SILICON NUTRITION FOR RICE IN IRON TOXIC LATERITE SOILS OF KOLLAM DISTRICT

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Silicon nutrition for rice in iron toxic laterite soils of Kollam district"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDIX

LIST OF ABBREVIATIONS

As	-	Arsenic
Al	-	Aluminum
ANSA	-	Amino Napthol Sulphonic Acid
ANOVA	-	Analysis of variance
B	-	Boron
B:C	-	Benefit Cost
Ca	-	Calcium
Cd	-	Cadmium
CD	-	Critical difference
cm	-	Centimeter
DAT	-	Days after transplanting
dS m^{-1}	-	Deci Siemens per meter
EC	-	Electrical conductivity
et. al	-	And others
Fe	-	Iron
FYM	-	Farm yard manure
Fig.	-	Figure
g	-	Gram
i.e	-	That is
K	-	Potassium
KAU	-	Kerala Agricultural University
kg	-	Kilogram
kg ha^{-1}	-	Kilogram per hectare
L	-	Liter
LSi	-	Low silica
m	-	Metre
mm	-	Milli metre
mM	-	Miili molar
Mn	-	Manganese

m^2	-	Square meter
mg kg^{-1}	-	Milli gram per kilo gram
mg L^{-1}	-	Milligram per litre
mg ml^{-1}	-	Milligram per milli litre
N	-	Nitrogen
Na	-	Sodium
NS	-	Non significant
P	-	Phosphorus
PAS	-	Plant Available Silicon
POP	-	Package of Practices
pH	-	Soil reaction
ppm	-	Parts per million
RBD	-	Randomized Block Design
rpm	-	Rotations per minute
S	-	Sulphur
SAS	-	Statistical analysis software
SHI	-	Silicon Harvest Index
SUE	-	Silicon Use Efficiency
Si	-	Silicon
SE	-	Standard error
t ha^{-1}	-	Tons per hectare
UV	-	Ultraviolet
viz.	-	Namely
Zn	-	Zinc

LIST OF SYMBOLS

% - Percent

@ - At the rate

^{0}C - Degree Celsius

µ - Micro

₹ - Rupees

INTRODUCTION

1. INTRODUCTION

Rice is the most important cereal food crop of the world. It is the staple food for more than half of the world's population. Rice is cultivated in 113 countries and provides 27 per cent of the dietary energy supply and 20 per cent of dietary protein intake in the developing world. India is the second largest producer of rice after China and being the staple food, rice plays a vital role in India's economy occupying a central position in shaping the agricultural policy (Dangwal *et al.,* 2011).

India's rice production accounts for more than 20 per cent of global production. The rice production of India is 103.5 million tonnes for the year 2015-2016 (Demaree, 2016), with average productivity of 2400 kg ha^{-1}.The population of our country may stabilize around 1.4 and 1.6 billion by 2025 and 2050, requiring annually 380 and 450 million tonnes of food grains respectively (Yadav *et al.,* 2010). The slogan "Rice is life" states the importance of rice as a main food source, and is drawn from an understanding that rice based systems are crucial for food security, poverty alleviation and improved livelihoods.

Rice is the staple food of Kerala. In Kerala, rice is cultivated in 1.98 l ha with the production of 5.62 l t and an average productivity of 2874 kg ha^{-1} in 2014-2015 (Maneesh and Deepa, 2016). For the last few decades, the rice farming sector in Kerala is facing a multitude of problems, which has led to drastic decline in area and production. The key reasons for this decline are non availability and high cost of labour at the peak period of work and low profit coupled with multiple soils related constraints. Among these, the main problem yet to be addressed in detail is soil related constraints.

About 65 per cent of soils in Kerala are laterite, which require special management package as these soils are low to medium in organic carbon, N and K, very low in Ca, Mg and B. Apart from low nutrient status, high acidity and toxicity of Fe, Al and Mn are other important soil related constraints in laterite soils of Kerala (GOK, 2016). Due to these constraints the crop productivity in iron toxic laterite soil is poor especially in lowland situation. However, there is considerable scope for improving the productivity of these soils through proper nutrient management. Majority of rice area in Kollam district of Kerala also comes under this laterite soil, which requires proper management to overcome these soil related constraints.

Silicon is the second most abundant element in the earth's crust. It has been recognized as quasi-essential element. The role of silicon in plants are enhancement of growth and yield, resistance against lodging, enhancement of photosynthetic efficiency, effect on surface properties, resistance against disease causing organisms, resistance to herbivores, resistance to metal toxicity, resistance to salinity stress, reduction of drought stress and protection against temperature extremes. Silicon is also the only element that does not damage plants upon its excess accumulation and reduce the concentration of toxic elements like Fe, Mn and other heavy metals (Ma *et al.*, 2002).

Rice is known as silicon accumulator and the plant is benefitted from silicon nutrition. Silicon is the most vital element for sustainable production of rice, as it enhances yield, increases nutrient availability and reduces metal toxicities (Fe, Al, Mn) and biotic and abiotic stress. A constant supply of silicon is essential as silicon is amenable to leaching losses, desilication and crop removal. Fine silica, rice husk ash, sodium silicate, potassium silicate and calcium silicate are different sources of silicon. Rock dust, another commonly used Si source contains 20 to 50% Si. The Kerala Agricultural University has developed a nutrient package for iron toxic laterite soils of

Kerala, which includes application of 100 kg ha^{-1} fine silica as one component to improve rice yield. As fine silica is costly and its availability in large quantities is limited, the possibility of partially substituting fine silica with other locally available low cost sources need to be investigated.

With this background the present investigation was undertaken with the following objectives:

1. To partially substitute fine silica with alternate silicon sources and standardize the dose of silicon fertilizers to rice crop in iron toxic laterite soils.
2. To assess the effect of alternate nutrient package on the growth and productivity of rice.
3. To formulate a comprehensive and cost effective nutrient package for rice in iron toxic laterite soils.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Rice is one of the principal food crops in the world. The overall production of rice globally is projected to be around 5.75 billion tonnes and the average productivity is about 3.83 tonnes per ha. In India, rice accounts to 40 percent of food grain production and is grown in 44.8 million ha and its cultivation provides profitable occupation and livelihood to about 70 per cent of people in rural areas. Total rice production estimated in the country is 125 million tonnes (Karnick, 2009).

Kerala is a food deficit state and rice is its major food crop. Over the past several years paddy sector of the state had shown declining trends both in area and production mainly due to the non-availability and high cost of labour and also due to multiple soil related constraints (Thomas, 1996). Most of the soils of Kerala are lateritic in nature, where the main soil related constraints are Mn and Al toxicity and high P fixation rates. Laterite soils have large amount of free iron oxide, which often leads to crust formation, resulting in poor emergence of rice seedlings after sowing and ultimately producing poor crop stand thereby reducing crop yields (Mahajan and Gupta, 2009).

Silicon is the second most abundant element in the earth's crust (Bond and McAuliffe, 2003). The average concentration of Si in the lithosphere is about 28 per cent and in soils normally ranges between 23-35 per cent. In soil solutions, the predominant form is monosilicic acid $Si(OH)_4$. Rice (*Oryza sativa* L.) is the most active Si accumulating plant, and accumulates Si to levels up to 10% of shoot dry weight (Epstein, 1999; Epstein, 2009). It has been estimated that 200 million tons of silicon are removed annually from arable soils globally, when crops are harvested (Matichenkov *et al.*, 2000).

Literature related to the following topics are elaborately discussed in this chapter:

2.1 Importance of silicon nutrition in plants

2.2 Silicon in soils

2.3 Silicon sources

2.4 Silicon uptake, transportation and accumulation

2.5 Beneficial effects of silicon in rice

2.1. IMPORTANCE OF SILICON NUTRITION IN PLANTS

Silicon is not considered as an essential element, but is a beneficial element for crop growth, especially for Poaceae crops. Silicon has been officially designated as a "beneficial substance" by the Association of American Plant Food Control Officials and plant available Si may now be listed on fertilizer labels (Devanur, 2015). Silicon plays a crucial role in amino acid and protein metabolism. Silica strengthens the plant, protects the plant against disease, insect, and fungi, increases crop production and quality, stimulates active immune systems of plants, increases plant nutrition, increase plant salt resistance and neutralizes Mn, Fe, Al metal toxicity in acid soils (Takahashi, 1995).

