"EFFECT OF SOURCES AND LEVELS OF SILICON ON YIELD OF PADDY."

By

Miss. SUPRIYA ANANDRAO AAREKAR

(Reg.No.10 / 263)

A thesis submitted to the

Mahatma Phule Krishi Vidyapeeth,

Rahuri- 413 722 Dist. Ahmednagar,

Maharashtra (India)

in partial fulfilment of the requirements for the Degree

of

MASTER OF SCIENCE (Agriculture)

in

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

DIVISION OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY,

COLLEGE OF AGRICULTURE, KOLHAPUR - 416 004

MAHARASHTRA (INDIA)

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2012

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part thereof has not been submitted by me or any other person to any other University or Institute for Award of Degree or Diploma

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CERTIFICATE

This is to certify that, the thesis entitled **"EFFECT OF SOURCES AND LEVELS OF SILICON ON YIELD OF PADDY."** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar, Maharashtra State in partial fulfilment of the requirement for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**, embodies the result of a piece of *bonafide* research carried out by **Miss. SUPRIYA ANANDRAO AAREKAR** under my guidance and supervision and that no part of this thesis has been submitted for any other degree or diploma in other form.

The assistance and help received during the course of this investigation and sources of reference have been duly acknowledged.

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Date : / / — Research Guide

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CERTIFICATE

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Place: College of Agriculture, Kolhapur

Date : / / (**Supriya. A. Aarekar**)

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LIST OF ABBREVIATIONS

%	:	Per cent
°C	:	Degree celcius
@	:	at the rate of
Agri.	:	Agriculture
BA	:	Bagasse Ash
$CaCO_3$	:	Calcium carbonate
CD	:	Critical Difference
CEC	:	Cation Exachange Capacity
cm	:	Centimetre (s)
CS	:	Calcium Silicate
CSS	:	Calcium Silicate Slag
Cu	:	Copper
DAP	:	Diammonium Phosphate
dS m^{-1}	:	Decisimen per metre
DTPA	:	Diethylene Triamine Penta Acetic Acid
EC	:	Electric conductivity
EDTA	:	Ethylene Diamine Tetra Acetic Acid
et al.	:	and other (et alli)
FA	:	Fly Ash
Fe	:	Iron
Fig.	:	Figure
g.	:	Gram
g $hill^{-1}$	:	Gram per hill
gL^{-1}	:	Gram per liter
g pot^{-1}	:	Gram per pot
ha^{-1}	:	Per hectare
K	:	Potassium
K_2O	:	Potash
kg ha^{-1}	:	Kilogram per hectare
Mn	:	Manganese
mg	:	Milli gram
mg pot^{-1}	:	Milli gram per pot
mL	:	Milli liter
mm	:	Milli metre
N	:	Nitrogen
O.C.	:	Organic carbon
P	:	Phosphorus
P_2O_5	:	Phosphorus pentaoxide
ppm	:	Parts per million
PU	:	Prilled Urea

q ha^{-1}	:	quintal per hectare
RHA	:	Rice Husk Ash
RP	:	Rock Phosphate
S.Em.	:	Standard error of mean
Si	:	Silicon
SiO_2	:	Silicon dioxide
SSP	:	Single Super Phosphate
t ha^{-1}	:	Tonne (s) per hectare
UB-DAP	:	Urea Briquettes containing diammonium phosphate
UB	:	Urea Briquettes
Viz.	:	Namely
Zn	:	Zinc

ABSTRACT

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"EFFECT OF SOURCES AND LEVELS OF SILICON ON YIELD OF PADDY."

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A Candidate for the degree of

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Research Guide : Dr. R.B. Pawar

Department : Soil Science and Agricultural Chemistry

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The pot culture experiment entitled "Effect of sources and levels of silicon on yield of Paddy" was conducted during *Kharif* 2011-2012 at College of Agriculture, Kolhapur with a view to study the effect of sources and levels of silicon on N,P,K and silicon uptake, yield, disease and pest resistance of paddy and optimum level of silicon for paddy.

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The present investigation was carried out in Completely Randomized Block Design. Thirteen treatments comprised of three levels of silicon (250, 500 and 750 kg Si ha^{-1}) through four sources of silicon viz. Rice Husk Ash, Calcium Silicate, Bagasse Ash and Fly Ash were replicated thrice along with one control as 0 kg Si ha^{-1}.

The plant height, total number of productive tillers per pot and dry matter per hill of paddy were found to increase significantly due to silicon application through different sources, however the differences between different sources and levels of silicon were not significant. The treatment CS-750 kg Si ha^{-1} (T_7) recorded significantly highest plant height (63.80 cm), number of productive tillers per pot (18.7) and dry matter accumulation per hill (9.66 g.) at harvest but it was at par with RHA-750 kg Si ha^{-1} (T_4), FA-750 kg Si ha^{-1} (T_{13}), BA-750 kg Si ha^{-1} (T_{10}), CS-500 kg Si ha^{-1} (T_6), RHA-500 kg Si ha^{-1} (T_3) ,FA-500 kg Si ha^{-1} (T_{12}) and BA-500 kg Si ha^{-1} (T_9).

Similar trend was observed in thousand grains weight, grain yield and straw yield of paddy. The significantly highest thousand grains weight (19.23 g.), grain yield (18.55 g pot^{-1}) and straw yield (29.74 g pot^{-1}) were recorded in CS-750 kg Si ha^{-1} (T_7). The incidence of pest and disease was not observed on experimental paddy crop.

The total uptake of N, P, K and Si was increased significantly with application of silicon. The significantly highest uptake of N, P, K, and Si (370.47, 125.60, 516.74 and 1277.82 mg pot^{-1}, respectively) was recorded in the treatment CS-750 kg Si ha^{-1} (T_7).

The results of the present investigation indicated that application of silicon @ 250 kg ha^{-1} significantly increased growth and yield of paddy through different sources (Rice Husk Ash, Bagasse Ash, Fly Ash and Calcium Silicate). However considering the availability and cost, bagasse ash proved as good source of silicon for increasing the growth and yield of upland paddy.

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1. INTRODUCTION

Rice is the most important crop of India and it occupies 23.3 per cent of gross cropped area of the country, contributes 43 per cent of total food grain production and 46 per cent of total cereal production. Considering world wide distribution India has the largest area under rice cultivation (42.49 M.ha) and occupies second position in production (88.28 M.t) next to China. According to Agricultural Statistical Information Maharashtra, rice is second important crop grown over an area of 15.35 lakh hectare. The average productivity of the state is 1.85 tonnes per hectare. Area under rice crop in Kolhapur district is 1.10 lakh hectares with an average productivity of 2.53 tonnes per hectare (Anonymous 2006).

The gain due to modern rice production technology has been discriminatory against the resource poor areas which is also dominated by small and marginal farmers. There are various constraints in rice production as pest and diseases, water management, low soil fertility and poor agronomic practices. Indiscriminate use of chemicals including insecticides, fungicides, rodenticides and herbicides which are harming the ecosystem. Integrated approach for nutrient, pest and soil health management involving blend of organics and inorganics is urgently required to ameliorate the situation. Sustainable agriculture emphasizes the conservation of on farm resources which are renewable. Therefore it becomes the need to focus and fine-tune our efforts for development of resource conservation technologies for higher input use efficiency.

Silicon is second most element abundantly available on earth crust. It's content in soils varies greatly ranging from less than 1 to 45 % by dry weight (Sommer *et al.* 2006). Silicon dioxide (SiO_2) comprises 50 to 70 % of the soil mass. Soil-silicon compounds usually are present as SiO_2 and various aluminosilicates. Quartz together with crystalline forms of silicates (Plagioclase, Orthoclase and Feldspars), secondary or clay and silicon rich minerals (Kaolin, Vermiculite and Smectite) and amorphous silica are major constituents of most soils (Orlov 1985). In high rainfall regions due to heavy weathering less resistant silicates release silica which will be rapidly leached out to nearby streams. Although silicon is present in soil in large amounts, it’s availability to plants is limited. Due to the desilication process subtropical and tropical soils are generally low in plant available silicon would benefit from silicon fertilization (Korndorfer and Lepsch 2001).

The accessibility of silicon to plant greatly depends on weathering rate of silicate minerals and release of silicon to soil solution. Plant absorbs silicon as a monosilicic acid (orthosilicic acid) by diffusion and mass flow process. The response of crops to silicon application particularly rice and sugarcane have been studied by several investigators (Padmaja and Verghese 1972; Dong *et al.* 1981). Rice is having the ability to absorb and accumulate silicon metabolically while many upland crop plants seem to lack such ability. A rice crop producing 5 t ha^{-1} grain yield in a lateritic soil of India has been found to remove 468 kg Si ha^{-1} (Sahu 1990). Numerous experiments have shown that Si deposition in the plant tissues can improve yield, lodging resistance, insect pest and disease resistance in rice plants. So Silicon has long been recognized as a beneficial element for rice, although it has not been proved as an essential element.

Although Si is abundant in the earth crust because of low solubility (Lindsay 1979) many soils contain inadequate supply or are naturally low in plant available Si. Depletion of Si may occur in traditional soils with continuous monoculture, intensive cultivation of high yielding cultivars of rice and can be a limiting factor for sustainable rice production (Miyake 1993).

Silicon does not form a constituent of any cellular components but primarily deposited on the walls of epidermis and vascular tissues conferring strength, rigidity and resistance to pests and diseases. Silicon nutrition also manages many abiotic stresses including physical stresses like lodging, drought, radiation, high temperature, freezing and chemical stresses like salt, metal toxicity and nutrient imbalance (Epstein 1994). It plays a role in phosphorus nutrition and there is an interrelationship with phosphorus (Silva 1971).

Silicon plays an important role in hull formation in rice and in turn seems to influence grain quality (Sawant *et al.* 1997). Silicon deposited in leaf blade promoted photosynthesis by reducing water stress, improving light transmission and light receiving forms and silicon deposited in the husk increase percent filled spikelets by reducing excessive water loss

(Ma 1990). The hulls of poor-quality and milky-white grains (kernels) are generally low in silicon content, which is directly proportional to the silicon concentration in the rice straw (Aleshin *et al.* 1978).

Many Indian farmers are not aware about benefits of silicon and silicon sources. The ideal silicon source must have characteristics as : a relatively high content of silicon, provide sufficient water-soluble silicon to meet the needs of the plant, be cost effective, ease in availability, have a physical nature that facilitates storage as well as application and not contain substances that will contaminate the soil (Gascho 2001). Many potential sources meet the first requirement; however only a few meet all of these requirements.

Crop residues especially of silicon-accumulating plant such as rice are used as silicon sources either intentionally or unintentionally. The important byproducts of rice production are rice straw and rice hull. The former one is used as animal fodder in some areas and latter one is used as fuel in rice mills, hotels and brick-making industries. The rice hull ash thus obtained has silicon as a major constituent. It is already being used in rice nurseries and main fields in different parts of southern India.

Another important silicon source is bagasse ash which is one of the organic waste obtained from sugar industries. Besides these farm wastes industrial wastes like fly ash and basic slag are also silicon sources. The use of silica fertilizers in the form of either soluble silicates or of calcium silicate slag is still very restricted. Effective practical means of application and affordable sources of Si are needed.

An adequate supply of silica is essential if grasses and cereals are to give a good yield. Rice is largest silicon accumulator. Si plays a very important role in increasing yield, disease and pest resistance of rice. In view of this the present investigation is aimed to evaluate various indigenous sources of silicon (Rice Husk Ash, Bagasse Ash and Fly Ash) along with calcium silicate with following objectives.

1. To study the effect of sources and levels of silicon on N,P,K, silicon uptake and yield of paddy.
2. To find out optimum level of silicon through different sources.
3. To study the effect of sources and levels of silicon on disease and pest resistance.

2. REVIEW OF LITERATURE

The role of silicon in plant growth is manifested by many researchers worldwide. Even though it is not considered as essential plant nutrient it is known as quasi essential plant nutrient. In this chapter effect of sources and levels of silicon on growth, yield, disease and pest resistance of paddy, nutrient and silicon uptake by paddy and soil fertility has been reviewed as under.

