Si in straw and grains and its uptake were highest in BI-33 and Rasi followed by BI-43 and IRRI-49. Application of 966 kg Si ha⁻¹ significantly increased per cent Si and its uptake in straw as well as grain in both the soils over non Si supplied soils and noticed highest in BI-33 and Rasi compared to B1-34 and IRRI-49. This was mainly attributed to additional supplement of Si fertilizer and genotype characters like biomass production, root bearing ability. Duration of the crop also play dominant role in silicon accumulation by rice genotypes. The application of calcium silicate showed greater accumulation of Si in rice plants compared to control pots. Deren *et al* (1994) noticed increased Si concentration in plant tissue with increasing rate of Si fertilization, but within each Si treatment and control, cultivar varied for Si concentration and its uptake. The temperate japonica recorded greatest tissue concentration in all the treatments indicating some genotypes accumulate greater amount of Si whether the element is limiting or in excess. Similar results were also noticed by Winslow (1992) and Winslow *et al.*, (1997) in South America.

The Si uptake was maximum at harvesting stage followed by flowering stage and least at maximum tillering stage in all the genotypes under both the moisture regimes in Mangalore as well as Mudigere soils. This may be

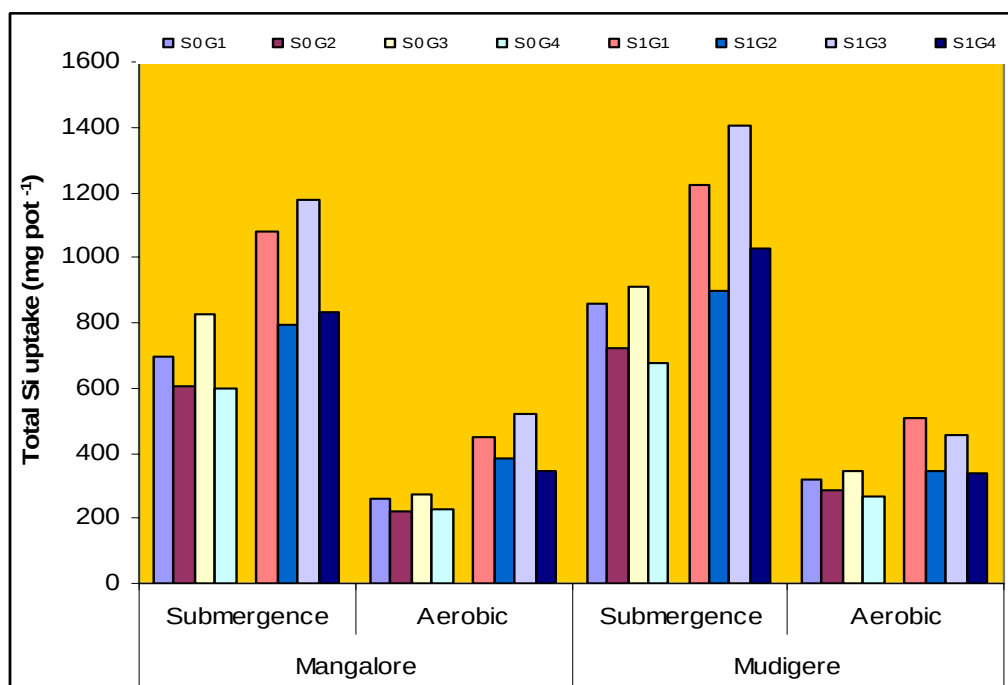


Fig 10 Total Si uptake by different genotypes under different moisture regimes with and without addition of calcium silicate as a Si source