Silicon fertilizer has a twofold effect on the soil–plant system. First, improved plant-silicon nutrition strengthens plant protective properties against diseases, insect attack, and unfavorable climatic conditions. Second, soil treatment with bio-geochemically active silicon substances enhances soil fertility through improved water uptake, physical and chemical soil properties and maintenance of nutrients in plant-available forms. Plants vary widely in their capacity to take up silicon. In accumulating plants, silicon uptake largely exceeds water uptake and in non-accumulating plants silicon uptake is similar to or less than water uptake. In soil, silicon is not a much mobile element to plants. Therefore, a continued supply of this element would be required mainly for the healthy and productive development of plant during all growth stages (Savant *et al.*, 1997a).

Silicon deficiency affects the development of strong leaves, stems, and roots and makes the rice plants susceptible to pests and diseases. Silicon deficiency is common in areas with poor soil fertility, old degraded soils, organic soils with less Si reserves and also occurs in highly weathered soils in rainfed lowland and upland areas. The critical level of Si in soil is 40 mg kg^{-1} and the critical level of Si in rice (leaf and straw) is 5%. Silicon deficiency leads to soft and droopy leaves, which cause lodging and mutual shading, reduced photosynthetic activity, reduced grain yields, increased occurrence of diseases such as blast, reduced number of panicles and filled spikelets per panicle (IRRI, 2016).

2.1.1 Importance of Silicon in Rice

Rice is a high silicon accumulating plant and the plant is benefited from Si nutrition. Rice crop can uptake silicon in the range of 230-470 kg ha^{-1}. In 1955, silicon was first recognized as a fertilizer in Japan and since then 1.5-2.0 t ha^{-1} of silicate fertilizer have been applied to silicate deficient paddy soils. As a result, a 5-15% increase in rice yield has been reported by Savant *et al.* (1999). Adequate supply of silicon to rice from tillering to elongation stage, increases the number of grains panicle^{-1} and the ripening percentage (Korndorfer *et al.*, 2001).

Silicon is absorbed as plant available silicon (PAS) *i.e,* monosilicic acid by rice plants in far higher quantities than the macronutrients, for example, silicon uptake is 108 per cent greater than Nitrogen (N) uptake. In continuous cropping with high silicon accumulator species such as rice, the removal of PAS can be greater than the supply via natural processes releasing it into the soil unless fertilized with silicon (Savant *et al*, 1997a; Epstein, 2001).

Si is a beneficial element for plant growth and is agronomically essential for improving and sustaining rice productivity. Besides yield enhancement, Si has many fold advantages of increasing nutrient availability (N, P, K, Ca, Mg, S, Zn), decreasing nutrient toxicity (Fe, Mn, P, Al) and minimizing biotic and abiotic stress in plants.

Application of Si to soil or plant is practically useful in laterite derived paddy soils, not only to increase yield but also to alleviate the iron toxicity problems. Si increases the mechanical strength of the culm, thus reducing crop lodging (Devanur, 2015).

2.2. SILICON IN SOILS

In the soil solution or liquid phase, Si is present as monosilicic acid and polysilicic acid as well as complexes with organic and inorganic compounds such as aluminium oxides and hydroxides. While it is the PAS that is taken up by the plants and has a direct effect on crop growth, the polysilicic acid, and inorganic and organic complexes are vital sources/sinks that replenish the monosilicic acid succeeding crop use. Si occurs mainly as monosilicic acid (H_4SiO_4) in soil solution and is absorbed by plants in this form (Ma and Takahashi, 2002).

Daniela *et al.* (2006) stated that the Si compounds in the soils are classified into soil solution and adsorbed Si forms (Monosilicic and polysilicic acids), amorphous forms (phytoliths), poorly crystalline and microcrystalline forms (allophane, and secondary quartz) and crystalline forms.

Depletion of plant available soil silicon in intensively cultivated rice soils could be the possible soil related limiting factor contributing to declining rice yields (Singh *et al.*, 2006). The solubility of silicon in the soil is affected by a number of dynamic processes occurring in the soil including the particle size of the silicon fertilizer, the soil pH, organic complexes, presence of aluminium, iron and phosphate ions, temperature, dissolution reactions and soil moisture. Silicon can be added via irrigation water and fertilization. Silicon has a significant effect on the soil properties such as improving soil aggregation, soil water holding capacity and increasing the exchange and buffering capacity of the soil (Berthelsen *et al.*, 2003).

2.3. SILICON SOURCES

Si is available as organic resources or industrial by products. Inorganic materials such as quartz, clays, micas, and feldspars, even though rich in silicon, are poor silicon-fertilizer sources because of the low solubility of the silicon. Calcium silicate, generally obtained as a by product of an industrial process is one of the most commonly used silicon fertilizers. Potassium silicate, although expensive, is highly soluble and can be used in hydroponic culture and for foliar application. The most common commercially used Si sources are fine silica (SiO_2), calcium silicate slag ($CaSiO_3$), calcium meta silicate ($CaSiO_3$), sodium silicate ($NaSiO_3$), magnesium silicate ($MgSiO_3$), potassium silicate ($KSiO_3$) and silica gel (soluble SiO_2). Recently rock dust or rock powder has gained attention as a silicon fertilizer. Application of fine silica @ 100 kg ha^{-1} or sodium silicate 250 kg ha^{-1} is recommended for higher yield in rice grown in iron toxic laterite soils (KAU, 2016)

Rock dust is one of the cheaper and easily available alternate material, which contains approximately 48-51 per cent silicon and many macro and micro nutrients. Application of rock dust increased the tuber yield in coleus by 14.81 per cent. (Divya, 2008). Rocks have fast solubility rate both in weak organic acids and water, quickly releasing nutrients within minutes and increasing the pH of solution until the system is saturated (Keller, 1950). Rock dust contains most of the nutrients essential for plant growth, except nitrogen (Divya, 2008). The application of ground silicate rocks to highly weathered low fertile acid soils has been suggested as alternative to conventional fertilization with water soluble fertilizer (Coroneos, 1996).

Organic sources includes rice hulls, rice husk ash and sugarcane bagasse, which have an adequate Si concentration and can be used as Si sources (Ma and Takahashi, 2002).

Rice husk is one of the most commonly available agricultural wastes in many rice producing countries around the world. Globally, about 600 million tons of rice paddy is produced each year. Rice husk represents about 20% by weight of the rice harvested. About 80% by weight of the raw husk is made of organic matter such as cellulose, lignin etc. and the rest mineral components such as silica, alkalis and trace elements. It is of little to commercial value and because of its high silicon content, it is not suitable to feed to either human or animals. Rice husk ash is valuable for its roles in increasing soil fertility, substituting for inorganic fertilizer, and improving soil characteristics by its addition of organic matter to the soil (Njoku *et al.*, 2011; Okonkwo *et al.*, 2011).

Rice straw hauled away from rice fields and used for various purposes, such as animal feed or bedding, biogas production, or mushroom cultivation, may retain its nutrient value as a source of Si; thus the end products of these uses should be recycled. Composting of rice straw offers a potential way of recycling plant Si, because it reduces the bulk of straw to be handled. Silicon content in rice straw and rice husk ranges from 4-20 per cent and 9-26 per cent respectively (Savant *et al.*, 1997a). Application of rice husk ash @ 500 kg ha^{-1} is recommended for rice grown in iron toxic laterite soils (KAU, 2016).

2.4. SILICON UPTAKE, TRANSPORTATION AND ACCUMULATION

2.4.1 Silicon Uptake and Transportation in Rice

In soil solution, Si is mainly present as monosilicic acid, with concentrations usually within the range of 0.1-0.6 mM. Monosilicic acid is the predominant form of Si absorbed by roots by active uptake. Silicon uptake is performed by lateral roots, but not root hairs (Ma *et al.*, 2001).

Silica transportation in rice is mainly due to the presence of three low silica genes (LSi) *i.e.*, LSi1, LSi2 and LSi6 (Yamaji and Ma, 2009).

LSi1 is a low silicon rice gene that belongs to aquaporin family, controlling the silicon accumulation in rice. LSi1 is primarily located in the basal zones of roots rather than at root tips. This gene is constitutively depressed in roots. LSi1 was localized on the plasma membrane of the distal side of both exodermis and endodermis cell, where Casparian stripes are located. LSi2 is localized on the proximal side of the same cells. LSi1 shows influx transport activity for Si, while LSi2 shows efflux transport activity. LSi1 and LSi2 were responsible for transport of silica from root cells to the apoplast (Ma and Yamaji, 2008).