2.1 Effect of sources and levels of silicon on growth and yield of paddy.

2.2 Effect of sources and levels of silicon on nutrients and silicon uptake by paddy.

2.3 Effect of sources and levels of silicon on disease and pest resistance.

2.4 Effect of sources and levels of silicon on soil fertility.

2.1 Effect of sources and levels of silicon on growth and yield of paddy.

The reorganization of the beneficial effects of silicon in rice plant dates back to as early as 1926 when Sommer (1926) presented evidences indicating essentiality of silicon in rice growth.

The silicon applied basally at 47 kg ha^{-1} as calcium and magnesium silicate significantly increased grain yield of paddy by more than 500 kg ha^{-1} (Anonymous 1964).

Tanaka and Kawano (1965) showed that the leaf openness of the second leaf from top is conducive. The supply of silica resulting in physical environment leading to better aeration, root activity, nutrient absorption and the consequent complementary effect would have resulted in higher grain and straw yield of rice.

Yoshida *et al.* (1969) observed that leaf erectness decreases with increasing N application but Si application increases leaf erectness, decreasing mutual shading caused by dence planting and high N application.

Better filling of grains by the application of silica was earlier reported by Vijayakumar (1977) who found an increase in thousand-grains weight by the application of silica.

Nayar *et al.* (1982) conducted a field experiment on an Inceptisol in the dry season to study the changes in content and uptake of silica in relation to growth and yield of 12 rice varieties in the duration range of 90 to 140 days. The grain yield was in the range of 4.6 to 8.4 t ha^{-1} which resulted in total removal of 439 to 1308 silica kg ha^{-1} by crop.

Application of silica to rice was found to increase the grain yield under both upland and waterlogged conditions (Datta and Shinde 1985). Snyder *et al.* (1986) showed that application of calcium silicate increased rice yields in Histosols. Singh and Singh (1986) recorded significant higher grain as well as straw yield of rice with application of fly ash (up to 20%).

An application of 187 kg ha^{-1} Si as sodium metasilicate doubled plant silicon concentration and increased grain yield of upland rice by 48 per cent (Winslow 1992). The maintenance of photosynthetic activity due to silicon fertilization could be one of the reasons for increased dry matter production in rice crop (Agurie *et al.* 1992).

Sawant *et al.* (1994) reported that in lateritic soil the RHA treatment improved the plant vigor and at times increased the number of tillers per hill and grain yield. Miah *et al.* (1995) showed that silicon application has beneficial effect on rice particularly when applied during reproductive stage and effects also vary from variety to variety.

The increase in grain yield might be due to more efficient use of solar radiation, moisture and nutrients since silicon makes the rice plant more erect (Rani *et al.* 1997). Silicon application also affects rice grain quality. The percentage of perfect grain in brown rice and in milled rice hull with silicon application was increased by 7.5% and 3.5 % respectively, as compared with the NPK application (without silicon) (Kang *et al.* 1997). Sawant *et al.* (1997b) observed increase in yield of paddy from 4.6% to 48% due to silicon applications.

Korndorfer *et al.* (2001) studied the relationship between rice plant and yield and reported that lower silicon straw concentration was associated with lower relative yield.

Sudhakar *et al.* (2004) studied that the application of Si through any of the sources as basic slag, rice straw compost and fly ash significantly increased dry matter, grain and straw yields relative to the control (no Si). Although Si sources were statistically on par among themselves, basic slag tended to be better than rice straw compost followed by fly ash.

A field experiment conducted by Saleque *et al.* (2004) shows that the application of cow dung and rice husk ash in combination with fertilizer doses increased rice yield by about 1 t ha^{-1} per year over that obtained with chemical fertilizer alone.

Mukherjee and Sen (2005) showed application of rice husk at 9 t ha^{-1} significantly increased the plant height, number of tillers per hill, dry matter accumulation, chlorophyll content and leaf area index. Rice husk and fertility levels had a significant and positive effect on grain and straw yield.

Subramoniam and Chandrasekaran (2005) undertaken a study to assess the use of fly ash, coir pith and rice husk ash in improving the lateritic soils of Kanyakumari district under irrigated rice cultivation and reported maximum grain yield of 60 t ha^{-1} in the treatment with fly ash (15 t ha^{-1} and lime 12 t ha^{-1}).

Singh *et al.* (2005b) reported that N and Si applications had significant influence on dry matter production in all crop growth stages. Dry matter production increased significantly and progressively with increasing Si levels up to 150 kg ha^{-1}. The number of productive tillers, grains per panicle and test weight increased markedly with increasing N levels up to 180 kg ha^{1}. N and Si applications significantly increased all yield components.

A field experiment was conducted during the rainy (kharif) seasons of 1999 and 2000 to study the effect of level and time of silicon application on the growth, yield and economics of rice by Singh *et al.* (2005a). They reported that different silicon levels significantly increased plant height, dry matter production, panicles per m^2, filled grains per panicle, test weight and yield of rice. The maximum grain yield (6588 kg ha^{-1}) was recorded with the highest level of silicon, i.e. 180 kg Si ha^{-1}.

Singh *et al.* (2007) studied effect of recycling Si carriers through rice straw compost at different times of Si application on rice productivity in rice-wheat cropping systems. Rice straw compost at 50% + 50% calcium silicate gave the highest number of effective tillers per hill (10.65), grains per panicle (124.5), panicle weight (2.44 g), panicle length (20.57 cm), 1000-grains weight (18.56 g), grain yield (6.4 t ha^{-1}) and straw yield (10.0 t ha^{-1}).

Prakash *et al.* (2007) shown application of Si through RHA along with P as RP or DAP increased grain and straw yield indicating better performance of RP or DAP as a source of P in Mangalore's acid soils. Thus recycling of plant Si materials such as RHA helps to mobilize soil P and achieve sustainable rice yield.

Shashidhar et al. (2008) reported that application of calcium silicate at 2 t ha^{-1} was found to be effective in increasing plant height, number of tillers per hill and panicle length over the control, and resulted in 25 - 30 % higher grain yield.

Surapornpiboon *et al.* (2008) showed that under drought condition supplemental Si application in the rice culture solution would ameliorate the decrease of stomatal resistance and lead to the increase of dry weight, relative water content and Si concentration in leaf blade tissue.

Results of field experiment conducted by Jawahar and Vaiyapuri (2010) during 2008-2009 to study the effect of sulphur and silicon on growth and yield of rice indicated that sulphur @ 45 kg ha^{-1} and silicon 120 kg ha^{-1} recorded highest values for growth (plant height, number of tillers per plant and dry matter production), yield attributing characters (number of panicles per m^2 and number of grains per panicle) and yield (grain and straw) of rice, respectively.

Prakash *et al.* (2010) reported highest grain yield in soils of Ponnampet and Mangalore with application of calcium silicate 4 t ha^{-1}. Muriithi *et al.* (2010) while evaluating different rice blast management approaches using different sources of silicon reported that chemical silicon sources were significantly effective in increasing rice biomass. Calcium silicate greatly increase total number of productive tillers, thousand seeds weight, plant height and grain yield.

Ghanbari *et al.* (2011) reported that silicon application increased number of filled spikelets and decreased blank spikelet. Wattanapayapkul *et al.* (2011) also reported increase in grain yield of paddy due to silicon application.

The influence of crop residue amendments (rice straw, burnt rice husk and legume residue) on the chemical properties of an acid soil and rice yields was investigated at Abakaliki for two crop growing seasons (2006 and 2007) by Ogbodo (2011). The highest grain yield of 3.40 t ha^{-1} in the study was recorded with rice cultivars ITA 315 planted on soil treated with burnt rice husk. The superior yield of rice on residue (rice straw, burnt rice husk and legume residue) treated soil was attributed to the improved soil chemical properties.

Nwite *et al.* (2011) evaluated the effects of the different ash materials and their mixtures as wood ash, leaf ash and rice husk ash @ 10 t ha^{-1} soil application to rice crop. The results showed improvements in soil pH, organic carbon and total N in the amended plots over the control. Rice grain yield increased due to the soil amendments from 1.8 to 6.5 t ha^{-1} in the first year and from 2.1 to 6.8 t ha^{-1} in the second year with leaf ash consistently giving the highest values.

2.2 Effect of sources and levels of silicon on nutrients and silicon uptake by plant.

Okuda and Takahashi (1962) noticed that the added silicon increased the translocation rate of absorbed phosphorus to the grain especially at the phosphorus deficient level.

Takahashi and Okuda (1964) reported silicon generally decreased iron and manganese uptake by rice. This effect favorably influenced the growth and ripening of rice especially when the phosphorus supply was low. Thus silicon increased the phosphorus/iron, phosphorus/manganese ratios and promoted the translocation of absorbed phosphorus to top of the panicle. Silicon did not show a substitution effect for phosphorus to rice when the phosphorus supply was high. Silicon also decreased an excessive phosphorus uptake and prevented poor fructification induced by an overdose of phosphorus.

Sadanandan and Verghese (1969) reported that with adequate silicon the uptake of nitrogen was increased. Nayar *et al. (*1982) studied the content and uptake of silica (SiO_2) in relation to growth and yield. They stated that the silica content of the leaf blade, Culm and whole plant increased with progress of growth. It was low during the vegetative period and high after flowering.

Ma and Takahashi (1990) proved the beneficial effect of Si on the growth of rice was clearly shown when P was low or high. This effect may have resulted from decreased Mn and Fe uptake and thus increased P availability within P deficient plants or from reduced P uptake when P was high. The concentrations of Fe and especially Mn in rice shoots were decreased by Si at all P levels. The uptake of Fe and Mn was decreased by 20 and 50%, respectively.

Ma and Takahashi (1991) suggested that the short term availability of Si in the straw applied to the soil is low and the application of materials with a higher availability of Si such as slags may be desirable for satisfactory growth of rice plant.

Talashilkar and Chavan (1996) studied the effect of rice hull ash on yield, silicon uptake pattern and phosphorus uptake by 17 cultivars of rice. They observed that silicon uptake by all varieties increased with the ageing of the crop.

Shi *et al.* (1996) reported that a combined application of Si, Zn and Mg facilitated the uptake of N, K, Zn and Mg by rice plants and their transportation to the developing grains, increased protein content of grain and helped the accumulation of starch in the seed. Therefore combined application of Si, Zn and Mg enhanced rice yield and quality. Sawant and Sawant (1996) conducted a field experiment during 1992 wet season and observed application of gray rice hull ash to nursery at 0.25, 0.5, 1.0 and 2.0 kg m^2 increased P, K and Si contents of four week-old seedlings.

Dhamapurkar (1999) showed that application of calcium silicate slag @ 2, 3, 4, 5 and 6 t ha^{-1} along with UB-DAP resulted into additional uptake of silica to the tune of 107, 88, 96, 65 and 182 kg ha^{-1} over the treatments receiving respective dose of calcium silicate slag with prilled urea and single super phosphate.

Talashilkar *et al.* (2000) reported that N and P fertilizers significantly increased total Si uptake by rice. Incorporation of 2, 4 and 6 t CSS ha^{-1} with PU+SSP caused a significant increase in silicon uptake. They also observed that total uptake of N, P,Ca and Mg by rice showed increasing trend when increasing doses of CSS were applied in conjuction with N and P.

Mongia *et al.* (2003) showed total uptake of silica in rice plants increased from 162 (control) to 434 kg ha^{-1} @ 10 t ha^{-1} flyash addition registering an increase of more than 100 per cent over control. Regarding P uptake the results showed significantly higher uptake at each level of FA application over the control.

Silicon application @120 kg Si ha^{-1} significantly increased growth parameter, yield attributes and these together led to increased crop yield. Silicon application @ 180 kg Si ha^{-1} also increased nutrient concentration and uptake (N, P, K, Zn, and Si). However Si application decreased Fe and Mn concentrations (Singh *et al.* 2005c).

N and P contents in grain and straw significantly increased due to Si application up to 180 kg ha^{-1}, while K and Zn concentrations increased with Si dose up to 120 kg ha^{-1}. Si application reduced Fe and Mn concentrations. Si content and its uptake at different growth stages and at harvest increased with increasing Si dose up to 180 kg ha^{-1}. Use of full quantity of Si as basal was superior to split application with respect to nutrient uptake. (Singh *et al.* 2006).

Rambo *et al.* (2011) studied that chemical conversion of micronized RHA to produce xerogel silicas was shown to be possible way of making use of this inconvenient agricultural residue. The tests of xerogel silicas for the cultivation of rice indicated that these sources of silicon provided increments in the soil Si content and as a consequence, increasing the grain yield and dry matter production in the rice plant leaves.