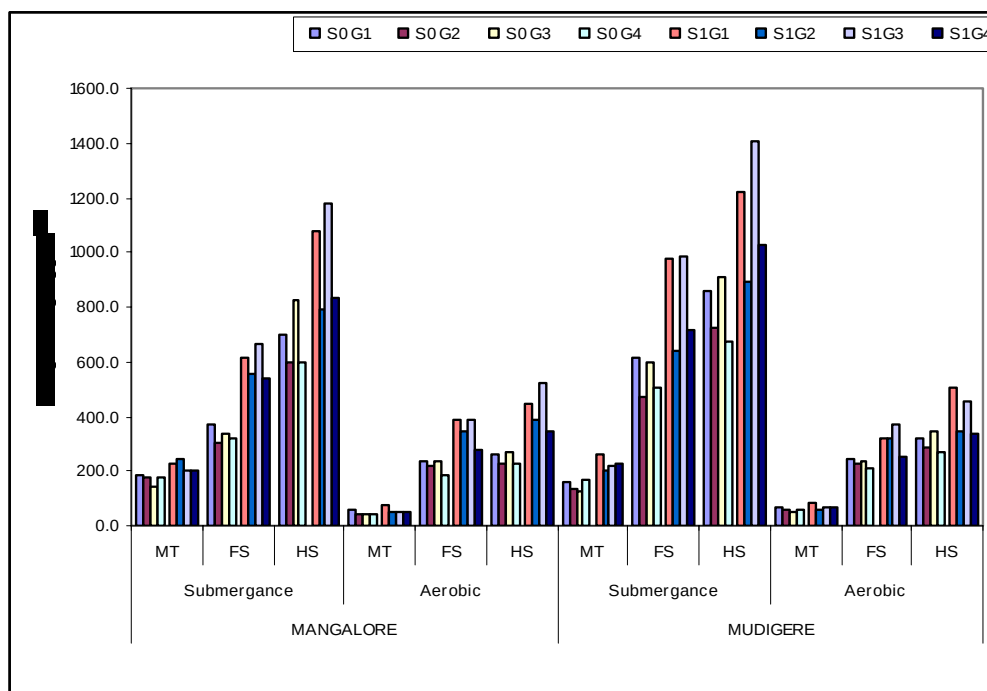


Fig 11 Uptake of Si by different genotypes at different growth stages under different moisture regimes in Mangalore and Mudigere soil

reasoned as the plants harvested at maximum tillering stage are relatively young and their requirement for Si was comparatively less, but as they grow older they required more Si for growth and metabolism. The results are in agreement with the findings of Islam and Saha (1969), Yoshida *et al.* (1959), Talashilkar and Chavan. (1956) and Inanaga *et al.* (2002). Nayar *et al.* (1982b) reported that the silica content of the leaf blade, culm and whole plant increased with progress of growth and was low during vegetative growth and high after flowering stage. The silica absorption was slow during the initial growth stages, but increased with the onset of reproductive growth period after flowering.

Ma *et al.* (2001) reported that the lateral roots played vital role in silicon accumulation in rice plant, but not root hairs. Ma *et al.* (2002) noticed that Si concentration of barley grain showed large variation ranging from 0 to 3600 mg kg⁻¹ in SV and from 0 to 3800 mg kg⁻¹ in BCCAM barley. The variation in Si concentration in plant species was largely due to efficiency of plant roots for Si acquisition (Takahashi and Hino, 1978). The genotypic variation in rice for Si accumulation has been documented and its effects were found to enhance productivity (Savant *et al.*, 1997). Rice showed highest uptake ability of Si followed by wheat, sorghum, maize, rye and barley. A significant variation in Si uptake was noticed among rice genotypes at varied levels of Si application (Ma and Tamai., 2002).

Under submerged condition, the genotypes recorded relatively highest uptake of Si compared to aerobic condition at both Mangalore and Mudigere soils. This was mainly attributed to dissolution and solubility of Si in submerged soil as influenced by soil pH, soil redox potential, soil temperature and Si concentration in soil solution. The amount of Si dissolved from paddy soil increased with increasing soil temperature and decreasing soil redox potential. This increase was attributed to Si release from Ferro silicate complexes under reductive soil condition (Sumida, 1992). The concentration of

available Si increases under submergence, particularly soils having high organic matter. The increase in Si availability is associated with the presence of reduced amorphous aluminum and iron hydroxides in soils following flooding (Dobermann and Fairhurst, 2000).

5.5 Interaction effect of Si and N on growth and yield of rice

Nitrogen is essential for plant growth and development, and often a limiting factor for high productivity. If applied excess it may limit the yield because of lodging, especially for cultivars of the traditional and international groups, and promote shading and disease problems. These effects could be minimized by the use of Si. Hence the present investigation was aimed to evaluate the effect of Si and N on wetland rice and their interaction effect on yield components at Mudigere and Ponnampet. The results of this study are presented in Table 26 to 34 and Figure 12 and 13. The field experimental photos are given in plates 3 and 4.

5.5.1 Effect of Si and N and their interaction on biometrical observation

The data presented in Table 26 indicate that application of increased levels of N alone increased the plant height, number of tillers and days to 50 per cent flowering. However, there was no significant difference with the application of increased levels of N. The number of tillers increased with increased application of N even up to 150 kg ha⁻¹ at Ponnampet. The soils of Ponnampet are normally sandy loam in texture with low organic carbon content. The region also receives high rainfall responsible for high leaching losses of N. Hence, there was a good response for added N even upto 150 kg N ha⁻¹. The results are in agreement with the findings of Munir *et al.* (2003) who reported that increase in number of stalks as a response to nitrogen fertilization was related to cultivar stimulation to produce tillers, which is related to the greater nitrogen availability to plants and participation of N in structural functions of the plant, such as cell multiplication and differentiation and formation of tissues. These results are also in accordance with the findings of



Plate 1 Field experiments at Mudigere: Kharif 2005

Contd...



Plate 1 Field experiments at Mudigere: Kharif 2005



Plate 2 Field experiments at Ponnampet: Kharif 2005

Contd...