Silicon in xylem sap is present in the form of monosilic acid and is unloaded by LSi6, a homolog of LSi1 in rice. LSi6 is a transporter involved in intravascular transfer *i.e.* transfer of silicon from the large vascular bundles to the panicles. Knockout of LSi6 gene reduced silicon in panicles and increased silicon in flag leaves, showing its physiological role in silicon distribution in the plant (Ma *et al.*, 2011).

2.4.2. Silicon Accumulation and Deposition

Silicon is translocated from the roots as silicic acid through the xylem until it deposits under the cuticle and in intercellular spaces (Heckman, 2003). Silicon is absorbed by the plant as monosilicic acid, the absorbed water is lost through transpiration and the silicon stays in the plant tissue, when silicon concentration increases in the plant, monosilicic acid polymerizes into silica gel through a non-enzymatic reaction (Mitani and Ma, 2005).

The chemical nature of polymerized silicon has been identified as silica gel. Of the polymerized silica within the plant, 87-89% exists as a very slightly soluble form in hulls, leaf blades, and leaf sheaths. In these tissues, silica tends to be deposited as a 2.5 μ thick layer in the space directly underneath the thin cuticle layer forming a Cuticle-Silicon double layer. The location and the mechanical strength of this Cuticle Si double layer helps to maintain erect leaves, minimize transpiration and protects the rice plant from fungal diseases and insect pests (Devanur, 2015; Savant *et al.*, 1997a).

Sangster *et al.* (2001) reported that after 8-10 days of silica gel formation, silicon was almost completely found as a solid form in the aerial parts. Amorphous silica is therefore virtually the only form of silicon in plants. Amorphous silica particles that precipitate in plant cells are called Phytoliths or Plant opal. Phytoliths can be accumulated without any energy by polymerization of silicic acid when its concentration exceeds 2 mM. Proportions and locations of phytoliths vary with the species, but also with the age of the plant. In the leaves, silicon is preferentially deposited in the abaxial epidermis, and then in both epidermis as the leaf grows. Among those tissues, phytoliths are found in specific cells called silica cells located on vascular bundles and/or are present as silica bodies in bulliform cells, fusoid cells or prickle hairs in rice.

The reported critical limit for optimum growth and yield of rice is 5% Si in rice straw. The silica content of the leaf blades, culm and the whole plant increased with the progress of growth and was low during the vegetative period and high after flowering. Silicon content in culms, leaves and sheaths were 8.8-10.2, 16.8-22, 14.4-20.6 per cent respectively. Silicon content of leaves increased with silicon supply and was closely associated with the silica bodies per unit leaf area in the epidermal system (Singh and Singh, 2005).

Rice accumulates 4-20% silicon in straw and almost every part of rice comprises this element, which is not at all added exogenously as fertilizer as done with N, P and K, the trinity of nutrients. In rice leaf blades, 90 per cent or more of silicic acid occurs as silica gel (Polysilicic acid) and 0.5 per cent as low molecular weight silicic acids (orthosilicic acid). The straw silica content at harvest ranged from 4.8 to 13.5 per cent in the dry season and from 4.3 to 10.3 per cent in wet season (Devanur, 2015).

2.5. BENEFICIAL EFFECTS OF SILICON IN RICE

2.5.1. Decreases Lodging

Silica applications have a significant effect on plant lodging and density of stands, especially in cereal crops such as rice, wheat, and barley. Deposits of silicon in rice shoots enhanced the thickness of the culm wall and the size of the vascular bundles that result in reduction in lodging. Thickening of the cell walls of the sclerenchyma tissue in the culm and/or shortening and thickening of internodes or increase in silicon content of the lower internodes provides mechanical strength to enable the plant to resist lodging (Heckman, 2013; Savant *et al.*, 1997a).

Ma and Takahashi (2002) observed that Si can counteract undesirable results of excessive nitrogen fertilization such as disease susceptibility and lodging. Strong winds that can increase lodging also act to desiccate the plant tissue. Si is seen effective in preventing excess water loss by forming deposits on the hulls of rice (Ma and Yamaji, 2006).

Silicon treatment seemingly serves to impart more strength to the stem to resist breaking than those plants in non-Si treatments by increasing the number of silicate cells and silica content in stalks even at higher levels of nitrogen (Fallah, 2012).

2.5.2. Increases the Synthesis of Proteins and Chlorophyll

Silicon is an important constituent of DNA and RNA, *i.e.* silicon increases the synthesis of proteins and chlorophyll (Devanur, 2015). Silicon nutrition strengthened the DNA molecules in plants. Therefore, the introduction of silicon improves the viability of the plants at the genome level and enhances the natural resistance of plants in agricultural lands (Bocharnikova *et al.*, 2014). Silicon increased the number of chlorophyll per unit area (Liang, 1998).

2.5.3. Increases Crop Growth and Yield

2.5.3.1. Increases Rate of Photosynthesis

Si nutrition improved photosynthesis, possibly through enhanced mesophyll conductance and also due to stronger stems producing more erect leaves, which capture more sunlight. Si is present in leaves just beneath the cuticle giving a more erect leaf habit than in its absence and thus it improves photosynthesis (Detmann *et al.*, 2012).

Silica promoted crop growth by increasing number of tillers, leaf area and photosynthetic activity of the lower leaves. The photosynthetic activity is improved by more erectness of rice, which is ultimately provided by silica (Singh and Singh, 2005). Yoshida (1981) noticed a 10 percent increase in the photosynthetic rate due to improved erectness of leaves and there was an increased rice yield due to proper silicon management.

Pawar and Hegde (1978) also observed that foliar spray of 100-400 ppm Si applied twice per week to rice up to the booting stage increased tillering, vegetative growth and photosynthetic efficiency. Application of 100 mg Si kg^{-1} soil increased dry matter production, plant height, and leaf area ratio in rice (Rani *et al.*, 1997).

2.5.3.2. Increases Crop Yield

Silicon stimulates growth, reinforces culms and roots, and favours early panicle formation, increases the number of spikelets panicle^{-1} and percentage of matured rice grains and helps to maintain erect leaves, which are important for higher rate of photosynthesis (Savant *et al.*, 1997a). Padmaja and Verghese (1966) found that when sodium silicate was applied to soil as an amendment in laterite soil, it increased the tillering, height of plants, depth of penetration of the root system and the proportion of thicker to thinner roots in rice. Tisdale *et al.* (1993) found that Si enhances top length, number of stems and fresh and dry weight of rice.

Murali *et al.* (2007) observed that, the yield components *viz.*, number of productive tillers m^{-2}, panicle per unit area, filled grains per panicle and test weight were higher with application of N and K with furnace slag as silicon source. Korndorfer *et al.* (2001) concluded that there was an average increase in grain yield (1007 kg ha^{-1}) due to the application of silicon in the form of calcium silicate.

Sunilkumar (2000) and Rani *et al.* (1997), observed that an ample supply of silicon increases the the number of grains per panicle, number of panicles, the percentage ripening and improves the light receiving posture of rice plants, thereby improving photosynthesis. Si-N interaction was found to be non-significant, but increased application of Si and N seperately resulted in significant increase in rice yield (Singh and Singh, 2005; Singh *et al.*, 2006).

Silicon plays a vital role in hull formation and also influence grain quality in rice (Jawahar and Vaiyapuri, 2012; Bhaskaran, 2014). The poor quality of hulls, milky-white grains low in silicon content, which is directly related to the straw Si concentration in rice (Savant *et al.*, 1997a). Gholami and Falah (2013) and Ahmad *et al.* (2013) reported that application of Si fertilizers enhanced the growth parameters, increased yield, yield attributes and quality of rice crop.

Application of azomite clay (rock powder) increased the plant height and early flowering in tomatoes (Yarrow, 1998). Application of khondalite (rock powder) @ 1 t ha^{-1} along with FYM @ 12.5 t ha^{-1} resulted in a saving of 25 to 50 per cent of chemical fertilizers in cassava (Shehana *et al.*, 2006).

Ahmad *et al.* (2013) observed that maximum straw yield (12.61 t ha^{-1}) was obtained when 1.00 per cent silicon was applied and it was followed by 0.50 per cent silicon and 0.25 per cent, respectively, while minimum (10.49 t ha^{-1}) was found in control. Jawahar and Vaiyapuri (2012) stated that, among the different treatments imposed, Si at 120 kg ha^{-1}

resulted in more gross income, net return, B:C ratio and return rupee^{-1} invested in rice crop.