2.3 Effect of sources and levels of silicon on disease and pest resistance.

Use of silicon in rice cultivation protects rice plant from fungal diseases and insect pests as effectively as pesticides without negative effects on the environment.

Panda *et al.* (1975) reported that, larvae of yellow rice borer were unable to attack resistant rice plants because of the high silica content in stem.

Yamauchi and Winslow (1989) studied grain yield, dry matter production and susceptibility to grain discoloration syndrome of upland rice in relation to nutrient supplies as N, K, Mg and Si. Among these nutrients Mg and Si were found to be involved in the protection of rice plants against grain discoloration and their application increased the grain yield of three varieties by an average of 34%.

Swain and Prasad (1991) quantified the Si concentration in roots of rice varieties and found that those genotypes with greatest concentration of Si had greater resistance to root knot nematodes (*Meloidogyne spp*) and that Si increased with plant age.

Salim and Saxena (1992) found that at high level of silicon fewer plant hopper nymphs became adults and there was a decrease in adult longevity and female fecundity.

In Florida, it was shown that Si was as effective as conventional fungicides in controlling diseases such as leaf scald (*Monographella albescens*), blast (*Magnaporthe grisea*), sheath blight (*Thanatephorus cucumeris*), brown spot (*Cochliobolus miyabeanus*) and grain discoloration (Datnoff *et al*. 1992).

Talashilkar *et al.* (2000) reported application of silicon in combination with PU+SSP as well as UB+DAP resulted in significant reduction in number of hills affected by stem borer in comparison to no silicon treatments which shows the importance of silicon in building up pest resistance in rice.

Ranganathan *et al.* (2006) studied that pyridine N-oxide and morpholino pyridine N-oxide imparted disease and pest resistance by increasing silicon uptake of rice plants.

Buck *et al.* (2008) studied the effect of silicon absorption through the leaves on rice blast (*Pyricularia oryzae*) control using potassium silicate (K_2SiO_3) in different doses (0,1,2,3,4,8 or 16 g Si L^{-1}) and number of spraying at two solution pHs. Potassium silicate pulverization on the leaves did not increase Si absorption or accumulation by the plant; however there was a reduction on blast incidence. The greatest reduction on blast incidence was observed at 4 g Si L^{-1}, regardless of solution pH.

Results obtained in study undertaken by Zanao *et al.* (2009) suggest that Si has the potential to reduce the development of brown spot regardless of low or high Mn conditions. This information may prove to be invaluable in the field especially in areas where soils have toxic or deficient Mn levels.

Chandramani *et al.* (2010) found the occurrence of leaf folder, stem borer and gall midge was negatively correlated with silica content. The main cause for the death of insects due to fly ash application was wearing of mandibles and main feeding organs of insects which resulted in functionless mandibles so that the insects of paddy die without food. Further the incidence of major insects was negatively correlated with yield.

2.4 Effect of sources and levels of silicon on soil fertility.

Slag might neutralize the soil acidity with the formation of silicic acid and could thus diminish the solubility of such elements as Mn, Fe and Al (Nayar and Aiyer, 1968).

Phosphorus desorption by soil has been found to increase when silicate material were applied to some Hawaiian latosols (Roy *et al.* 1971).

Vyas and Motiramani (1971) concluded that application of organic matter @ 1.0 gm (10000 ppm) and silicate at 0.1 g (1000 ppm) and 0.3 g per 100 g of soil proved to be effective in increasing the available phosphorus from native as well as added phosphorus. Both basic slag and sodium silicate were significantly effective but due to increase in soil pH with sodium silicate basic slag was considered to be superior to sodium silicate. Silicates material applied to the soil slightly affect the uptake of phosphorus although the application of silicates increased the amount of available phosphorus by releasing part of phosphorus which was fixed in the soil.

Chinnasamy and Chandrashekharan (1978) noticed that application of silicates released more of phosphorus.

Anilakumar *et al.* (1990) reported silicon content in well drained lateritic sandy loam soil which ranged from 115.5 –150.9 ppm at different days after transplanting of paddy.

Subramanian and Gopalswamy (1991) carried an incubation study for a period of 45 days to study the influence of moisture, organic matter, phosphate and silicate on the availability of silicon and phosphorus in four rice soils of Tamil Nadu. Continuous submergence of soil and addition of FYM @ 5000 and 12500 ppm resulted in an increase in the availability of silicon and phosphorus. The addition of silicon significantly increased the available silicon in all soils and phosphorus in acid soils. The available silicon and phosphorus increased initially and subsequently decreased with passage of time.

Liang *et al.* (1994) conducted an experiment to study the silicon supplying power of 23 paddy soils. They found that the available silicon content of the surveyed soil ranged from 151 to 387 SiO_2 mg kg^{-1} with mean value of 237 SiO_2 mg kg^{-1}.

Sikka and Kansal (1995) conducted a greenhouse experiment to evaluate the effect of fly-ash application on dry-matter yield, nutrient composition of 60 day-old rice and wheat plant, pH and available nutrient status of soils. They observed that moderate rates of fly-ash application (2-4% w/w) had a beneficial effect on the dry-matter yield of paddy but a higher level (8% w/w) had a significant depressing effect. The pH and available nutrient status of soils after harvest of the rice and wheat crops were not affected by the application of fly ash. However, the mean DTPA-extractable Fe content in soils increased significantly from 12 ppm in the control to 18.1 ppm in soils amended with 8% fly ash.

Sawarkar *et al.* (1995) concluded that phosphorus availability in chromusert soil with pH 7.5 could be successfully increased by the application of single super phosphate as well as half burnt ash obtained from Poha industry where rice husk was used as fuel.

Sawant *et al.* (1997a) suggested that depletion of plant available Si in soils used for rice production might be a limiting factor contributing to declining yields. They suggested that crop rotations using non Si accumulator crops may allow soil Si equilibrium concentrations to re-establish and thus naturally replenish plant available levels of Si.

Dhamapurkar (1999) studied that the water soluble (SiO_2) silica content in typical lateritic soil at Dapoli was 22 kg ha^{-1}.

Selvakumari *et al.* (2000) observed that the continuous addition of lignite fly ash resulted in significant increase in pH, EC, exchangeable Na, available N, P, K, Ca, Mg, S and silicon in the post harvest soil after fourth crop of rice.

Snyder (2001) established silicon soil in Histosol of Everglades by using sodium acetate solution which test range of low (< 7 Si mg lit^{-1}), medium (7-24 Si mg lit^{-1}) and high (>24 Si mg lit^{-1}).

Takahashi *et al.* (2003) studied that continuous application of rice straw contributed to the improvement of soil fertility, the promotion of growth, N uptake by paddy and upland crops while short term effects on dry matter production and N uptake by crops were little.

Mandal et al. (2004) stated that rice crop residues are highly siliceous, and have the potential of transforming electrochemical properties of acidic soils that reduces P fixation;

improving base retention and increasing the soil pH. If rice residues are managed properly, then it can warrant the improvements in soil physical, chemical and biological properties and sustain productivity of rice-wheat cropping system.

Chang *et al.* (2007) studied that available phosphorus (P) increased significantly with fly ash application as there was high content of P (786 mg kg^{-1}) in the applied fly ash. In addition high content of silicon and high pH of fly ash contributed to increase available-P content by ion competition between phosphate and silicate and by neutralization of soil acidity respectively.

A Study was undertaken by Husnain *et al.* (2010) and assessed the balance of N, P, K, Si, Ca, Mg, and Na in a lowland sawah (rice fields) in the Citarum Watershed, Java, Indonesia. The results showed a positive balance for N, P, Ca, Mg, and Na; however, K and Si showed a negative balance. The balance values were estimated at 5, 8, 387, 65, 281, -198 and -21 for N, P, Ca, Mg, Na, Si and K, respectively. The decrease in Si and K observed in this study is likely due to the substantial uptake of these nutrients without adequate replenishment through fertilizer.

Masulili *et al.* (2010) studied application of biochar (made from rice husk) and reported decreased soil bulk density, soil strength, exchangeable Al, soluble Fe and increased porosity, available soil water content, C-organic, soil pH, available P, CEC, exchangeable K, and Ca. Out of these improvements, only soil carbon, phosphorus, exchangeable Al, soluble Fe, and soil strength significantly influenced rice biomass.

3. MATERIAL AND METHODS

A pot culture experiment was conducted in wire house of department of Soil Science and Agricultural chemistry, College of Agriculture, Kolhapur during *Kharif* season of 2011-2012. The details regarding the materials used and methodology followed during the course of the present investigation have been given in this chapter.

3.1 MATERIALS

3.1.1 Location of experimental site

College of Agriculture, Kolhapur is located near National Highway No. 4 and Kolhapur-Kagal road, about 5 km South-East of Kolhapur city. The location of the campus is between $16^{0}42'$ N latitude and between $74^{0}14'$ E longitude. It's elevation is 548 m above the mean sea-level.

3.1.2 Climate and weather

The College of Agriculture, Kolhapur comes under the sub-montane zone with annual rainfall ranging from 700 to 2500 mm. The average annual rainfall is 1057 mm out of which 80 percent receives from south west monsoon in June to September while rest of rainfall receives in the month of October and November from North West monsoon.

3.1.3 Soil

Earthen pots were filled with 10 Kg Silicon deficient soil (Typic Haplustepts). The soil used for filling the earthen pots was collected from Agricultural Research Station, Radhanagari, Dist. Kolhapur which also comes under Sub-montane Zone but close to western ghat zone receiving 3500 to 5000 mm rainfall.

Table 3.1: Chemical properties of experimental soil

Soil chemical properties	
pH (1:2.5)	6.20
EC (dS m^{-1})	0.09
Organic carbon (%)	1.28
Calcium carbonate (%)	0.50
Available nitrogen (kg ha^{-1})	249.92
Available phosphorus (kg ha^{-1})	16.50
Available potassium(kg ha^{-1})	251.40
Available silicon (kg ha^{-1})	179.60
Water soluble silicon (kg ha^{-1})	29.43

3.1.4 Selection of crop

The paddy (Cv. Bhogavati) was selected as a test crop during *kharif* season 2011.

3.1.5 Experimental layout

The present investigation was carried out in Completely Randomized Block Design. Treatments comprised of three levels of silicon (250, 500 and 750 kg Si ha^{-1}) through sources of silicon as Rice Husk Ash, Bagasse Ash, Fly Ash and Calcium Silicate and were replicated thrice along with one control as 0 kg Si ha^{-1}.

3.1.5.1 Treatment details

Table 3.2: The treatment details and their symbols

Treatment details	Source of Silicon	Silicon content (%)	Levels (Kg ha^{-1})	Quantity of source applied (Kg ha^{-1})	Cost of source applied (Rs.ha^{-1})
T_1 (Control)	**Control**	--	--	--	--
T_2 (RHA 250)	**Rice Husk Ash**	34.2	250	731	731.00
T_3 (RHA 500)			500	1462	1462.00
T_4 (RHA 750)			750	2193	2193.00
T_5 (CS 250)	**Calcium Silicate**	48.0	250	521	4689.00
T_6 (CS 500)			500	1042	9378.00
T_7 (CS 750)			750	1563	14067.00
T_8 (BA 250)	**Bagasse Ash**	27.9	250	896	313.60
T_9 (BA 500)			500	1792	627.20
T_{10} (BA 750)			750	2688	940.80
T_{11} (FA 250)	**Fly Ash**	30.1	250	831	664.80
T_{12} (FA 500)			500	1662	1329.60
T_{13} (FA 750)			750	2493	1994.40

*Approximate market prices of sources in rupees per tonne

RHA- 1000/-, CS- 9000/-, BA-350/- and FA-800/-

3.1.6 Details of Cultivation Practices:

Table 3.3: Schedule of practices carried out in experiment.