Plate 2 Field experiments at Ponnampet: Kharif 2005

Filho *et al.* (1991), Ma *et al.* (1989), Deren *et al.* (1994), Samantaray *et al.* (1991), Umashankar *et al.* (2005) and Rati and Sharma (1996). However significant increase in number of tillers was noticed due to the supplement of $117 \text{ kg Si ha}^{-1}$ over control. There was no significant increase in plant height and days to 50 per cent flowering with the Si fertilization in both the locations. The results are in agreement with the findings of Singh and Singh (2005) and Singh *et al.* (2006) in India and Ma *et al.* (1989) in Japan, Munir *et al.* (2003) in Brazil, and Idris *et al.* (1975) in Bangladesh.

A positive interaction was noticed between Si and N with respect to number of tillers per hill. The highest number of tillers per hill was noticed due to the application of $117 \text{ kg Si ha}^{-1}$ (S2) and nitrogen at 150 kg ha^{-1} (N3) in both Mudigere (8.7) and Ponnampet (8.5). These results corroborate with the findings of Singh and Singh (2005) and Singh *et al.* (2006) in India, Munir *et al.* (2003) in Brazil.

5.5.2 Effect of Si and N and its interaction on per cent spikelet sterility, grain and straw yield

There was a significant increase in spikelet sterility due to the application of increased levels of N at both Mudigere and Ponnampet (Table 27 and Fig 13). The per cent spikelet sterility with the application of N at 150 kg ha^{-1} (N3) was 440 and 355 kg ha^{-1} at Mudigere and Ponnampet, respectively. Sheela and Thamos (1995) observed significant reduction in per cent sterility due to the application of lower level of N (75 kg N ha^{-1}) to an extent of 6 per cent over total grain yield. Present findings are also in accordance with Rathi and Sharma (1996) in Madhya Pradesh. However, significant reduction in per cent spikelet sterility was observed due to combined application of Si even with higher doses of N at both the locations. The number of spikelet sterility was influenced by the interaction of Si and N, decreasing per cent spikelet sterility with increased Si levels. Such effect can be explained by improvement of plant architecture (Deren *et al.*, 1994). The leaves become more erect, thus reducing

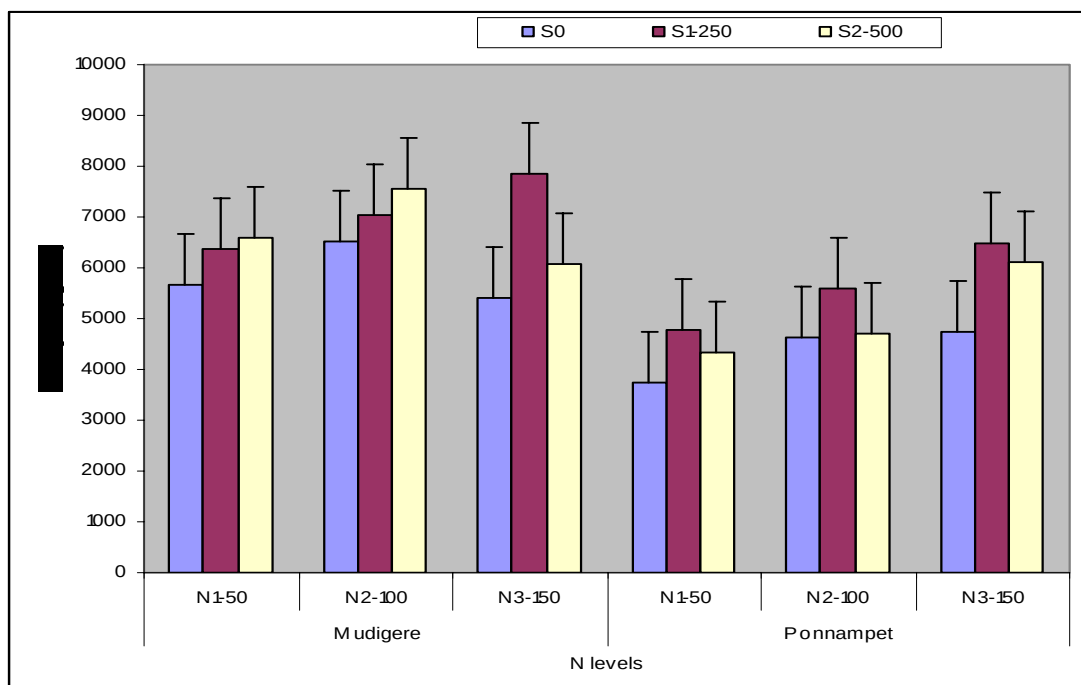


Fig 12 Effect of varied levels of N and Si on grain yield at Mudigere and Ponnampet soils