The beneficial effects of Si among plant species. Beneficial effects are usually noticeable in plants, which actively accumulate Si in their shoots. The more the accumulation of Si in the shoots, the more is the effect that is gained. This is because most effects of Si are expressed through the formation of silica gel, which is deposited on the surface of leaves, stems, and other organs of plants. On the other hand, the beneficial effects of Si vary with growth conditions (Singh and Singh, 2005).

Prakash *et al.,* (2011), developed two indices to determine the silicon uptake by the rice plant *i.e.* silicon harvest index (SHI) and silicon use efficiency (SUE). The SHI is an important tool for determining the amount of silicon in grain and straw. SHI varied from 0.17 to 0.20 with an average value of 0.18. Therefore, it can be concluded that about 82% of accumulated silicon was retained in straw and only about 18% was translocated to grain. Straw incorporation after the harvest of rice crop is an important strategy for improving or maintaining the soil's Si level.

Prakash *et al.,* (2011), stated that, SUE (kg grain produced per kg Si uptake) varied from 83 to 111, with an average value of 101. In the straw, the SUE varied from 30 to 38, with an average value of 33. Overall, the straw SUE was about three times lower than that of grain. The lower straw SUE was associated with a higher uptake of Si in the straw compared to that in grain.

2.5.4. Improves Availability of Applied Nutrients (N, P, K)

2.5.4.1. Nitrogen

Yoshida *et al.* (1969) have revealed that decrease in erectness of rice leaves following an excess of N application can be alleviated if silicon is supplied to the nutrient solution. Rice straw biomass generally increases with an increase in N rate.

In many cases, yield decreases when N rates are more than optimum. Due to a synergistic effect, the application of Si has the potential to raise the optimum N rate, thus enhancing the productivity of existing lowland paddy fields (Ho *et al.,* 1980). Fertilizing with nitrogen tends to make rice leaves droopy, whereas silicon keeps them erect. Application of NPK fertilizers in combination with Si significantly increased total N, P and K uptake of rice (Chanchareonsook *et al.,* 2002).

By adopting proper silicon management, erect leaves can easily account for a 10 per cent increase in the photosynthesis of the canopy and accordingly a similar increase in yield (Yoshida, 1981). Therefore, the maintenance of erect leaves by proper silicon fertilization for higher photosynthetic efficiency becomes more important when rice is grown with liberal applications of nitrogenous fertilizers in lowland rice fields having highly weathered tropical soils with low silicon supplying capacity (Yoshida *et al.,* 1969).

2.5.4.2. Phosphorus

Silicon fertilization made P more available to plants. Eneji *et al.,* (2008) found correlations between silicon and P uptake. Effect of Si under phosphorus deficiency could be due to an in-planta mechanism, implying an improved utilization of P, probably through an increase in phosphorylation or a decrease in manganese concentration.

Guntzer *et al.* (2012) observed that, when P was supplied in excess, silicon limited phosphorus uptake and caused chlorosis, possibly by reducing the transpiration rate. The application of calcium silicate to highly weathered soils enhanced upland rice response to applied phosphate. The efficiency of phosphate fertilizer seemed to be enhanced when it was applied along with silicon.

Phosphorus absorbed by the rice crop increased from 26 to 34% when phosphorus as single superphosphate (@ 26 kg ha^{-1}) was applied along with a silicate fertilizer (Savant *et al.*, 1997a).

Ma and Takahashi (1990; 1991) reported that overall beneficial effect of Si may be attributed to a higher P: Mn ratio in the shoot due to the decreased manganese and iron uptake, thus indirectly improving phosphorus utilization within the rice plants. They have concluded that the interaction between phosphorus and silicon is indirect in phosphorus deficient soil.

2.5.4.3. Potassium

Interaction of applied potassium and silicon in soil have beneficial effects on rice yields. Silicon application increased upland rice yield response to applied potassium (Burbey *et al.*, 1988).

Silicification of cell walls seems to be linked with potassium nutrition. Application of potassium and silicon at the spikelet-differentiation stage resulted in an increase in the number of spikelets m^{-2}, the percentage of ripened grains, and 1000 grain weight (Ota, 1988). Additions of Si resulted in an increase in uptake of potassium possibly due to the stimulating effect of Si on K uptake, which could be due to the activation of H^{+}-ATPase in the membranes (Liang, 1999).

According to Nogushi and Sugawara (1966), potassium deficiency reduces the accumulation of silicon in the epidermal cells of the leaf blades, thus increasing the susceptibility of the plant to rice blast. Burbey *et al.*

(1988) reported decreased neck blast incidence in upland rice due to the K x Si interaction. Potassium uptake both in soil and hydropics is improved even at low silicon applications through the activation of H^+ ATPase (Mali and Aery, 2008).

Low soil moisture and high humidity are environmental conditions that are common in upland rice regions. These environmental conditions can reduce silicon and potassium absorption by rice plants and may decrease their ability to resist biotic and abiotic stresses. Therefore, silicon management integrated with potassium may be more important for sustaining rice yields in upland areas than in lowland areas (Savant *et al.*, 1997a).

2.5.5. Decrease Metal Toxicities of Fe, Al and Mn

Silicon decreases the metal toxicities of Fe, Al and Mn (Singh and Singh, 2005). Soil contamination with metals like cadmium, aluminium, iron, and manganese can occur in cropping soil and result in significant biomass and grain yield loss.

2.5.5.1. Iron Toxicity

In humid tropical and subtropical area, iron toxicity is one of the major physiological problems in rice growth. Silicon increases the oxidizing power of roots, which converts ferrous iron into ferric iron, thereby preventing a large uptake of iron and limiting its toxicity (Qiang *et al.*, 2012).

Silicon will regulate iron uptake from acidic soils through the release of hydroxyl ion by roots (Wallace, 1993). Fe^{2+} toxicity injures plants by inhibiting the elongation of rice roots.

Zhang *et al*. (2011) and Batty and Younger (2003) reported that iron plaque on the surface of rice roots was harmful to the roots, which decreased root activity and inhibited nutrient uptake. The cortex cells and epidermal cells within rice roots died due to formation of iron plaque. The effect of iron plaque on the plant growth may depend on the amount and thickness of iron plaque and the status of the nutrients.

2.5.5.2. Aluminium Toxicity

Excess aluminium is toxic to plants causing stunted roots, reduced availability of P, S and availability of other nutrient cations through competitive interaction. Si application alleviates aluminium toxicity. Silicon and aluminium interact in the soil, creating sub-colloidal and inert aluminosilicates, thereby reducing phytotoxic aluminium concentration in the soil solution (Liang *et al.*, 2007). Barbosa *et al*. (2012) reported that toxicity of Al in soils can cause damage to plants and consequently decrease yield.

Si application reduces aluminium toxicity by ex-planta mechanism by stimulating phenolic exudation by roots that would chelate and thus decrease its absorption by roots (Kidd *et al.*, 2001). Al inhibits root growth and nutrient uptake. Si and Al interaction occurs in the soil solution, leading to the formation of Al-Si complexes, a non-toxic form. However, interaction between Al and Si within the plant has also been suggested (Cocker *et al.*, 1997). Aluminium can be detoxified by in-planta mechanisms either by forming hydroxyl aluminosilicates in the apoplast in roots or by a sequestration in phytoliths (Guntzer *et al.*, 2012).

2.5.5.3. *Manganese Toxicity*

Manganese toxicity results in necrotic and brown spots on leaves. Silicon can suppress the increase of phenolic compounds caused by the excess accumulation of manganese and prevent the onset of toxicity symptoms (Rogalla and Romheld, 2002).

In rice, silicon reduced the Mn-oxidizing power of the roots. Mn toxicity is reduced in silicon fertilized plants because silicon increases manganese binding to cell walls, which limits cytoplasmic concentrations (Liang *et al.*, 2007; Li *et al.*, 2012). Si induces a more homogenous distribution of manganese in leaves, limiting spot necrosis (Ma *et al.*, 2001).

Okuda and Takahashi (1962) observed alleviative function of Si on Mn in hydroponically cultured rice. Li *et al.* (2012) stated that the application of Si with high Mn increased shoot and root dry matter weights by 40.1 per cent and 29.8 per cent respectively in the sensitive rice cultivar, and by 21.1 per cent and 96.7 per cent in the tolerant cultivar.