Sr.No.	Name of operation	Date of Operation
1	Preparation of pots for sowing paddy	21.05.2011
2	Collection of initial soil samples	21.05.2011
3	Application of rice husk ash, calcium silicate, bagasse ash and fly ash as per treatment	23.06.2011
4	Sowing of paddy for seedling preparation	08.06.2011
5	Application of basal dose of fertilizer	07.07.2011
6	Transplanting of seedlings in pots	08.07.2011
7	First top dressing of N	08.08.2011
8	Second top dressing of N	09.09.2011
9	Harvesting	05.11.2011

3.1.6.2 Application of Silicon sources and fertilizers

Different silicon sources as Rice Husk Ash, Bagasse Ash, Fly Ash and Calcium Silicate were applied as basal dose at effective root zone 30 days prior to transplanting. The recommended fertilizers dose of 100:50:50; N:P_2O_5:K_2O kg ha $^{-1}$ was applied. A basal dose of 40:50:50; N:P_2O_5:K_2O kg ha^{-1} was applied at the time of transplanting through urea, single super phosphate and muriate of potash in all treatments including control. The second split dose of nitrogen i.e.40 kg N ha^{-1} was applied at tillering stage (30 days after transplanting) and third split dose of nitrogen i.e. 20 kg N ha^{-1} was applied at panicle initiation stage(60 days after transplanting) through urea.

3.1.6.3 Nursery for seedlings:

Nursery was raised in June 2011 in pots with same experimental soil.

3.1.6.4 Transplanting

One month old five seedlings having 4-5 leaves were transplanted per pot keeping equal distance from each other.

3.1.6.5 Irrigation

Optimum soil moisture was maintained in each treatment by periodically watering the pots during the crop period as per requirements considering rainfall and crop growth stages.

3.2 Observations

3.2.1 Plant observations:

Table 3.4: Details of plant observations.

Sr.No.	Observation
A	Growth studies I.Pre-harvest studies: 1. Plant height 2. Total no. of productive tillers II.Post harvest studies: 1. Length of panicle (cm) 2. No. of grains per panicle 3. Grains weight per panicle (g) 4. Thousand grains weight (g) 5. Grain yield (g pot^{-1}) 6. Straw yield (g pot^{-1}) 7. Dry matter per hill
B	Disease and pest incidence (periodical monitoring)

3.2.1.1 A. Growth studies

I. Preharvest studies

Plant height

The plant height of five plants were measured from the ground level up to the tip of main panicle at maturity and the average height of plants was expressed in centimeters.

Total number of productive tillers per pot

The number of productive tillers per pot in each pot was recorded at harvest.

II. Postharvest studies

Length of panicle (cm)

Panicle length from five tillers selected randomly in each pot was recorded from base to the tip of the panicle. The mean value was calculated and expressed in centimeters.

No. of grains per panicle

Five panicles were selected randomly and their grains were separated and counted. The mean value was worked out and recorded as number of grains per panicle.

Grains weight per panicle (g)

After counting grains from five selected panicles they were weighed separately and their mean was calculated.

Thousand grains weight (g)

Total grain weight was taken and it was converted to thousand grains weight for respective treatments as in some treatments total grains were less than 1000.

Grain yield

The grains from each panicle were removed, separated for, the produce from each pot were sun dried for seven days and their final air-dried weight per pot was recorded in gram.

Straw yield

The straw yield per pot was obtained by weighing the air dried straw and chaff which remained after removal of grains. It was considered as straw yield per pot (g).

Dry matter per hill

The chopped plant material was kept in perforated brown paper bags, suitably labeled and dried to constant weight in thermo statistically controlled oven at $60^0C \pm 2^0C$ temperature. Then mean dry weight per hill from respective treatments was worked out.

B. Pest and disease incidence

The incidence of pest and disease in each treatment was recorded during crop growth period by adopting standard procedure in consultation with entomology department.

3.3 METHODS

The analytical work was done in the research laboratory of the Division of Soil Science and Agricultural Chemistry, College of Agriculture, Kolhapur during the academic year 2011-2012. The following analytical methods were employed.

3.3.1 Soil Analysis

Before sowing and after harvest of crop pot wise representative soil samples were collected with screw augar and analyzed by adopting standard procedures.

Table 3.5: Methods used for soil analysis

Sr.No	Parameter	Method	Reference
1	pH (1:2.5)	Potentiometric	Richard (1954)
2	EC (1:2.5)	Conductometric	Richard (1954)
3	Organic carbon(%)	Wet oxidation	Walkley and Black (1934)
4	$CaCO_3$ (%)	Rapid titration	Piper (1966)
5	Available N	Alkaline Permanganate	Subbiah and Asija (1956)
6	Available P	0.025 *M* HCl in 0.03 *M* NH_4F (P1) extract method	Bray and Kurtz (1945)
7	Available K	1*N* Neutral Ammonium Acetate extract	Knudsen and Peterson (1982)
8	Available Silicon	Ammonium Acetate (0.5*M*) pH 4.8 extract method	Fox *et al.*(1967)
9	Water soluble silicon (1:10)	Distilled water	Nayar *et al.*(1977)

1) Soil reaction (pH)

The soil pH was measured with the help of pH meter having glass electrode and calomel electrode using 1:2.5, soil : water ratio as described by Richard (1954).

2) Electrical conductivity (dS m^{-1})

It was determined with the help of conductivity meter using soil : water ratio of 1: 2.5 (Richard 1954).

3) Organic carbon (%)

Organic carbon in soil (0.5 mm sieved) was determined by Walkley and Black wet oxidation method as described by Walkley and Black (1934).

4) Calcium carbonate (%)

Calcium carbonate in soil was determined by Rapid titration method as described by Piper (1966).

5) Available nitrogen (N kg ha^{-1})

It was determined by Alkaline Permanganate method (0.32% $KMnO_4$) as described by Subbiah and Asija (1956).

6) Available phosphorus (P kg ha^{-1})

Available phosphorus was determined by Bray's method using 0.025 *M* HCl in 0.03 *M* NH_4F extractant. The soil : extractant ratio was 1:10 and the shaking time was 5 minutes. Phosphorus in the extract was determined colorimetrically by using spectrophotometer at 882 nm wavelength (Bray and Kurtz, 1945).

7) Available potassium (K kg ha^{-1})

It was extracted with neutral normal Ammonium Acetate (NH_4OAc, pH 7.0) and the soil : extractant ratio was 1:5 and shaking time was 5 minutes. Potassium in soil was determined flame photometrically as described by Knudsen and Peterson (1982).

8) Available silicon (Si kg ha^{-1})

Available silicon was determined by Blue silicomolybdous acid method using 0.5 *M* Ammonium Acetate extractant at pH 4.8. The soil : extractant ratio was 1:5 and the shaking time was 60 minutes. Silicon in the extract was determined colorimetrically by using spectrophotometer at 660 nm wavelength as described by Fox *et al.* (1967).

9) Water soluble silicon (kg ha^{-1})

Ten gm of soil was put in 200 ml polyethylene cup and 100 ml distilled water was added into the cup. The cup was shaken on a shaker for 2 hours and allowed to stand overnight. It was again shaken for 1 hr. and supernatant was filtered through Whatman no. 42 filter paper into 20 ml scintillation vial. Silicon was determined by Blue silicomolybdous acid method on spectrophotometer at 660 nm wavelength as described by Nayar *et al*. (1977).

3.3.2 Proximate analysis of sources of silicon and plant samples

Proximate analysis of sources used was done by adopting the standard procedures.

The treatmentwise grain and straw samples were collected at harvest, processed and analyzed for total N,P,K and Si content.

Table 3.6: Proximate analysis of sources of silicon

Parameter	Rice Husk Ash	Calcium Silicate	Bagasse Ash	Fly Ash
pH (1:10)	9.20	7.20	9.60	7.50
EC (dS m^{-1})	0.05	0.11	0. 10	0.09
Organic carbon (%)	1.60	Nil	2.72	0.73
Total N (%)	Nil	Nil	Nil	Nil
Total P (%)	0.30	0.08	0.67	0.38
Total K (%)	0.60	0.05	0.75	0.40
Ca (%)	1.60	12.00	2.04	2.15
Mg (%)	0.40	3.30	0.65	1.30
Total Si (%)	34.20	48.00	27.90	30.10
Fe (%)	0.19	0.28	0.30	0.10
Mn (%)	0.03	0.03	0.04	0.02
Zn (%)	0.02	0.01	0.02	0.07
Cu (%)	0.01	0.02	0.01	0.01

Table 3.7: Methods used for analysis of plant and silicon sources.

Sr.No	Parameter	Method	Reference
1	Total N	Microkjeldahl Method (Diacid Digestion Method)	Parkinson and Allen(1975)
2	Total P	Vandomolybdate Yellow colour in Nitric Acid System. (Triacid Digestion Method)	Jackson (1973)
3	Total K	Flame photometry (Triacid Digestion Method)	Chapman and Pratt (1982)
4	Total Si	Triacid Digestion Method	Nayar *et al.* (1975)
5	Ca and Mg	EDTA Complexometric Titration (Diacid Digestion Method)	Jackson (1973)
6	Micronutrients (Fe, Mn, Zn,Cu)	Atomic absorption spectrophotometry	Zoroski and Burau (1977)
7	Organic Carbon	Ignition Method	Chopra and Kanwar (1980)

1) Total Nitrogen (%)

The silicon sources and plant samples (0.2 g each) were digested by using concentrated H_2SO_4 (5 ml) and H_2O_2 (5 ml). The volume was made by distilled water to 100 ml after digestion of sample. A suitable aliquot was taken for nitrogen distillation and nitrogen was determined by Microkjeldahl method (Parkinson and Allen 1975).

2) Total phosphorus (%)

The silicon sources and plant samples (0.2 g each) were wet digested with nitric acid, sulphuric acid, and perchloric acid. The volume was made to 100 ml with distilled water after digestion and was used for determination of phosphorus. The total phosphorus was determined by using triacid extract and the yellow colour was developed with combined nitric acid vandatemolybdate reagent. Phosphorus was determined colorimetrically by using spectrophotometer at 420 nm wavelength (Jackson 1973).

3) Total Potassium (%)

The silicon sources and plant samples (0.2 g each) were wet digested with sulphuric acid, nitric acid and perchloric acid. The volume was made to 100 ml with distilled water after digestion and was used for determination of potassium by flame photometer (Chapman and Pratt 1982).

4) Total Silicon (%)

It was determined by Rapid micro-determination method. Finely ground plant samples and silicon sources (0.1 g) were digested in concentrated nitric acid (5 ml), perchloric acid (1 ml) and sulphuric acid (0.5 ml) followed by dissolution in Na_2CO_3. The silica was converted into molybdenum reactive form with 10% ammonium molybdate solution, which was estimated colorimetrically using ascorbic acid on spectrophotometer at 660 nm wavelength (Nayar *et al*. 1975).

5) Total Fe, Mn, Zn, Cu (%)

The sources of silicon (0.2 g each) were wet digested with nitric acid and perchloric acid. The volume was made to 100 ml with distilled water after digestion and digest was used for determination of micronutrients by using Atomic Absorption Spectrophotometer described by Zoroski and Burau (1977).

6) Total Ca and Mg (%)

The sources of silicon (0.2 g each) were wet digested with nitric acid and perchloric acid. The volume was made to 100 ml with distilled water after digestion and digest was used for determination of Ca and Mg by using EDTA Complexometric Titration described by Jackson (1973).

7) Organic carbon (%)

The sources of silicon were ignited in muffle furnace at 550^{0}C. From loss in weight the percent organic matter were calculated and from this percent organic matter value, percent organic carbon were calculated by method described by Chopra and Kanwar (1980).

3.3.3 Uptake of nutrients by the crop

The uptake of nitrogen, phosphorus, potassium and silicon (mg per pot) was worked out by multiplying the percentage of these nutrients in grain and straw with the corresponding dry matter yields of the respective constituent.

3.4 Statistical analysis

The experimental data were analyzed statistically by applying the technique of “Analysis of variance” and significance was tested by variance ratio i.e. F value at 5 per cent level of significance as described by Panse and Sukhatme (1967). Standard error of mean (S.Em.) and critical difference (CD) was worked out to evaluate differences between treatment means.

4. RESULTS AND DISCUSSION

The present study was undertaken to evaluate various indigenous sources of silicon along with calcium silicate in pot culture experiment at wire house of the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Kolhapur during *Kharif* season of 2011-2012. The details of results obtained regarding the growth, yield and nutrient uptake of paddy during the course of the present investigation have been presented and discussed in this chapter under following main subheadings.