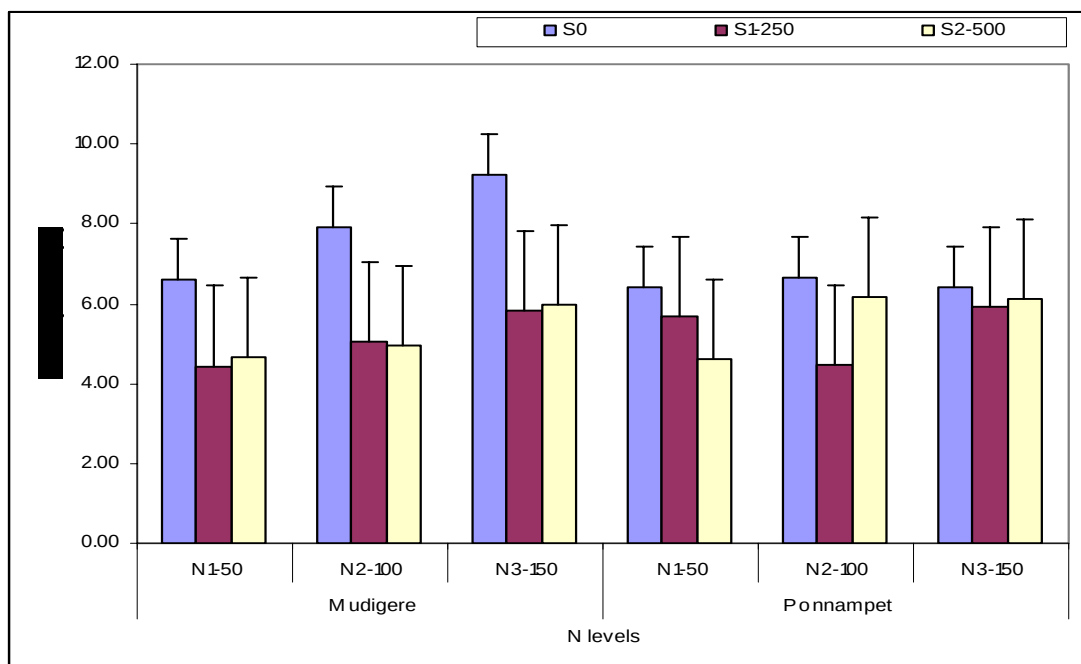


Fig 13 Effect of Varied levels of N and Si on percent reduction of blank spikelets/ spikelet sterility at Ponnampet and Mudigere

the leaf shading and increasing the photosynthetic rate, especially under high population densities and high nitrogen rates and /or low Si rates tend to turn leaves more decumbent, as a result of greater leaf opening angles (Yoshida *et al.*, 1969). The higher N application (100 or 150 kg N kg⁻¹) along with increasing levels of Si showed maximum decrease in spikelet sterility. Similar results were also noticed by Munir *et al.* (2003) in soils of Brazil. The fertility expresses the per centage spikelets that turned into grain. This yield component is dependent on pollen grain meiosis, anthesis, pollination, fertilization and carbohydrate translocation, and influenced by Si fertilization along with even higher levels of N application (Munir *et al.*, 2003).

N fertilization influences spikelet fertility in rice. This can be explained as observed in the present findings that, increased application of N increased the number of tillers and there by spikelet sterility. At vegetative stage, there was greater N accumulation in plant which increases number of tillers, causing mutual shading, thereby reducing the area of active photosynthesis, which reduces the production of assimilates that otherwise would be directed to grain filling and increasing the number of spikelet sterility. The results are in accordance with the findings of Ma *et al.* (1989) and Munir *et al.* (2003).

The application of N alone increases grain yield (Table 28 and Figure 13) up to 100 kg N ha⁻¹ (N2) and further application decreased the grain yield at Mudigere. This was mainly attributed to reduction in photosynthesis rate due to self shading and increased number of tillers and decreased production of assimilates and there by reduction in grain yield (Munir *et al.*, 2003, Ma *et al.*, 1989). The yield increase was observed due to the application of nitrogen even up to 150 kg ha⁻¹ (N3) in soils of Ponnampet. This was mainly attributed to low soil organic carbon and available N content and sandy loam texture of the soil. The leaching of N due to heavy rainfall in these soils besides their low organic carbon content and sandy loam texture require high N application rates to achieve higher yields. Hence increased application even up to 150 kg N ha⁻¹

increased the grain yield at Ponnampet. The results are in agreement with the findings of Singh and Singh (2005) and Singh *et al.* (2006) in soils of Uttar Pradesh and recorded higher yield with the application of N even up to 180 kg ha⁻¹. The supply of nitrogen enabled rice plant to assimilate sufficient photosynthesis under low native N soils resulting in increased dry matter production and these together produced more grains and more number of filled grains leading to higher grain yield (Jaiswal and Singh. 2001). Significant increase in grain yield was noticed due to the application of Si along with higher levels of N over N alone treated plots (Table 28 and Figure 13). The highest grain yield was noticed in the plots treated with Si at 117 kg Si ha⁻¹ (S2) plus N at 150 kg ha⁻¹ (N3) in both the soils of Mudigere (7860 kg ha⁻¹) and Ponnampet (6490 kg ha⁻¹). This may be attributed to the reduction in per cent spikelet sterility as noticed in the present investigation, increased rate of photosynthesis, increased number of productive tillers and reduction of incidence of insect pests and diseases (Table 33 and 34). These results are also in agreement with the findings of Munir *et al.* (2003), Singh and Singh (2005), Singh *et al.* (2006), Osuna *et al.* (1991) and Idris *et al.* (1975).