2.5.6. Decreases Heavy Metal Toxicity

Silicon decreases heavy metal toxicities like Cadmium (Cd) and Arsenic (As) (Singh and Singh, 2005). Excess toxic metals adversely influence the plant availability of beneficial nutrients. Silicon deposition in the roots reduces apoplastic bypass flow and provides binding sites for metals, resulting in decreased uptake of salts and toxic metals from the roots to shoots (Ma and Yamaji, 2006).

Jia-wen *et al.* (2013) proposed that the silicon alleviates heavy metal toxicity by two different ways *i.e.* avoidance and tolerance. Through avoidance, Si increases the pH of growth media, mediates exudate of the root (such as organic acids and phenolic) to chelate heavy metals *in vitro* and modulates the activity of metal transporters. By tolerance, Si can reduce the heavy metal toxicity by homogenous distribution of heavy metals in leaves, restraining heavy metal ion transport from root to shoot, chelating heavy metal ions with ligands (histidine, organic acids, niacinamide, phytochelatins, and metallothioneins) in plants, compartmentation of heavy metals into vacuoles or cell walls, stimulating enzymatic and non-enzymatic anti-oxidants and by structural alterations in plants.

Matichenkov *et al.* (2000) confirmed that the leaching of heavy metals reduced significantly by 50 per cent with the addition of diatomaceous earth.

2.5.6.1. Cadmium Toxicity

Silicon nutrition is known to decrease cadmium uptake and transport by rice and to enhance cadmium tolerance (Meharg and Meharg, 2015). Foliar application of silicon reduced Cd concentration in rice grains and shoots, while increasing their biomass (Neumann *et al.,* 1997). Cadmium toxicity and accumulation in rice would be related to cadmium sequestration in the shoot cell walls (Guntzer *et al.,* 2012).

2.5.6.2. Arsenic Toxicity

Inorganic arsenic in rice grain is a global problem as rice is the predominant source of this carcinogen to the human diet (Meharg *et al.,* 2009). Arsenite, the dominant form of arsenic under anaerobic conditions in paddy soils, is a silicic acid analogue and rice is competent in assimilating arsenite. Excess silicon, either in soil or hydroponic culture, reduces inorganic arsenic uptake and translocation to plant shoots (Li *et al.,* 2009).

Meharg and Meharg (2015) stated that, when the availability of arsenic in soil solution was correlated to soil silicon content, the higher silicon content in soil solution decreased arsenic assimilation in rice. Si fertilization of paddy soils reduced arsenic concentrations in wholegrain rice by 22 per cent.

2.5.7 Increases Abiotic Stress Tolerance

2.5.7.1 Alleviate Salt Stress

Excessive salinity in arable soil is a worldwide problem due to mainly rising water tables. Si reduced plant uptake and transport of sodium from roots to shoots and increased binding of sodium to the cell wall (Madi and Aery, 2008; Yeo *et al.* 1999). Ma *et al.* (2001) observed that the alleviation of Na^+ toxicity was due to the formation of sodium and silicon complexes in the soil solution.

Silicon can alleviate salt stress in higher plants by various ways *i.e.* improved photosynthetic activity, increased enzyme activity, enhanced K/Na selectivity ratio, and increased concentration of soluble substances in the xylem, resulting in limited sodium absorption by plants (Sahebi *et al.*, 2015).

Si induced a reduction in transpiration rate and a partial blockage of the transpirational bypass flow. Si induced stimulation of the root plasma membrane H+-ATPase under salt stress and decreased the permeability of the plasma membrane of the cells (Liang *et al.*, 2007).

Silicon nutrition can alleviate many abiotic stresses including physical stress like lodging, drought, UV and chemical stress like metal toxicity, salt toxicity and nutrient imbalance (Epstein, 1994). Adequate uptake of silicon can substantially increase the tolerance of rice to both biotic and abiotic stresses (Datnoff *et. al.*, 2001; Ma and Takahashi, 2002). Si deposition enhances the strength and rigidity of cell walls and increases the resistance of plants to various stresses (Ma *et al*., 2004).

Si fertilizer application can alleviate the adverse effects of salt stress on plants by increasing cell membrane integrity and stability through its ability to stimulate the plant's antioxidant system. Si deposited in the cell walls of roots, leaves, and stalks as silica gel reduces sodium absorption and transport, mitigating the adverse effects of salt on plant growth (Marafon and Endres, 2013; Yeo *et al*., 1999).

2.5.7.2 Alleviate Drought Stress

Drought is a situation when an area faces lack of precipitation and high evapotranspiration resulting in non-availability of the minimum amount of water (Ahmad *et al.,* 2013). Si content in plant decreases the transpiration rate resulting in high water use efficiency (Devanur, 2015).

The deposition of silicon in the leaves and hulls also decrease transpiration from the cuticle thus increasing resistance to drought stress (Ma and Yamaji, 2006). Drought stressed plants that were treated with Si fertilizer retained greater stomatal conductance, relative water content than untreated plants. Silicon treated leaves were larger and thicker, reducing the transpiration. Si increased resistance to strong winds generated by typhoons, related to the increased rigidity of the shoots through silicification. Silicon fertilization enhances the development of secondary and tertiary cells of the endodermis, which results in increased root resistance in dry soils and a quicker growth of roots (Guntzer *et al.,* 2012).

Pichani *et al.* (2008) observed that upland rice cultivars grown under high silicon culture solution resulted in an increase in relative water content and decrease in stomatal resistance of leaves when compared with upland rice varieties grown in non-silicon culture solution.

Ma *et al.* (2001) reported that silicon–cellulose membrane in the epidermal tissue protects plants against excessive loss of water by transpiration. Silicon can alleviate the water stress by decreasing transpiration by forming silicon cuticle double layer. Silicon deposition can decrease the transpiration rate in rice by 30 per cent.

2.5.8. Increases Biotic Stress Tolerance

Silicon has been found to suppress many plant diseases and insect attack. The effect of silicon on plant resistance to pests can be due to the accumulation of absorbed silicon in the epidermal tissue or expression of pathogenesis-induced host-defence responses (Savant *et al.,* 1997a).

2.5.8.1. Pest Tolerance

Silicon increases the resistance of plants to many insects in rice like stem borer, leaf folder, brown plant hopper, leaf hoppers, etc. The silica deposition on epidermal layers offers a physical barrier to insects by preventing the physical penetration by insects. Sucking and leaf eating caterpillars have a low preference for the silicified tissues than low silica containing plant parts. Entomologists found that the incisor region of the mandibles of stem borers fed on rice plants with a high silicon content were more damaged. The insect's behaviour responses seem to be affected by the presence of high levels of Si in the plant (Savant *et al.,* 1997a)

Salim and Saxena (1992) observed decreased food intake, fewer nymphs becoming adults, decreased female and male longevity and fecundity, and eventually decreased insect population on susceptible rice variety Taichung Native 1 due to increase in silicon concentration in the nutrient solution. The presence of silicated cells on leaves inhibited scraping by leaf folder larva of the green tissue on Si-treated plants; consequently, larval weight gain was significantly less on Si-treated plants than on the control plants (IRRI, 1991).

Massey and Hartley (2006) stated that when silicon was applied adequately, it reduced the susceptibility of plants to chewing insects like stem borer, mainly by making plant tissue less digestible and also by causing damage to the mandibles of feeding insects.

Soluble silicic acid (as low as 0.01 mg ml^{-1}) in the sap of the rice plant acts as an inhibitor of the sucking activity of the brown plant hopper (Yoshihara *et al.*, 1979).

2.5.8.2. Disease Tolerance

Silicon has been found to decrease several diseases in rice like sheath blight, brown spot, grain discoloration, etc. Silicon enhanced resistance to diseases by two different mechanisms. The first mechanism is that Si behaves as a physical barrier, where the Si is deposited beneath the tissue. This forms a cuticle Si barrier that can mechanically inhibit the fungal penetration, reducing the infections. The second mechanism that explains Si-enhanced resistance to pathogens proposes that Si acts as a modulator in the host plant to the pathogen. Plants treated with Si increase the production of natural defence compounds including the elevated production of lignin, phenolics and phytoalexins (McGinnity, 2015).