4.1 Effect of sources and levels of silicon on growth and yield of paddy.

4.2 Effect of sources and levels of silicon on nutrients and silicon uptake by paddy.

4.3 Effect of sources and levels of silicon on disease and pest resistance.

4.4 Effect of sources and levels of silicon on soil fertility.

4.1 Effect of sources and levels of silicon on growth and yield of paddy.

4.1.1 Effect of sources and levels of silicon on plant height, total number of productive tillers per pot and dry matter per hill :

The data in respect of plant height, total number of productive tillers per pot and dry matter per hill as influenced by sources and levels of silicon is presented in Table 4.1. The plant height, total number of productive tillers per pot and dry matter per hill of paddy were found to increase significantly due to silicon application through different sources. The results revealed that the treatment T_7 recorded significantly highest plant height (63.80 cm) but it was at par with T_4 (63.73 cm), T_{13} (63.57 cm) T_{10} (63.55 cm) T_6 (63.50 cm), T_3 (63.49 cm), T_{12} (63.45 cm) and T_9 (63.23 cm) except T_5 (62.97 cm), T_2 (62.83 cm), T_{11} (62.75 cm) and T_8 (62.33 cm).

Similar trend was observed in respect of total number of productive tillers per pot. The treatment T_7 recorded significantly highest total number of productive tillers per pot (18.7) but it was at par with treatments T_4 (18.3), T_{13} (18.0), T_{10} (17.7), T_6 (17.7), T_3 (17.3), T_{12} (17.3) and T_9 (17.0) except T_5 (16.3), T_2 (16.0), T_{11} (16.0) and T_8 (15.7).

The dry matter accumulation per hill at harvest was found to increase significantly with application of silicon. The dry matter per hill at harvest was significantly highest with treatment T_7 (9.66 g hill^{-1}) but it was at par with the treatments T_4 (9.63 g hill^{-1}), T_{13} (9.60 g hill^{-1}), T_{10} (9.58 g hill^{-1}), T_6 (9.58 g hill^{-1}), T_3 (9.54 g hill^{-1}), T_{12} (9.52 g hill^{-1}) and T_9 (9.50 g hill^{-1}) except T_5 (9.23 g hill^{-1}), T_2 (9.22 g hill^{-1}), T_{11} (9.16 g hill^{-1}) and T_8 (9.13 g hill^{-1}).

The increase in plant height, total number of productive tillers per hill and dry matter per hill at harvest might be attributed due to increased availability of phosphorus and other beneficial effect of silicon on growth of paddy. These results are in confirmative with those reported by Sawant *et al.* (1994), Singh *et al.* (2005a), Singh *et al.* (2007), Muriithi *et al.* (2010) and Sudhakar *et al.* (2004) who also reported increase in growth and dry matter of paddy due to silicon application through different organic and inorganic sources.

Table 4.1: Effect of sources and levels of silicon on plant height, total number of productive tillers per pot and dry matter per hill of paddy

Treatment	Plant height (cm)	Total Number of Productive tillers per pot	Dry matter per hill (g)
T_1 (Control)	61.60	14.3	8.52
T_2 (RHA 250)	62.83	16.0	9.22
T_3 (RHA 500)	63.49	17.3	9.54
T_4 (RHA 750)	63.73	18.3	9.63
T_5 (CS 250)	62.97	16.3	9.23
T_6 (CS 500)	63.50	17.7	9.58
T_7 (CS 750)	63.80	18.7	9.66
T_8 (BA 250)	62.33	15.7	9.13
T_9 (BA 500)	63.23	17.0	9.50
T_{10} (BA 750)	63.55	17.7	9.58
T_{11} (FA 250)	62.75	16.0	9.16
T_{12} (FA 500)	63.45	17.3	9.52
T_{13} (FA 750)	63.57	18.0	9.60
S.E. $\pm$	00.28	0.64	0.08
C.D.(P=0.05)	00.82	1.87	0.24

4.1.2 Effect of sources and levels of silicon on yield attributes of paddy:

4.1.2.1 Effect of sources and levels of silicon on length of panicle, grains weight per panicle, number of grains per panicle and thousand grains weight of paddy

The data on length of panicle, grains weight per panicle, number of grains per panicle, thousand grains weight, grain yield and straw yield of paddy as influenced by sources and levels of silicon is presented in Table 4.2.

The length of panicle, grains weight per panicle and number of grains per panicle increased due to application of silicon; however the increase was not significant. The thousand grains weight of paddy increased significantly due to application of silicon through different sources. The significantly highest thousand grains weight was recorded with the treatment T_7 (19.23 g.), however it was at par with T_4 (19.13 g.), T_{13} (19.07 g.), T_{10} (19.0 g.), T_6 (18.83 g.), T_3 (18.80 g.), T_{12} (18.70 g.) and T_9 (18.63 g.). The increase in thousand grains weight might be attributed due to the beneficial role of silicon in improving photosynthetic activity and plant nutrition. Similar increase in thousand grains weight of paddy due to silicon application were reported by Singh *et al.* (2007). Better filling of grains by the application of silica was earlier reported by Vijayakumar (1977) who also found an increase in thousand grains weight of paddy due to silica application.

Table 4.2: Effect of sources and levels of silicon on length of panicle, grains weight per panicle, no. of grains per panicle, thousand grains weight, grain and straw yield of paddy

Treatment Details	Length of panicle (cm)	Grains weight per panicle (g)	No. of grains per panicle	Thousand grains weight (g)	Grain yield (g pot^{-1})	Straw yield (g pot^{-1})
T_1 (Control)	17.0	1.02	48.3	17.26	16.17	26.44
T_2 (RHA 250)	18.2	1.05	54.0	18.37	17.45	28.65
T_3 (RHA 500)	18.7	1.09	55.0	18.80	18.30	29.41
T_4 (RHA 750)	19.0	1.11	56.0	19.13	18.52	29.65
T_5 (CS 250)	18.9	1.07	54.7	18.40	17.48	28.66
T_6 (CS 500)	19.0	1.10	55.3	18.83	18.44	29.45
T_7 (CS 750)	19.1	1.11	56.3	19.23	18.55	29.74
T_8 (BA 250)	17.5	1.04	53.0	18.33	17.31	28.36
T_9 (BA 500)	18.3	1.07	55.0	18.63	18.23	29.25
T_{10} (BA 750)	18.5	1.09	55.3	19.00	18.46	29.46
T_{11} (FA 250)	18.1	1.04	53.7	18.35	17.35	28.46
T_{12} (FA 500)	18.6	1.07	55.0	18.70	18.27	29.31
T_{13} (FA 750)	18.8	1.10	55.7	19.07	18.47	29.54
S.E. $\pm$	0.45	0.06	48.3	0.28	0.34	0.37
C.D.(P=0.05)	N.S.	N.S.	N.S.	0.81	0.98	1.06

4.1.2.2 Effect of sources and levels of silicon on grain yield:

The effect of sources and levels of silicon on grain yield of paddy is presented in Table 4.2 and depicted in Fig 1. The grain yield of paddy increased significantly due to silicon application. The treatment T_7 recorded significantly highest grain yield (18.55 g pot^{-1}), however it was at par with the treatments T_4 (18.52 g pot^{-1}), T_{13} (18.47 g pot^{-1}), T_{10} (18.46 g pot^{-1}), T_6 (18.44 g pot^{-1}), T_3 (18.30 g pot^{-1}), T_{12} (18.27 g pot^{-1}) and T_9 (18.23 g pot^{-1}).

The increase in grain yield with silicon application is attributed to the increase in number of tillers per hill, number of grains per panicle and test weight of paddy due to silicon application. Similar increase in grain yield of paddy by silicon application were reported by Nayar *et al.* (1982), Singh *et al.*(2005b) and Prakash *et al.* (2010).

4.1.2.3 Effect of sources and levels of silicon on straw yield:

The effect of different levels of silicon on straw yield is presented in Table 4.2 and depicted in Fig. 1. The data indicated that the straw yield of paddy increased significantly with silicon application. The treatment T_7 recorded significantly highest straw yield (29.74 g pot^{-1}), however it was at par with T_4 (29.65 g pot^{-1}), T_{13} (29.54 g pot^{-1}), T_{10} (29.46 g pot^{-1}), T_6 (29.45 g pot^{-1}), T_3 (29.41 g pot^{-1}), T_{12} (29.31 g pot^{-1}) and T_9 (29.25 g pot^{-1}).

The increase in straw yield of paddy due to silicon application might be attributed to the beneficial role of silicon in increasing photosynthetic activity, dry matter accumulation, uptake of N, P, K, and Si by paddy. Similar increase in straw yields of paddy due to silicon application were reported by Singh *et al.* (2005b), Singh *et al.* (2007) and Jawahar and Vaiyapuri (2010).

4.2 Effect of sources and levels of silicon on nutrients and silicon uptake by paddy.

The total uptake of N, P, K and Si as influenced by different levels of silicon through different sources is presented in Table 4.3 and depicted in Fig 2. The total uptake of nitrogen increased significantly due to application of silicon. The significantly highest total uptake of nitrogen was recorded in treatment T_7 (370.47 mg pot^{-1}) however, it was at par with treatments T_4 (368.54 mg pot^{-1}), T_{13} (366.80 mg pot^{-1}), T_{10} (363.61 mg pot^{-1}), T_6 (360.08 mg pot^{-1}), T_3 (357.82 mg pot^{-1}), T_{12} (355.69 mg pot^{-1}) and T_9 (355.63 mg pot^{-1}).

The total uptake of P and K increased significantly due to silicon application. The significantly highest total uptake of P and K was found with treatment T_7 (125.60 and 516.74 mg pot^{-1}, respectively), however P uptake was at par with treatments T_4 (123.73 mg pot^{-1}), T_{13}(120.74 mg pot^{-1}) and T_{10} (118.06 mg pot^{-1}) and uptake of K was at par with treatments T_4 (513.65 mg pot^{-1}), T_{13} (510.23 mg pot^{-1}), T_{10} (503.96 mg pot^{-1}) , T_6 (506.61 mg pot^{-1}), T_3 (501.76 mg pot^{-1}) and T_{12} (500.77 mg pot^{-1}).

The increase in total uptake of N, P and K due to application of silicon might be attributed to the role of silicon in increasing the availability of soil phosphorus which might have increase the biomass and root activity. The increase in uptake of nutrients due to application of silicon were reported by Sawarkar *et al.* (1995), Rani *et al.* (1997), Talashilkar *et al.* (2000), Singh *et al.* (2006) and they attributed it to the beneficial role of silicon in improving the photosynthesis of plant and phosphorus availability from soil.

Table 4.3: Effect of sources and levels of silicon on total uptake of N, P, K and Si by paddy.

Treatment Details	Total Uptake of nutrients (mg pot^{-1})			
	N	P	K	Si
T_1 (Control)	294.40	88.70	436.05	1013.59
T_2 (RHA 250)	333.56	106.91	482.86	1163.46
T_3 (RHA 500)	357.82	115.10	501.76	1220.79
T_4 (RHA 750)	368.54	123.73	513.65	1267.20
T_5 (CS 250)	343.95	107.89	485.73	1172.69
T_6 (CS 500)	360.08	119.60	506.61	1234.21
T_7 (CS 750)	370.47	125.60	516.74	1277.82
T_8 (BA 250)	327.06	97.77	476.62	1143.37
T_9 (BA 500)	355.63	108.20	493.87	1205.78
T_{10} (BA 750)	363.61	118.06	503.96	1255.07
T_{11} (FA 250)	332.75	101.53	481.16	1150.79
T_{12} (FA 500)	355.69	112.46	500.77	1212.66
T_{13} (FA 750)	366.80	120.74	510.23	1262.06
S.E. $\pm$	8.30	2.55	6.20	13.24
C.D.(P=0.05)	24.19	7.43	18.05	38.58

The total uptake of silicon increased significantly due to application of silicon. The silicon uptake increased significantly with increase in levels of silicon and the highest uptake was recorded at Si 750 kg ha^{-1} level in different sources, followed by

Si 500 kg ha^{-1} and Si 250 kg ha^{-1} , however the differences among different sources at same level were not significant indicating higher accumulation of silicon in paddy with increase in its availability. The highest total uptake of silicon was recorded in treatment T_7 (1277.82 mg pot^{-1}), however it was at par with treatments T_4 (1267.20 mg pot^{-1}), T_{13} (1262.06 mg pot^{-1}) and T_{10} (1255.07 mg pot^{-1}).

Paddy is known as heavy accumulator of silicon and silicon is absorbed by paddy from soil in higher amount than other macro nutrient (Nayar *et al.* 1982). The increase in total uptake of silica with increase in levels of silicon was also reported by Dhamapurkar (1999), Talashilkar *et al.* (2000) and Mongia *et al.* (2003).