The straw yield was found to increase significantly with each increment in N level and highest straw yield was recorded with the application of 150 kg N ha⁻¹ (Table 28) in soils of both Mudigere (8006 kg ha⁻¹) and Ponnampet (5923 kg ha⁻¹). Higher straw yield was mainly attributed to increased number of tillers per hill and plant height. The dry matter production increased significantly with each increment in N level due to increased chlorophyll formation which ultimately improved photosynthesis (Singh *et al.*, 2006, Singh and Singh, 2005, Rathi and Sharma, 1996, Sheela and Thomas, 1995, Samantaray *et al.*, 1991, Jaiswal and Singh, 2001, and Umashankar *et al.*, 2005) in different rice soils of India.

The application of varied levels of Si along with higher N also recorded significant increase in the straw yield and highest straw yield was noticed due

to the application of 117 kg Si ha⁻¹ (S2) along with 150 kg N ha⁻¹ in both the locations of Mudigere (8497 kg ha⁻¹) and Ponnampet (6600 kg ha⁻¹). The enhanced straw yield with Si at higher N levels may be attributed to leaf erectness which facilitated better penetration of sunlight leading to higher photosynthetic activity of plant and more formation of carbohydrates. Similar results were also noticed by Ma *et al.* (1989), Korndorfer *et al.* (2001), Rodrigues *et al.* (2003), Rani *et al.* (1997) and Singh *et al.* (2006).

The efficiency of grain production in crop plants is frequently expressed as grain harvest index. The grain harvest index reflects the partitioning of photosynthates between the grain and the vegetative part of the plant and improvement in grain harvest index emphasizing the importance of carbon allocation in grain production. The grain harvest index significantly decreased with increased application of N alone in soils of Mudigere, but neither increased nor decreased at Ponnampet soils. However, application of Si along with the higher levels of N increased the grain harvest index over N alone treated plots at Mudigere. Similar results were noticed by Fageria and Filho., (2001) for different rice genotypes in Brazil.

5.5.3 Effect of Si, N and their interaction on per cent Si and its uptake in straw and grain

The effect of Si and N and their interaction on per cent Si, N and uptake in straw and grain at Mudigere and Ponnampet are presented in the Table 29, 30, 31 and 32 respectively. Increased application of N up to 100 kg N ha⁻¹ increased the per cent Si and its uptake in both straw as well as grain at both the locations (Table 29 and 31). Further increase in application of N resulted in a declining trend. The results are in conformity with the findings of Samantaray *et al.* (1991), Mishra *et al.* (1995) and Savant *et al.* (1997). Application of N tends to decrease Si uptake in rice, and fertilizers containing NH₄⁺-N may decrease it more than NO₃⁻-N (Kono and Takahashi, 1958 and

Wallace 1989). Sumida (1992a) reported that high amounts of $\text{NH}_4\text{-N}$ in soil resulting from high N rates may limit Si uptake by the rice plants.

The Si uptake is mainly dependent on Si supplying ability of the soil and with increased application of Si, there was increase in per cent Si and its uptake in both straw and grain at both Mudigere and Ponnampet soils. These results are in agreement with the findings of Sumida (1992a), Singh *et al.* (2006), Osuna *et al.* (1991) and Korndorfer *et al.* (2001). The per cent Si and its uptake in straw as well as grain increased at both the locations due to increased application of Si along with varied levels of N over control plots. The results are corroborating with the findings of Savant *et al.* (1997) and Singh *et al.* (2006). However, Savant *et al.* (1997) noticed a positive interaction between Si and N in rice for higher per cent Si and its uptake in straw as well as grain and grain yield.

5.5.4 Effect of Si and N and their interaction on per cent N and uptake in rice

The effect of Si and N and their interaction on per cent N and its uptake in straw and grain at Mudigere and Ponnampet are presented in the Tables 29, 30, 31 and 32.

The per cent N increased with increased application of N alone in both straw as well as grain at both the locations of Mudigere and Ponnampet. Similar results were also noticed by Singh *et al.* (2006) and Mishra *et al.* (1995). However, increased application of $234 \text{ kg Si ha}^{-1}$ decreased the per cent N in straw as well as grain in both the locations. Similar observations were also made by Sumida, (1992a) and Yoshida *et al.* (1969). The application of higher levels of Si with increased levels of N decreased the per cent N and its uptake in both grain as well as straw at both the locations over control. These results were also in agreement with the findings of Sumida (1992a).