Fauteux *et al.* (2006) concluded that Si is not only involved in structural and physiological plant processes, but also plays an important role in plant resistance to pathogenic fungi. Application of silicon to crops suppresses pests and diseases and it leaves no pesticide residue in food or the environment, is comparatively cheap and could easily be integrated with other disease management practices (Liang *et al.* 2006).

Si might form complexes with the organic compounds of cell walls of epidermal cells, thus increasing their resistance to the enzymes released by the pathogen. The antifungal compounds like momilactones were found to accumulate in silicon applied rice plants and these acted against blast pathogen. Another mechanism of resistance was reported in which Si stimulates chitinase activity, peroxidases and polyphenoxidases activation after fungal infection. Glycosidically bound phenolics extracted from silicon supplied plants when subjected to acid displayed strong fungistatic activity. (Ma *et al.*, 2001).

Silicon application increased resistance to blast and it is due to the density of silicified cells in leaf epidermis, which acted as a barrier and decreased the number of blast lesions (Datnoff *et al.*, 2001). Low uptake of silicon has been shown to increase the susceptibility of rice to leaf blight, brown spot, and grain discoloration (Kobayashi *et al.*, 2001).

Prabhu *et al.* (2001) observed that the grain discoloration in various lowland and upland rice genotypes decreased as the soil SiO_2 increased. Rodrigues *et al.* (2003) investigated that the Si-mediated resistance against *M. grisea* in rice by a specific leaf cell reaction that interfered with the development of *M. grisea*.

Seebold *et al.* (2000) reported that the severity of leaf scald caused by *Monographella albescens* was reduced by silicon application. Correa-Victoria *et al.* (2001) observed that the severity of leaf scald on rice was significantly reduced to 17.4 per cent as the silicon rates increased from 0 to 3 t ha^{-1}. Prabhu *et al.* (2001) observed leaf scald suppression with increasing rates from 0 to 4 t ha^{-1} of SiO_2. The lesion length was reduced from 0.6 cm to 0.4 cm at the rate of 1 t ha^{-1} of SiO_2.

The review presented in this chapter highlights the significance of silicon nutrition in rice such as reduction in lodging, increase in the synthesis of proteins and chlorophyll, enhancement of crop growth and yield, improvement in the availability of applied nutrients, reduction in toxicity of Fe, Al and Mn, increase in biotic and abiotic stress tolerance etc. But the true potential of silicon fertilizers is its effectiveness in the amelioration of the abiotic stress especially that of Fe, Al and Mn toxicities. However, this ameliorative potential of silicon has not so far exploited for enhancing the productivity of iron toxic laterite soils of Kerala. With this background, the present study was conducted to assess the possibility of substituting fine silica with alternate silicon sources and to find out the effect of these sources on growth and productivity of rice for formulating a cost effective nutrient package for rice in iron toxic laterite soil.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

An investigation entitled "Silicon nutrition for rice in iron toxic laterite soils of Kollam district" was carried out at College of Agriculture, Vellayani to assess the possibility of partially substituting fine silica with alternate silicon sources and to find out the effect of these sources on growth and productivity of rice for formulating a cost effective nutrient package for rice in iron toxic laterite soils. The field investigation was carried out in farmer's field at Vilakkudy Panchayath, in Kollam district and chemical analysis was conducted at Department of Agronomy, College of Agriculture, Vellayani.

The experiment details with special reference to the materials used and methods adopted are discussed in this chapter.

3.1. EXPERIMENTAL SITE

3.1.1. Location

The field experiment was laid out in farmer's field at Vilakkudy Panchayath in Kollam district. It is geographically located at 9.025°N latitude, 76.84°E longitude and at an altitude of 27 m above mean sea level. The experimental field had fairly leveled topography and good drainage.

3.1.2. Soil

The soil of experimental site was sandy clay loam, belonging to the taxonomical order oxisols.

Soil samples for initial analysis were collected from the experimental field. Soil samples were drawn from surface 15 cm from ten different places of the field, pooled, reduced to required quantity and air dried. The air dried soil samples were ground and passed through 2 mm sieve and stored in air tight containers.

Table 1. Analytical methods followed in soil analysis

S. No.	Parameter	Method	Reference
1	Textural analysis	International pipette method	Robinson (1922)
2	Electrical conductivity	Conductivity meter	Jackson (1958)
3	pH	pH meter	Jackson (1958)
4	Organic carbon	Chromic acid wet digestion method	Walkley and Black (1934)
5	Available N	Alkaline permanganate method	Subbaiah and Asija(1956)
6	Available P	Bray extraction and photoelectric colorimetry	Jackson (1958)
7	Available K	Flame photometry	Pratt (1965)
8	Available Si	Photoelectric colorimetry	Korndorfer *et al.* (1999)

Table 2. Physico-chemical properties of the soil

S. No.	Parameter	Content (%)
I	Mechanical composition	
1	Sand (%)	51
2	Silt (%)	5.5
3	Clay (%)	43.5
4	Texture	Sandy Clay loam
II	**Chemical properties**	
1	Soil reaction (pH)	4.50 (Strongly acidic)
2	Electrical conductivity (dS m^{-1})	0.10 (Safe)
3	Organic carbon (%)	1.01 (High)
4	Available nitrogen (kg ha^{-1})	550.5 (Medium)
5	Available phosphorus (kg ha^{-1})	16.86 (Medium)
6	Available potassium (kg ha^{-1})	196.90 (Medium)
7	Available silicon (kg ha^{-1})	45.02 (low)

The samples were analyzed for pH, soil texture, electrical conductivity (EC), organic carbon, available nutrients such as N, P, K and Si, following standard procedures given in Table 1. The soil analysis data are presented in Table 2.

3.1.3. Cropping History of the Field

The area was under a bulk crop of fodder cowpea before the experiment.

3.1.4. Season

The experimental site experiences warm humid tropical climate. The experiment was conducted during the *Virippu* (*Kharif*) season from July to October, 2016. The data on various weather parameters, *viz.* weekly rainfall, maximum and minimum temperature and relative humidity during the period are presented in Appendix- I and graphically represented in Fig. 1

3.2 MATERIALS

3.2.1 Variety

Uma, a medium duration variety (120-135 days) with medium red bold grain released from Regional Agricultural Research Station (RARS), Moncompu, was used for the study. It is characterized by dwarf stature, medium tillering and resistance to lodging. It is also resistant to brown plant hopper and gall midge. This variety is suitable for cultivation during all the three seasons *viz. virippu, mundakan* and *puncha* in Kerala.

3.2.2 Source of Seed Material

The seeds for the study were obtained from Rice Research Station, Moncompu, Kerala.

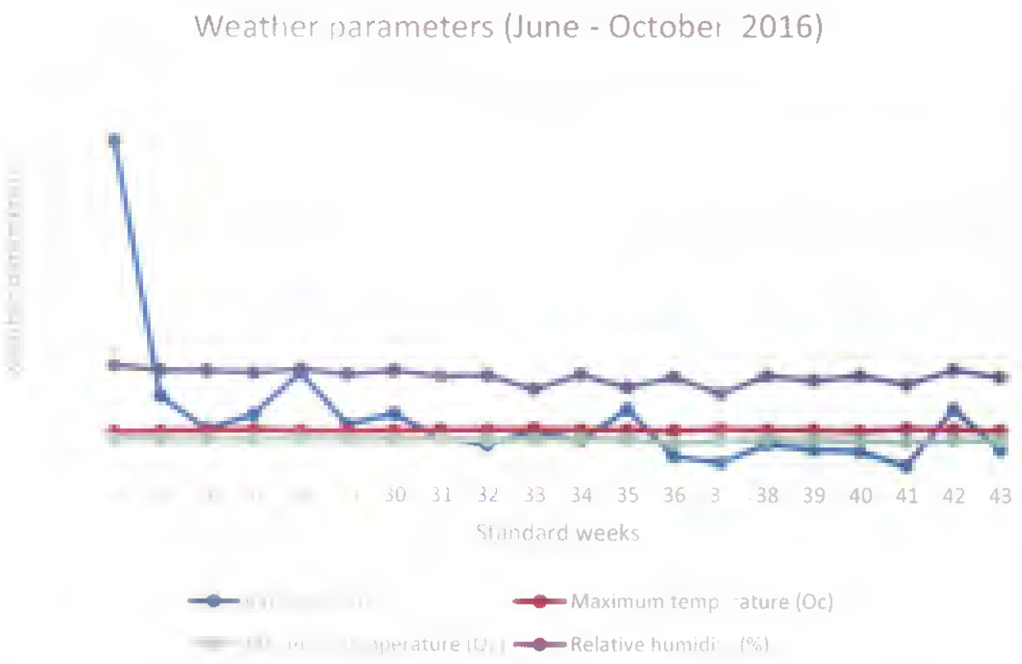

Fig. 1. Weather parameters during cropping period (June to October, 2016)

3.2.3. Manures and Fertilizers

Farmyard manure (0.5% N, 0.2% P, 0.5% K), purchased from the local source was used as organic nutrient source for the experiment. Urea (46% N), rajphos (20% P_2O_5) and muriate of potash (60% K_2O) were used as the inorganic sources of nitrogen (N), phosphorus (P) and potassium (K) respectively. Sources of silicon used were potassium silicate (45% Si), rock dust powder (35% Si), rice husk ash (60-85% Si), fine silica (99% Si).