4.3 Effect of sources and levels of silicon on disease and pest resistance.

The incidence of pest and disease was not observed on paddy crop throughout its growth period during experimentation.

4.4 Effect of sources and levels of silicon on soil fertility.

The data in respect of effect of silicon sources and levels on different chemical properties of soil is presented in Table 4.4. There was slight increase in pH, EC, organic carbon and calcium carbonate due to application of silicon, however the differences were not significant.

There was decrease in available N and K content of soil after harvest of paddy over the control (T_1) which might be due to higher uptake of these nutrients by paddy; however the differences were not significant. The available P increased slightly with increase in levels of silicon but the differences were not significant.

The plant available silicon increased significantly over the control (T_1) due to application of silicon through different sources as Calcium Silicate, Rice husk ash, Fly ash and Baggase ash. The significantly highest available silicon was found in treatment T_7 (278.21 kg ha^{-1}) which was followed by T_4 (276.27 kg ha^{-1}), T_{13} (273.28 kg ha^{-1}), T_{10} (272.53 kg ha^{-1}), T_6 (265.81 kg ha^{-1}), T_3 (264.51 kg ha^{-1}), T_{12} (264.32 kg ha^{-1}) and T_9 (263.57 kg ha^{-1}). Similar trend was observed in water soluble silicon. The significantly highest water soluble silicon was recorded in treatment T_7 (36.81 kg ha^{-1}), however it was at par with treatments T_4 (36.70 kg ha^{-1}), T_{13} (36.56 kg ha^{-1}), T_{10} (36.53 kg ha^{-1}), T_6 (36.49 kg ha^{-1}), T_3 (36.46 kg ha^{-1}),T_{12} (36.39 kg ha^{-1}) and T_9 (36.33 kg ha^{-1}). The increase in available silicon and water soluble silicon after harvest of paddy over control (T_1) might be due to residual effect of application of silicon through different silicon sources as Calcium Silicate, Rice husk ash, Fly ash and Bagasse ash.

Similar residual effects of calcium silicate were reported by Liang *et al.* (1994) and Dhamapurkar (1999).

5. SUMMARY AND CONCLUSION

A pot culture experiment was conducted in wire house of Department of Soil Science and Agricultural Chemistry, College of Agriculture, Kolhapur during *Kharif* season of 2011-2012.

The experiment was laid out in Completely Randomized Block Design with three replications. Rice Husk Ash, Calcium Silicate, Bagasse Ash and Fly Ash were used as sources of silicon. Paddy (var.Bhogavati) was grown by adopting recommended package of practices.

Treatmentwise plant growth observations and crop yield were recorded. The uptake of N, P, K and Si was determined by adopting standard procedures. Similarly after harvest of paddy representative soil samples were analyzed by adopting standard procedures. The experimental data were analyzed statistically by applying the technique of "Analysis of variance" and significance was tested by variance ratio i.e. F value at 5 per cent level of significance. The results obtained from the experiment are summarized below.

5.1 Effect of sources and levels of silicon on growth and yield of paddy.

5.1.1 Effect of sources and levels of silicon on plant height, total number of productive tillers per pot and dry matter per hill.

The plant height, total number of productive tillers per pot and dry matter per hill of paddy were found to increase due to silicon application through different sources, however the differences between different sources and levels were not significant. The results revealed that the treatment T_7 recorded significantly highest plant height (63.80 cm) but it was at par with T_4, T_{13}, T_{10}, T_6, T_3, T_{12} and T_9.

Similar trend was observed in respect of number of tillers per pot. The treatment T_7 recorded significantly highest total number of productive tillers per pot (18.7) but it was at par with treatments T_4, T_{13}, T_{10}, T_6, T_3, T_{12} and T_9.

The dry matter accumulation per hill at harvest was found to increase significantly with application of silicon. The dry matter per hill at harvest was significantly highest with treatment T_7 (9.66 g) but it was at par with the treatments T_4, T_{13}, T_{10}, T_6, T_3, T_{12} and T_9.

5.1.2 Effect of sources and levels of silicon on yield attributes of paddy.

5.1.2.1 Effect of sources and levels of silicon on length of panicle, grains weight per panicle, number of grains per panicle and thousand grains weight of paddy.

The length of panicle, grains weight per panicle, and number of grains per panicle increased due to application of silicon, however the increase was not significant.

The thousand grains weight of paddy increased significantly due to application of silicon. The significantly highest thousand grains weight was recorded with the treatment T_7 (19.23 g), however it was at par with T_4, T_{13}, T_{10}, T_6, T_3, T_{12} and T_9.

5.1.2.2 Effect of sources and levels of silicon on grain and straw yield:

The grain yield of paddy increased significantly with silicon application, however the differences between different sources and levels were not significant. The treatment T_7 recorded significantly highest grain yield (18.55 g pot^{-1}), however it was at par with the treatments T_4, T_{13}, T_{10}, T_6, T_3, T_{12} and T_9.

Similar trend was observed in respect of straw yield. The treatment T_7 recorded significantly highest straw yield (29.74 g pot^{-1}), however it was at par with T_4, T_{13}, T_{10}, T_6, T_3, T_{12} and T_9.

5.2 Effect of sources and levels of silicon on nutrient and silicon uptake by plant.

The total uptake of nitrogen increased significantly due to application of silicon. The significantly highest total uptake of nitrogen was recorded in treatment T_7 (370.47 mg pot^{-1}), however it was at par with treatments T_4, T_{13}, T_{10}, T_6, T_3, T_{12} and T_9.

The total uptake of P and K increased significantly due to silicon application. The significantly highest total uptake of P(125.60 mg pot^{-1}) and K (516.74 mg pot^{-1}) was found with treatment T_7, however uptake of P was at par with treatments T_4, T_{13} and T_{10} and uptake of K was at par with treatments T_4, T_{13}, T_{10} , T_6, T_3 and T_{12}.

The total uptake of silicon increased significantly with increase in levels of silicon, however significant differences were not observed amongest the different sources at same level of silicon application. The highest total uptake of silicon was recorded in treatment T_7 (1277.82 mg pot^{-1}), however it was at par with treatments T_4, T_{13} and T_{10}.

5.3 Effect of sources and levels of silicon on disease and pest resistance.

The incidence of pest and disease was not observed on experimental paddy crop.

5.4 Effect of sources and levels of silicon on soil fertility.

pH, EC, organic carbon and calcium carbonate content of soil after harvest of paddy were not affected significantly due to application of silicon through different sources. The available N, P and K content of soil after harvest of paddy were not affected significantly due to different treatments.

The plant available silicon increased significantly over the control (T_1) due to application of silicon through different silicon sources. The significantly highest available silicon was found in treatment T_7 (278.21 kg ha^{-1}) which was followed by T_4, T_{13}, T_{10}, T_6, T_3, T_{12} and T_9. Similar trend was observed in water soluble silicon. The significantly highest water soluble silicon was recorded in treatment T_7 (36.81 kg ha^{-1}), however it was at par with treatments T_4, T_{13}, T_{10}, T_6, T_3, T_{12} and T_9.

Conclusions:

i. There was significant increase in plant height, total number of productive tillers, thousand grains weight, grain yield and straw yield over control due to silicon application, however there was no significant difference between levels of silicon and sources of silicon. Considering the availability and cost of material, bagasse ash proved as good source of silicon for paddy.

ii. The uptake of N, P, K and Si was significantly increased over control due to application of silicon through different sources.

iii. The application of silicon to paddy @ 250 kg silicon ha^{-1} was found to be optimum for increasing the growth, yield attributing characters and yield of paddy.

iv. The incidence of pest and disease was not observed on experimental paddy crop.

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*Originals not seen.

7. VITA

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Table 4.4 : Effect of sources and levels of silicon on chemical properties of soil after harvest of paddy.

Treatment	pH (1:2.5)	EC (dS m^{-1})	Organic Carbon (%)	$CaCO_3$ (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available Si (kg ha^{-1})	Water soluble Si (kg ha^{-1})
T_1 (Control)	6.20	0.12	1.29	0.5	262.38	22.18	258.41	174.20	29.19
T_2 (RHA 250)	6.22	0.14	1.34	0.6	260.29	22.85	256.20	239.01	35.24
T_3 (RHA 500)	6.22	0.16	1.36	0.7	259.24	23.07	256.16	264.51	36.46
T_4 (RHA 750)	6.23	0.16	1.36	0.8	258.20	23.17	255.85	276.27	36.70
T_5 (CS 250)	6.21	0.15	1.34	0.6	262.38	23.07	255.78	241.32	35.35
T_6 (CS 500)	6.22	0.15	1.36	0.6	261.33	23.44	255.63	265.81	36.49
T_7 (CS 750)	6.22	0.16	1.37	0.8	259.24	23.68	254.16	278.21	36.81
T_8 (BA 250)	6.20	0.15	1.31	0.5	258.20	22.62	258.00	237.66	34.98
T_9 (BA 500)	6.22	0.15	1.35	0.6	257.15	22.62	257.73	263.57	36.33
T_{10} (BA 750)	6.23	0.16	1.35	0.7	256.11	22.85	257.72	272.53	36.53
T_{11} (FA 250)	6.21	0.14	1.33	0.6	258.72	22.62	257.50	238.26	35.09
T_{12} (FA 500)	6.21	0.15	1.35	0.7	258.20	22.79	257.17	264.32	36.39
T_{13} (FA 750)	6.22	0.16	1.36	0.8	257.15	23.12	256.98	273.28	36.56
S.E. $\pm$	0.01	0.01	0.02	0.07	2.02	0.27	0.83	6.36	0.37
C.D.(P=0.05)	NS	NS	N.S.	NS	NS	NS	NS	18.52	1.06