5.5.5 Effect of Si, N and their interaction on the incidence of insect pests and diseases

The results of the interaction between Si and N nutrition on control of insect pests and diseases are presented in the Table 33 and 34. It was observed that application of increased levels of N alone increased the incidence of diseases and insect pests at both the locations. However, there was significant reduction in diseases (leaf blast, brown leaf spot, bacterial leaf blight and udabatta) as well as insect pests (leaf roller, case worm and hispa) with increased levels of Si along with varied levels of N which ultimately resulted in increased grain yield. The possible mechanisms involved in control of insect pests and diseases due to application of Si through mechanically induced resistance, or through production of phytoalexins and phenolic compounds. The contribution of Si on control of diseases was explained by Francois *et al.*, (2005) and Cherif *et al.*, (1992). Similarly Si also dominated in control of diseases through induced resistance either due to production of flavonoid phytoalexins or activated defense mechanism due to production Chitins (Fawe *et al.*, 1998 and Cherif *et al.*, 1992). Fawe *et al.*, (2001) proposed that Si played an active role in reinforcing plant disease resistance by stimulating natural defense reactions. The results are in agreement with the findings of Okuda and Takahashi (1965), Rodrigues *et al.* (2001, 2003 and 2004), Datnoff *et al.* (1997), Osuna *et al.* (1991) on various rice diseases. Panda *et al.*, (1975), Ma and Takahashi (2002) and Sassamoto (1961) reported that the larvae of the yellow rice borers, brown plant hopper, leaf rollers were unable to attack resistant rice plant because of high Si content of their stems and showed negative correlation between Si content and pest incidence. Similar results were also noticed by pan *et al.* (1979) in Taiwan, Meyer and Kepping (2005) in south Africa, Korndorfer *et al.* (2004) in Florida and Tahashilkar *et al.* (2000), Mishra *et al.* (1995), Panda *et al.* (1975) and Sasamoto, (1961) on various insect pests.

Practical implications:

1. The majority of soils studied were low to medium in available Si, and hence there is necessity of Si fertilization to rice soils
2. Sodium acetate-1 extractant was found to be the most suitable for available Si determination in rice soils

3. The critical limits of available Si for different extractants were depicted in this investigation and rice soils were also categorized into low, medium and high for available Si content.
4. There was wide variation in Si accumulation by studied rice genotypes at different growth stages under different moisture regimes
5. The interaction between Si and N was found to be positive and application of higher levels of N along with 117 kg Si ha⁻¹ was found very superior in obtaining higher grain yield

Future line of research work:

1. Mechanisms involved in Silicon uptake to be studied in detail and reasons for variation among genotypes.
2. There exists a need for genetic research for identifying the efficient Si accumulating rice cultivars for biotic and abiotic stress mechanisms.
3. Detailed investigations are warranted to understand the role of developing cheaper and efficient Si source for aerobic and wetland rice.

Summary

VI. SUMMARY

An investigation was undertaken to study the available Si status in rice growing soils of Mangalore, Mudigere and Ponnampet. A green house experiment was conducted using eighteen representative soils from Mangalore, Mudigere and Ponnampet using KRH -2 rice hybrid as test crop. The grain and straw yields were recorded after the harvest of the crop and analyzed for per cent Si content. The available Si extracted by different extractants was correlated with plant growth indices to select suitable extractant for routine soil analysis.

The critical limits of soil and plant Si was determined in rice growing soils by conducting a pot experiment in eighteen soils with graded levels of Si. The grain and straw yields were recorded after harvesting the rice crop. The yield achieved on the unfertilized soil relative to the maximum yield achieved on the Si fertilized soil was calculated (Relative yield). Critical limits of soil Si were worked out by plotting the soil Si extracted by different extractants with per cent relative yield. Similarly, critical limits for straw and grain were also calculated.

There is a greater variation among the rice genotypes in relation to the nutrient acquisition and accumulation under different rice ecosystems. Such variation is also observed among different rice genotypes with regard to silicon. A green house pot experiment was conducted to evaluate four rice genotypes (BI-33, BI-43, Rasi and IRRI-49) in two different soils (Mangalore and Mudigere) to know the silicon accumulation under two moisture regimes (aerobic and submergence) with and without application of calcium silicate (S0- 0 kg Si ha⁻¹ and S1- 966 kg Si ha⁻¹) as Si source at three growth stages viz., MT- maximum tillering, FS- flowering stage and HS- harvesting stage.