3.3. METHODS

3.3.1. Design and Layout

Design: Randomized Block Design

Treatments- 7

Replications - 3

Plot size: 5 m x 4 m

Spacing: 20 cm x 15 cm

Variety: Uma

The layout of the field experiment is shown in Fig. 2.

3.3.2. Treatments

The treatments details are presented below:

T_1 - Fine silica @ 100 kg ha^{-1}

T_2 - Fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}

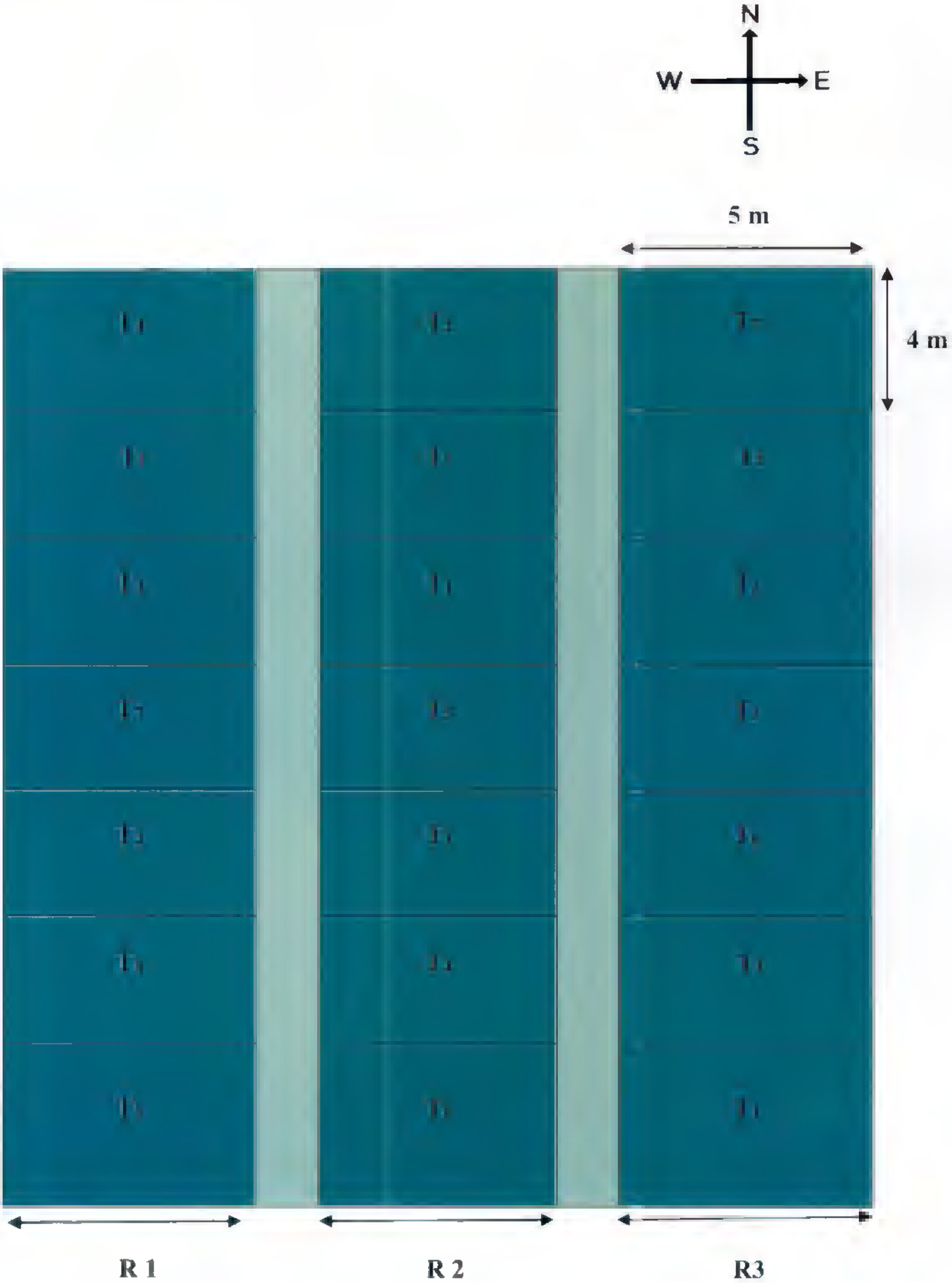

Fig. 2. Layout of the field experiment

T_3 - Fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%

T_4 - Fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%

T_5 - Fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}

T_6 - Fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}

T_7 - Fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5% .

Note:

All treatments were given a basal dose of lime @ 150 kg ha^{-1} and recommended dose of NPK @ 90:45:120 kg ha^{-1} as per the recommendation of KAU for iron toxic laterite soils. Recommended dose of FYM @ 5 t ha^{-1} was applied uniformly to all treatments.

Table. 3. Quantification of silicon in silicon sources as per treatments

TREATMENTS	Fine silica (kg)	Rice husk ash (kg)	Rock dust (kg)	Potassium Silicate (kg)	Total Si (kg)
T_1	100	-	-	-	100
T_2	75	-	8.75	-	83.75
T_3	75	-	-	1.08	76.08
T_4	50	-	8.75	1.08	59.83
T_5	75	75	-	-	150
T_6	50	150	-	-	200
T_7	50	75	-	1.08	126.08

3.3.3 Crop Husbandry Practices

3.3.3.1 Seeds and Sowing

Seeds were soaked for 12 hours and taken out and kept for germination. The seeds exhibited 100 per cent germination.

3.3.3.2 Main Field Preparation

The experimental area was ploughed well and the required quantity of lime was incorporated along with first ploughing and plots of 5 m x 4 m were prepared by constructing bunds of 30 cm width and 25 cm height. Irrigation and drainage channels were provided between plots in a row. In each plot FYM was incorporated at the time of final land preparation.

3.3.3.3 Transplanting

Seedlings of 25 days old were transplanted at 3-4 cm depth at a spacing of 20 cm x 15 cm. Water level was maintained at 1.5 cm during transplanting.

3.3.3.4 Fertilizer Application

Fertilizers were applied as per package of practices recommendations (POP) of KAU for iron toxic laterite soils. Full dose of P was applied as basal and N and K were applied in three equal split doses; as basal, at maximum tillering and panicle initiation (PI) stage. Silicon fertilizers *viz.*, fine silica, rice husk ash and rock dust were applied three weeks before transplanting and potassium silicate was sprayed at maximum tillering stage. The other cultural practices were followed as per POP of KAU (KAU, 2016).

3.3.3.5 After Cultivation

Manual weeding was done at 20 and 40 DAT. Water level was maintained to a height of 5 cm. Water was drained 15 days before harvest.

Plate 1. General view of the experimental plot before transplanting

Plate 2. General view – at harvest

3.3.3.6 Incidence of Pests and Diseases

No major pests and diseases were found to infest the crop beyond the economic threshold level demanding control measures, and hence scoring was not done.

3.3.3.7 Harvest

The crop was harvested when the straw just turned yellow. The net plot area was harvested separately, threshed, winnowed and weight of grain and straw from individual plots were recorded. The border rows were harvested separately.

3.4 BIOMETRIC OBSERVATIONS

Five plants or hills were selected randomly from the net plot area of each plot as observational plants and these plants were tagged for periodical observations on growth and yield parameters.

3.4.1 Plant Growth Parameters

3.4.1.1 Plant Height

Plant height was measured from the base of the stem to the tip of the youngest leaf using a meter scale and expressed in cm. Plant height was taken at maximum tillering, panicle initiation (PI) and at harvest stage from the observational plants in each treatment and average was worked out.