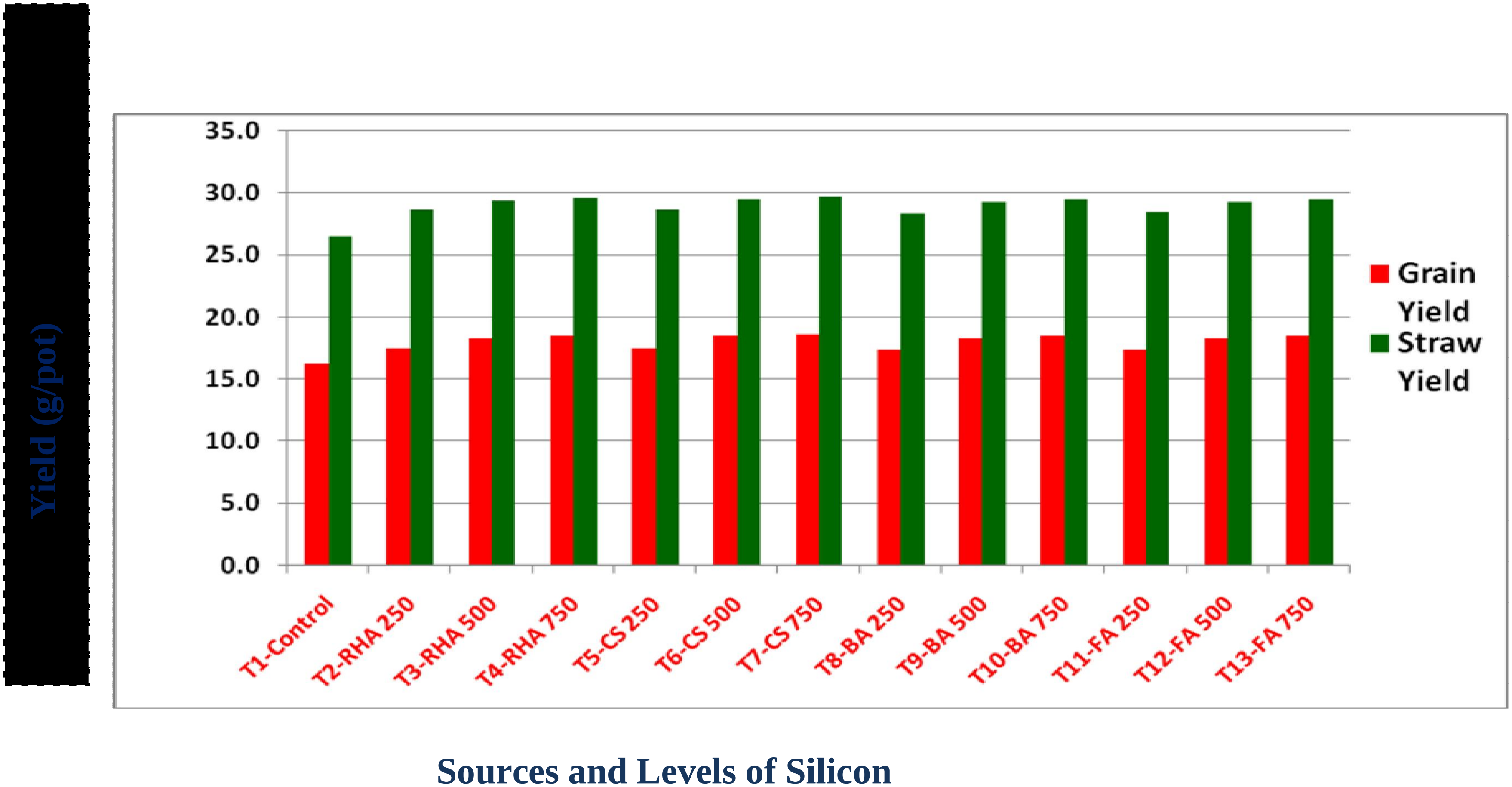
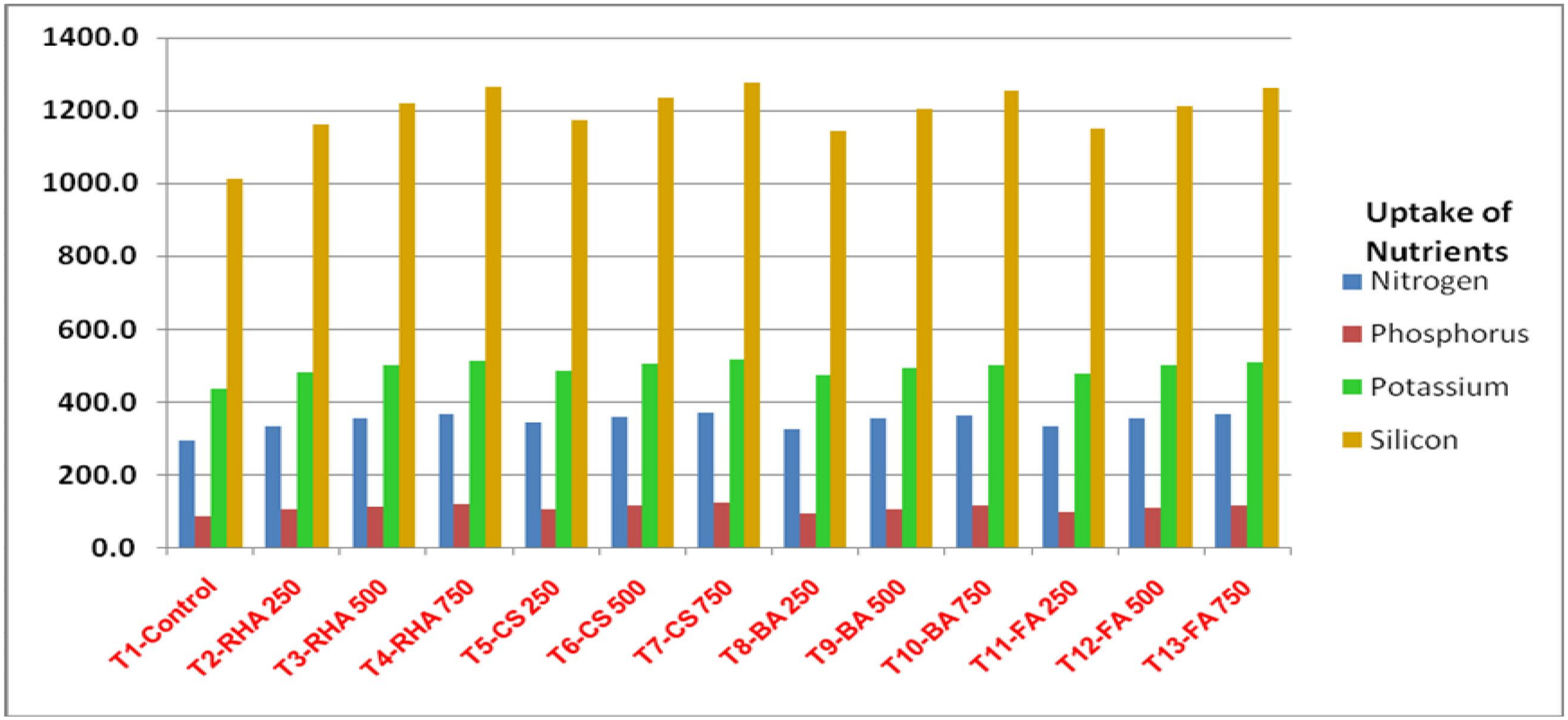


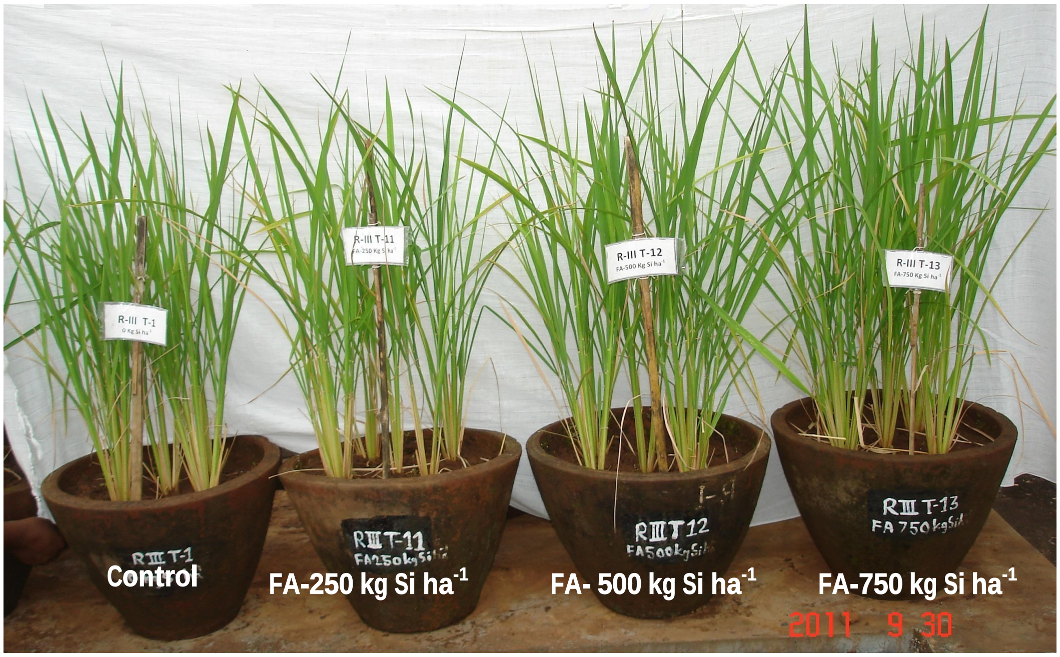
Fig. 4.1 Effect of sources and levels of silicon on grain and straw yield of paddy.

[redacted]

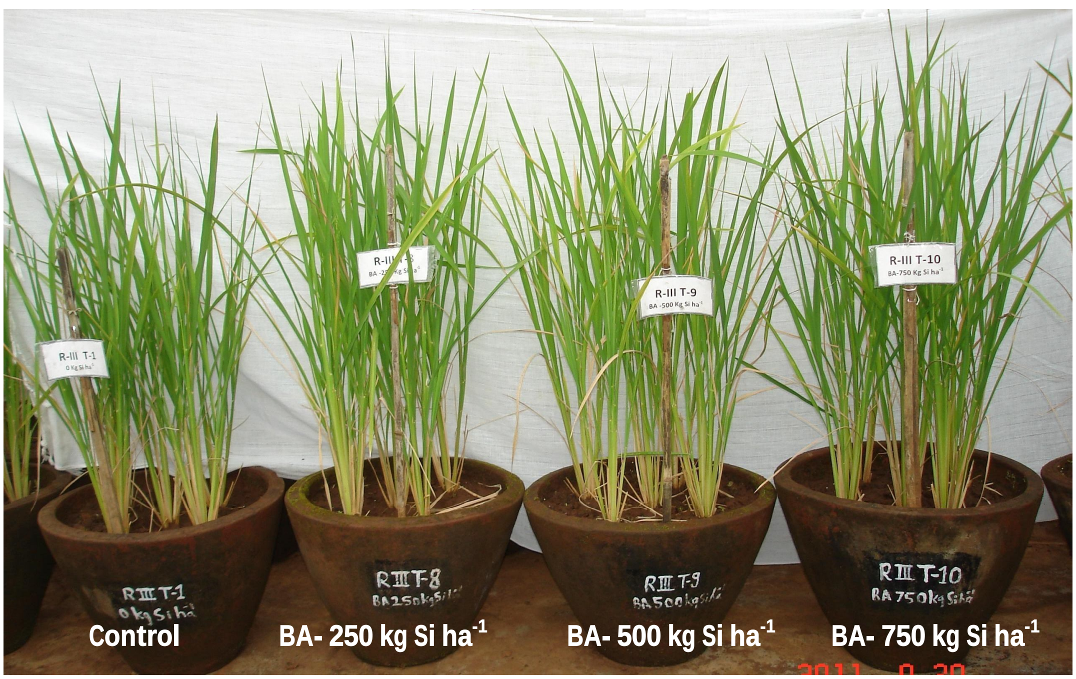


Sources and Levels of Silicon

Fig. 4.2 Effect of sources and levels of silicon on nutrients and silicon uptake by paddy.