Application of nitrogenous fertilizers is an important practice for increasing rice yields. However, when applied in excess it may limit yield because of lodging, promote shading and susceptibility to insects and diseases. Therefore two field experiments were conducted by treating the soils with three levels of Si (S1, S2 and S3) and three levels of N (N1, N2 and N3) to study the interaction effect of Si and N on the growth and yield of rice at Mudigere and Ponnampet. The salient findings of the investigations carried out are summarized below:

6.1 Silicon status of rice growing soils of Karnataka

- The available silicon content of Mangalore soils extracted by ammonium acetate and acetic acid ranged from 8.1-46.3 ppm and 18.1-78.4 ppm respectively.
- In Mudigere soils the available Si as extracted by 0.5M ammonium acetate and 0.5M acetic acid ranged from 9.2 to 64.6 ppm and 15.9 to 72.2 ppm, respectively.
- Among the soils studied, 45.0, 44.5 and 10.5 per cent soils were categorized as low, medium and high for 0.5M ammonium acetate method and 8, 66.9 and 25 per cent as low, medium and high in available Si for 0.5M acetic acid method respectively.
- It was observed that 75 to 85 per cent of the studied soils were low (< 20 ppm) to medium (20 -40 ppm) in available Si content
- Among the different locations, available Si status was in the following order: Mudigere > Mangalore > Ponnampet.

6.2 Evaluation of suitable extractant for available soil Si in rice soils

- The Si content as extracted by 0.5M acetic acid-1, 0.5M acetic acid-2, 0.5M acetic acid-3, 0.01M CaCl₂, distilled water-4, distilled water-1, 0.5M NH₄OAc, N NaOAc-1, N NaOAc-2, 0.1M citric acid and 0.005M H₂SO₄ ranged from 11.3 to 73.8ppm, 13.2 to 60.2ppm, 22.1 to 102.5ppm, 22.4 to 55.9ppm, 12.7 to 37.1ppm, 6.1 to 16.9ppm, 10.9 to

42.3ppm, 38.5 to 86.7ppm, 44.1 to 317.7ppm, 47.8 to 97.9ppm and 118 to 263.2ppm respectively.

- The available Si extracted by various extractants irrespective of the soils studied was in the following order: 0.005M H₂SO₄ > 0.1M citric acid > N NaOAc-2 > N NaOAc-1 > 0.5M acetic acid-3 > 0.5M acetic acid-2 > 0.5M acetic acid-1 > 0.01M CaCl₂ > 0.5M NH₄OAc > distilled water-4 > distilled water-1.
- The amount of soil Si extracted by ten extractants correlated positively and significantly with grain yield, grain Si, straw Si and Si uptake by straw as well as grain.
- Among the different extractants, available Si extracted by N NaOAc-1 recorded highest “r” values with grain yield (r= 0.78**), Straw Si (r= 0.86**), grain Si (r=0.56*), straw Si uptake (r=0.82**), grain Si uptake (r= 0.75**) and total Si uptake (r= 0.84**).
- The relationship between soil test values with the different crop parameters according to the “r” values followed the order: N NaOAc-1 > 0.5M acetic acid-2 > N NaOAc-2 > 0.5M acetic acid-1 > 0.01M CaCl₂ > 0.5M NH₄OAc > distilled water-1 > distilled water-4 > 0.1M citric acid > 0.005M H₂SO₄ > 0.5M acetic acid -3.
- Available Si extracted by N NaOAc-1 method noticed highest regression coefficient for grain Si uptake (R² = 56*), straw Si uptake (R² = 0.66**), per cent Si in straw (R² = 0.71**) and total per cent Si (R² = 0.60**).
- The relationship between crop parameters and available Si extracted by different methods according to R² values followed the order: N NaOAc-1 > 0.5M acetic acid-2 > N NaOAc-2 > 0.5M acetic acid-1 > 0.01M CaCl₂ > 0.5M NH₄OAc > distilled water-1 > distilled water-4 > 0.1M citric acid > 0.005M H₂SO₄ > 0.5M acetic acid -3
- N NaOAc-1, 0.5M acetic acid-2, N NaOAc-2 were considered as suitable extractants for routine soil test analysis of available Si in soils.

6.3 Critical limits of plant and soil Si in rice

- In general, soils of low to medium in available Si have highly responded to applied Si in achieving higher grain yields and soils containing higher levels of Si have moderately responded for application of Si. Among the soils studied, Mangalore soils have highly responded to the application of Si followed by soils of Ponnampet and least response was observed in soils of Mudigere.
- The relative yield is the yield achieved on the unfertilized soil relative to the maximum yield achieved on the Si fertilized soil ranged from 35.8 to 96.4 per cent.
- The critical limit of soil Si for 0.5M acetic acid -1, 0.5M acetic acid -2, 0.5M acetic acid-3, 0.01M CaCl_2 , distilled water-1, distilled water-4, 0.5M NH_4OAc , N NaOAc-1, N NaOAc-2, 0.1M citric acid and 0.005M H_2SO_4 were 54, 54, 87, 43, 30, 14, 32, 75, 85, 185 and 207 ppm respectively.
- The Critical limit for Si was 2.9 and 1.2 per cent for straw and grains respectively. Per cent straw Si less than 2.85 was considered as low, 2.85 to 3.4 per cent was considered as medium and more than 3.4 per cent was considered as high.

6.4 Evaluation of genotypic difference in relation to Si accumulation under different moisture regimes

- The highest plant height was recorded in BI-33 and Rasi in both the soils of Mudigere and Ponnampet under aerobic as well as wetland conditions. However, plant height was 1.5 times higher in wetland than in the aerobic conditions.
- The highest number of tillers was recorded in BI-33 and Rasi genotypes in both the soils under both the conditions with and without Si applied pots. In general, the highest number of tillers were noticed in aerobic than in submerged condition.

- The straw yield recorded was highest in Rasi (13.0, 31.0, and 35.5 g pot⁻¹ at maximum tillering stage, flowering stage and harvesting stage, respectively) and BI-33 (11.5, 25.5 and 30.5 g pot⁻¹ at maximum tillering stage, flowering stage and harvesting stage respectively) due to the application of 966 kg Si ha⁻¹ under submerged conditions. In aerobic condition, BI-33/Rasi and BI-33 recorded highest straw yield with the application of calcium silicate as Si source.
- Rasi genotype recorded highest per cent Si in straw at both Mangalore (2.50 %) and Mudigere (2.72 %) followed by BI-33 under aerobic condition. In general, Rasi/ BI-33 genotype recorded highest Si accumulation in straw with and without the application of CaSiO₃ as Si source.
- In general, per cent Si accumulation in grains was higher in submerged condition than aerobic condition and variation among different genotypes follow the order: Rasi > BI-33 > IRRI-49~BI-43.
- The Si uptake increased with the supplement of CaSiO₃ as Si source over control in submerged conditions and recorded highest in Rasi at harvesting stage in Mangalore (952.9 and 681.1 mg pot⁻¹) and Mudigere (1059.7 and 901.7 mg pot⁻¹) under submerged conditions of Si treated and non treated pots respectively.
- In aerobic system, the Si uptake increased with the application of Si and recorded highest in Rasi (421.7 mg pot⁻¹) at Mangalore and BI-33 (418.5 mg pot⁻¹) at Mudigere.
- The Si uptake was highest at harvesting stage followed by flowering stage and maximum tillering stage in both the soils under aerobic and submerged conditions.
- In general, total Si uptake of different rice genotypes followed the order:
 - o Submergence: HS and FS : Rasi > BI-33 > IRRI-49 > BI-43
MT : BI-43 > BI-33 > Rasi > IRRI-49
 - o Aerobic : HS and FS : Rasi/ BI-33 > BI-43 > IRRI-49
MT : BI-33 > IRRI-49/ Rasi > BI-43

6.5 Effect of Si, N and its interaction on growth and yield of rice

- There was a significant increase in number of tillers per hill with the application of $117 \text{ kg Si ha}^{-1}$ over control in both the studied soils. However, increased application of N alone decreased the number of tillers. The application of Si along with increased levels (up to 150 kg N ha^{-1}) increased the number of tillers and highest number of tillers was noticed in the plots treated with $117 \text{ kg Si ha}^{-1}$ and 150 kg N ha^{-1} in both the locations
- There was no significant difference in days to 50 per cent flowering due to the combined application of Si and N.
- A significant reduction in spikelet sterility was observed due to combined application of Si along with higher doses of N.
- The highest grain yield was recorded due to application of 100 kg N ha^{-1} and further application decreased the grain yield at Mudigere but not in Ponnampet. The increased application of N alone significantly increased the straw yield. However, combined application of N along with Si at Ponnampet recorded highest straw yield of 6600 kg ha^{-1} ($234 \text{ kg Si ha}^{-1}$ and 150 kg N ha^{-1}) and similar trend was also observed at Mudigere.
- Grain harvest index decreased significantly with the increased application of N alone plots. Application of higher levels of Si alone resulted in the higher accumulation of Si in straw as well as grain at both the locations. The interaction between Si and N was found to be statistically significant.
- The per cent N and its uptake in straw and grain significantly increased with increased application of N alone at both the locations. However, application of higher levels of Si ($234 \text{ kg Si ha}^{-1}$) reduced the per cent N in both straw and grain at Mudigere location and increasing trend was observed at Ponnampet location
- A Significant increase in the incidence of leaf blast, brown leaf spot and leaf roller was observed due to the increased application of N alone. However, significant reduction in the incidence of diseases (leaf blast,

brown leaf spot and bacterial leaf spot) and insect pests (leaf roller, case worm and hispa) were noticed due to the supplement of Si over control.

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* Originals not seen