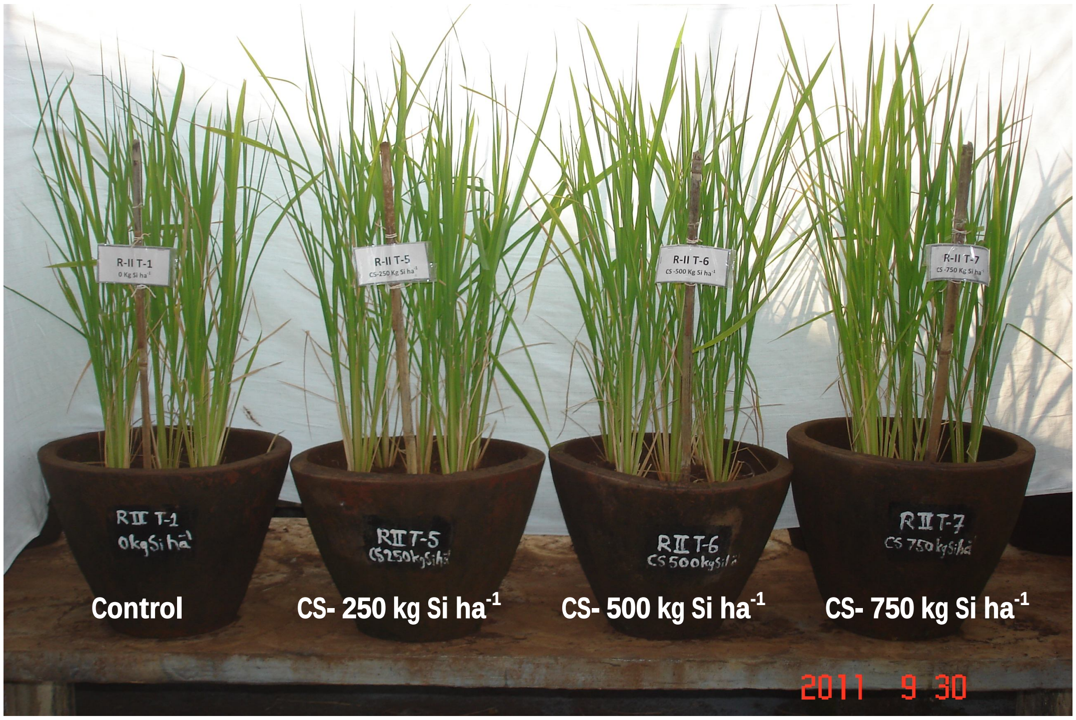


a) **Effect of levels of Fly Ash on paddy (Tillering)**

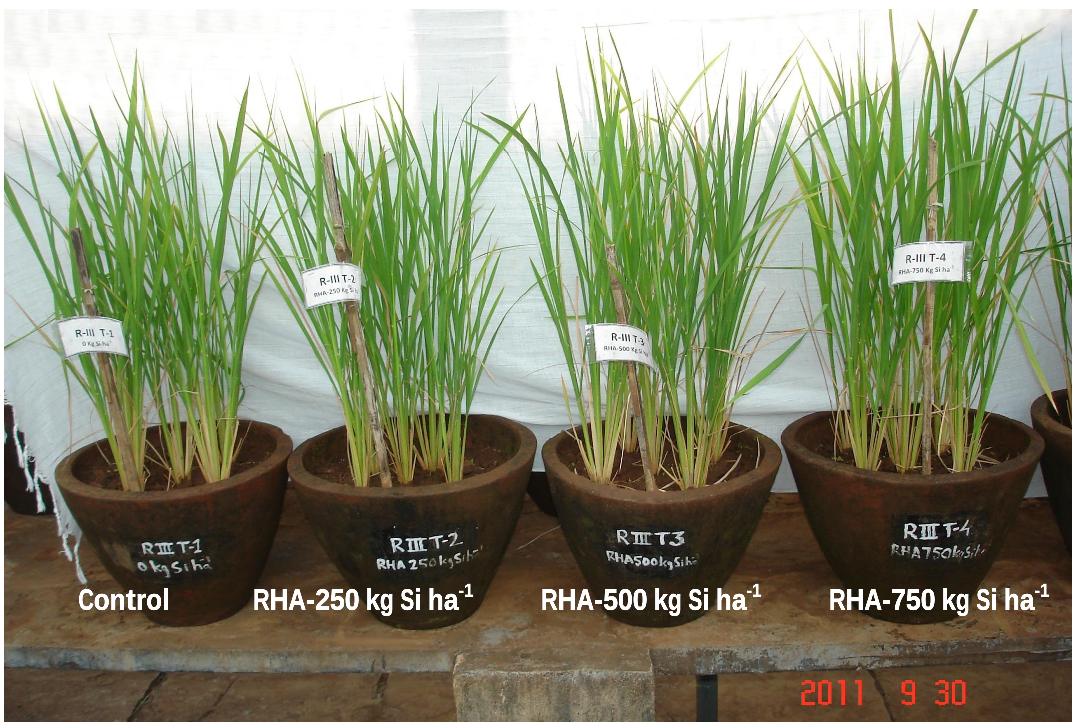


b) **Effect of levels of Bagasse Ash on paddy (Tillering)**

Plate No.2

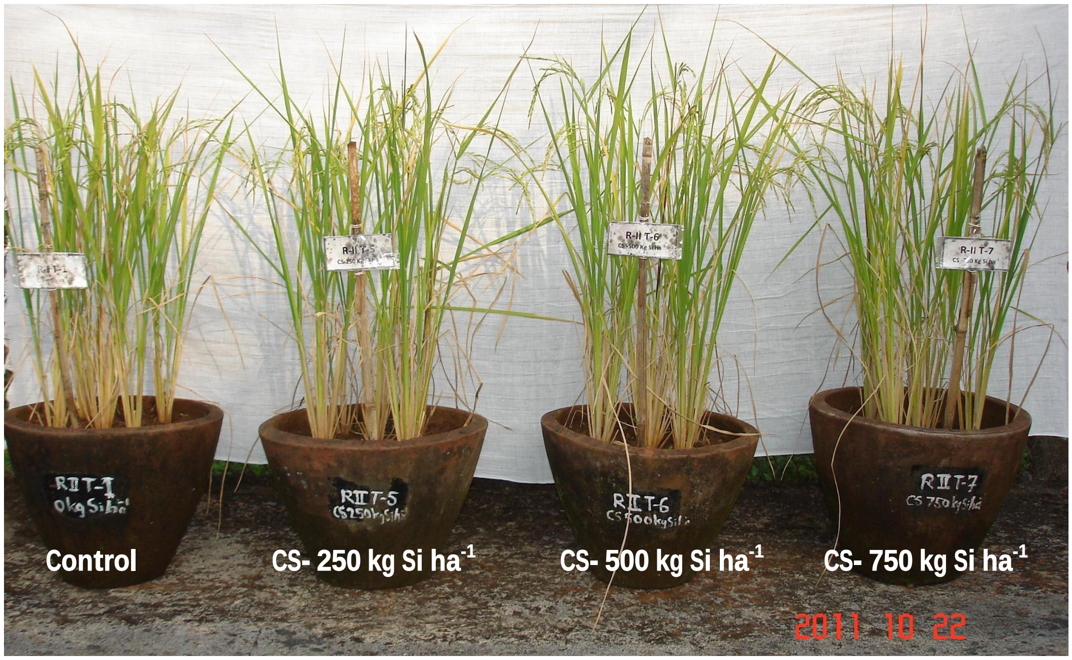


a) Effect of levels of Calcium Silicate on paddy (Tillering)

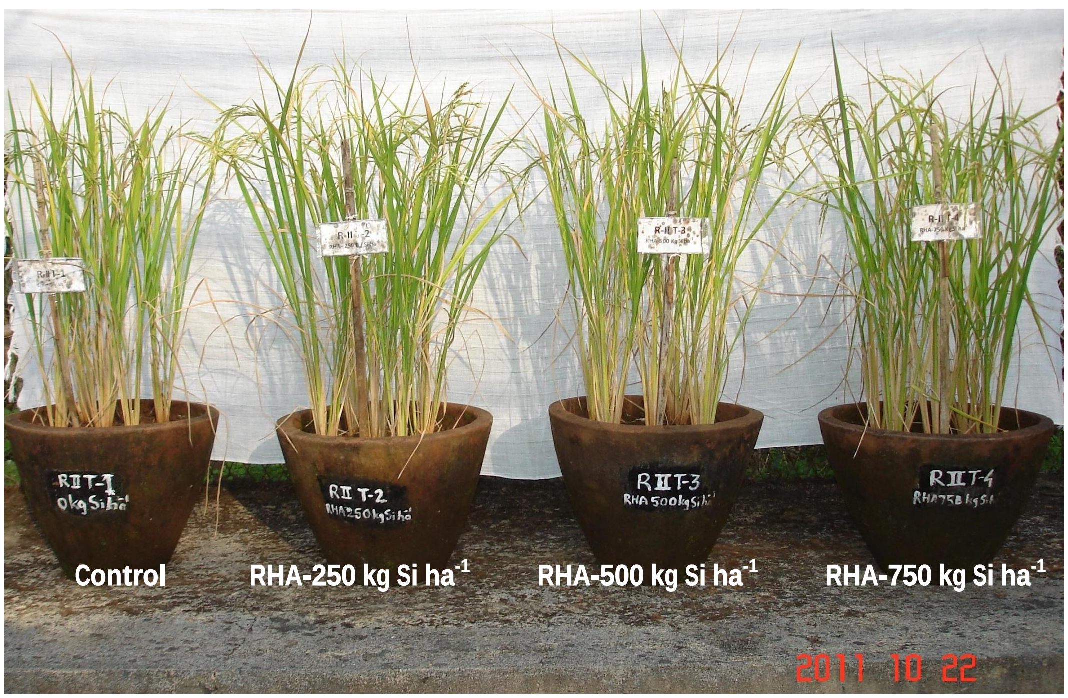


b) Effect of levels of Rice Husk Ash on paddy (Tillering)

Plate No.1

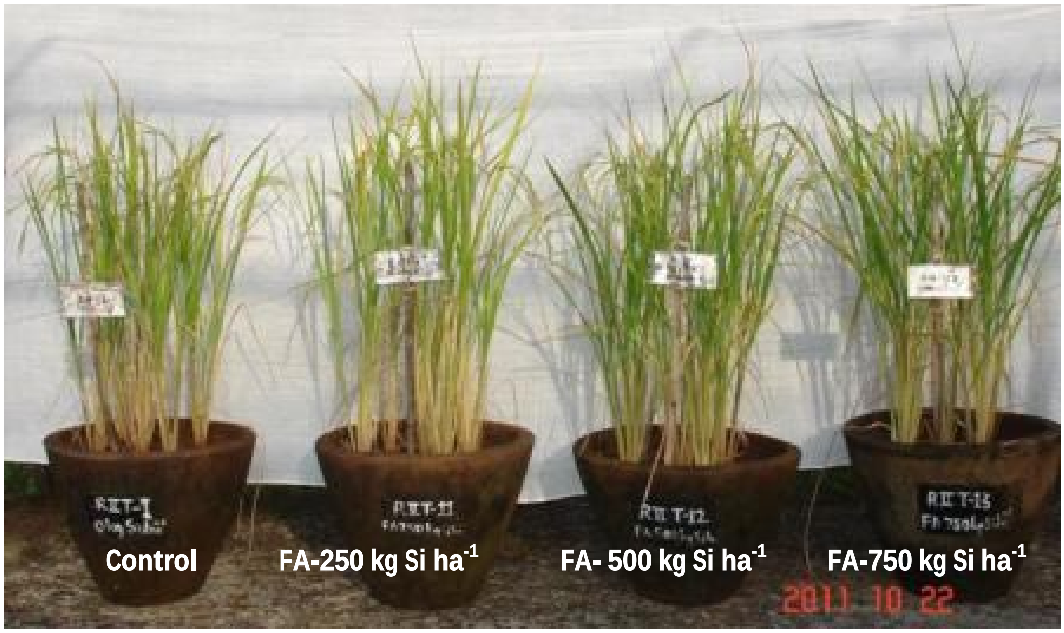


a) Effect of levels of Calcium Silicate on paddy (Maturity)

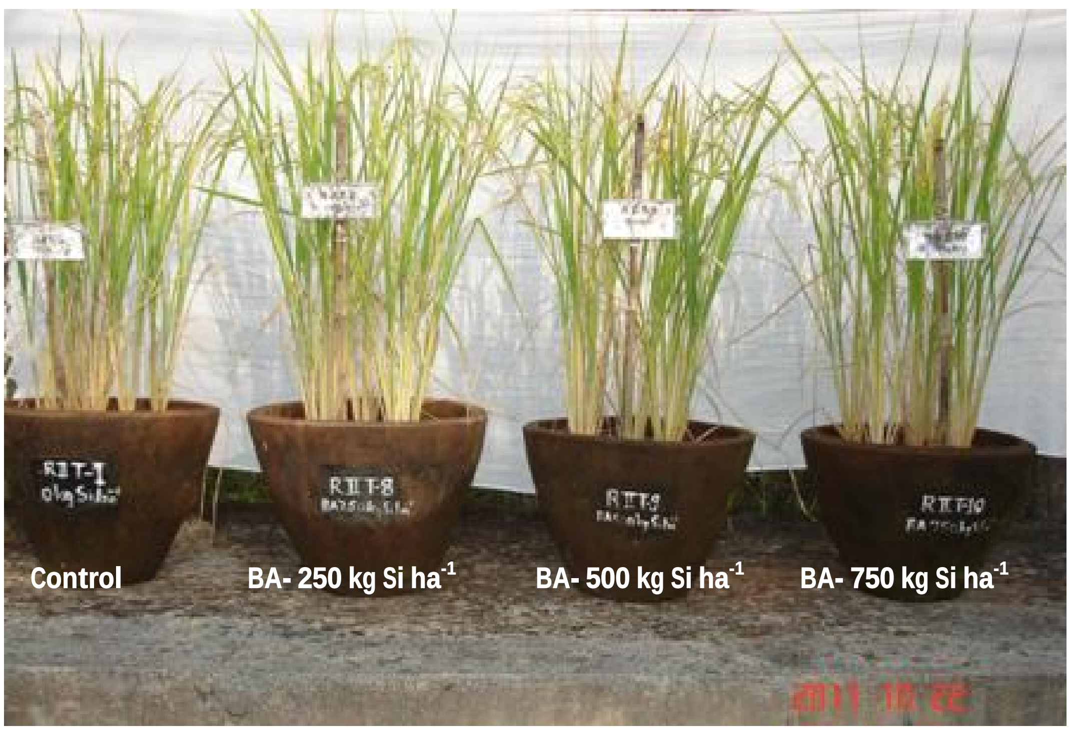


b) Effect of levels of Rice Husk Ash on paddy (Maturity)

Plate No.3



a) Effect of levels of Fly Ash on paddy (Maturity)



b) Effect of levels of Bagasse Ash on paddy (Maturity)

Plate No.4