3.4.1.2 Number of Tillers

The number of tillers m^{-2} at maximum tillering, PI and at harvest stage were counted and average was worked out.

3.4.1.3 Dry Matter Production

Dry matter production was recorded at maximum tillering, PI and at harvest stage. The sample plants were dried in an oven at 70 ± 5° C till constant weight and the dry weight expressed as kg ha^{-1}.

3.4.2 Yield and Yield Attributes

3.4.2.1 Number of Productive Tillers

The number of productive tillers m^{-2} was recorded at harvest stage and average was worked out.

3.4.2.2 Panicle Weight

Weight of panicle was recorded at harvest stage from each treatments and average was worked out and expressed in g.

3.4.2.3 Number of Filled Grains per Panicle

The number of filled grains collected from five panicles from each plot were counted and the mean value was expressed as number of filled grains per panicle.

3.4.2.4 Sterility Percentage

Sterility percentage was worked out using the following relationship.

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains panicle}^{-1}}{\text{Total number of grains panicle}^{-1}} \times 100$$

3.4.2.5 Thousand Grain Weight

One thousand grains were counted from the produce of each plot randomly and their weight was recorded and expressed in g.

3.4.2.6 Grain and Straw Yield

The crop was harvested from the net plot area in each treatment, threshed, dried to 13% separately and grain and straw weight were recorded and the grain yield and straw yield were computed and expressed in t ha^{-1}.

3.4.2.7 Harvest Index

From grain and straw yield, the harvest index was worked out using the following equation

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.4.3 Analysis of Plant Samples

Plant samples were collected at harvest stage and analyzed for different nutrients *viz.*, N, P, K and Si by standard procedures given in Table 4.

3.4.3.1 Uptake of Nutrients

The total uptake of N, P, K and Si by the plant at harvest was calculated as the product of the respective nutrient content and plant dry weight and expressed as kg ha^{-1}

Table 4. Analytical methods followed for plant analysis

S. No.	Parameter	Method	Reference
1	Total N	Modified kjeldhal method	Jackson (1958)
2	Total P	Vanadomolybdate yellow colour method	Piper (1966)
3	Total K	Flame photometry	Jackson (1958)
4	Total Si	Blue silicomolybdous acid method	Ma *et al.* (2002)

3.4.3.2 Determination of Silicon in Plant Sample

3.4.3.2.1 Plant Sample Digestion

Grain and plant samples were separately powdered and dried in an oven at 70 ± 5^{0}C for two days prior to analysis. The sample (0.5 g) was digested in a mixture of 3 ml each of HNO_3 (62%) and H_2O_2 (30%) and 2 ml of HF (46%) using microwave digester (milestone MLS 1200) with following steps. Digestion at 250 watts for five minutes, 500 watts five minutes and venting for five minutes. The digested samples were then diluted to 50 ml with 4% boric acid (Ma *et al.*, 2003).

3.4.3.2.2 Estimation of Silicon in Digested Plant Samples

Silicon concentration in the digested solution was determined as described below:

Digested 0.5 ml aliquot was transferred to plastic centrifuge tube. To this 3.75 ml of 0.2 N HCl, 0.5 ml of 10 % ammonium molybdate solution, 0.5 ml of 20 % tartaric acid solution and 0.5 ml reducing agent ANSA (Amino Naphthol Sulphonic Acid) were added and the volume was made up to 12.5 ml with distilled water. After 1 hour the absorbance was measured at 600 nm using UV visible spectrometer. Simultaneously silicon standards (0, 0.2, 0.4, 0.8 and 1.2

ppm) were prepared in the same matrix and measured using UV visible spectrometer.

3.5 SOIL ANALYSIS

Soil samples from each plot was collected from surface 15 cm in plastic bags, excess water was drained, air dried, ground, sieved with 2 mm sieve and stored in air tight container in laboratory for analysis. For soil pH estimation, samples were collected at 15 days interval from transplanting up to harvest. Soil samples collected at harvest stage were analyzed for soil texture, organic carbon, pH, EC and available nutrients such as N, P, K and Si by standard procedures shown in Table 1.

3.5.1 Determination of Silicon in Soil Sample

3.5.1.1 Extraction of Silicon in Soils

Five g soil was weighed in plastic centrifuge tube and 12.5 ml of 0.5 M acetic acid (1:2.5 ratio) was added. After shaking continuously for a period of one hour, it was centrifuged at 3000 rpm for 3 minutes and then filtered. Silicon in the extract was determined by adopting the procedure of Korndorfer *et al.* (2001).

3.5.1.2 Estimation of Silicon in Soils

Silicon in the extract was analysed by transferring 0.25 ml of filtrate into plastic centrifuge tube followed by the addition of 10.5 ml of distilled water, 0.25 ml of 1:1 HCl and 0.5 ml of 10 % ammonium molybdate solution (pH 7-8). After five minutes 0.5 ml of 20 % tartaric acid solution was added, and after another two minutes 0.5 ml reducing agent ANSA was added and the colour was developed. Absorbance was measured at 630 nm using UV visible spectrometer after five minutes.

Silicon standards (0.2, 0.4, 0.8 and 1.2 mgL^{-1}) were prepared, colour was developed and measured using UV visible spectrometer (Korndorfer *et al.*, 2001).

3.6. ECONOMIC ANALYSIS

The economics of cultivation was worked out based on the cost of various inputs and produce at the time of experimentation.

3.6.1 Net income

Net income was computed using the formula

Net income (₹ ha^{-1}) = Gross income (₹ ha^{-1}) – Cost of cultivation (₹ ha^{-1})

3.6.2 Benefit Cost Ratio (BCR)

Benefit Cost Ratio was computed using the formula

$$BCR = \frac{\text{Gross income (₹ } ha^{-1}\text{)}}{\text{Cost of cultivation (₹ } ha^{-1}\text{)}}$$

3.7. STATISTICAL ANALYSIS

The data obtained from field investigation was subjected to statistical analysis using analysis of variance (ANOVA) as applied to Randomized Block Design (Panse and Sukhatme, 1985). After statistical analysis CD values were worked out and data was interpreted.

RESULTS

4. RESULTS

The study entitled "Silicon nutrition for rice in iron toxic laterite soils of Kollam district" was carried out at College of Agriculture, Vellayani to assess the possibility of partially substituting fine silica with alternate silicon sources and to find out the effect of these sources on growth and productivity of rice for formulating a cost effective nutrient package for rice in iron toxic laterite soils. The field investigation was carried out in farmer's field at Vilakkudy Panchayath, in Kollam district and chemical analysis was conducted at Department of Agronomy, College of Agriculture, Vellayani. The results of the experiment are presented in this chapter.

4.1 GROWTH AND GROWTH ATTRIBUTES

4.1.1 Plant Height

The data with respect to plant height at maximum tillering, panicle initiation (PI) and at harvest are shown in Table 5.

Application of silicon has not shown any significant influence on plant height at maximum tillering stage.

However, silicon application has shown significant effect on plant height at PI stage. The application of fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} (T_6) resulted in the highest plant height of 76.78 cm, which was on a par with T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%), T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}), T_3 (fine silica @ 75 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%), T_1 (fine silica @ 100 kg ha^{-1}) and T_2 (fine silica @ 75 kg ha^{-1} + rock dust @ 25 kg ha^{-1}) with plant height of 76.70, 76.68, 75.50, 75.47 and 75.36 cm, respectively.

At harvest stage also silicon application significantly influenced plant height. The treatment T_6 resulted in maximum plant height of 113.90 cm and it was on a par with T_7(112.75 cm), T_5 (112.60 cm), T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) (111.23 cm) and T_1 (110.99 cm).

4.1.2 Number of tillers m^{-2}

The results of the statistical analysis of the data on number of tiller m^{-2} are given in Table 6.

At maximum tillering stage, number of tillers m^{-2} varied significant due to silicon nutrition. The treatment T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) produced maximum number of tillers m^{-2} (285), which was on a par with T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%), T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) and T_1 (fine silica @ 100 kg ha^{-1}) with the average tiller number of 281, 275 and 273 m^{-2} and these treatments were superior to all the other treatments. The lowest number of tillers m^{-2} of 252 was in T_2 (fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}), which was on a par with T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) and T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%).

At PI stage also, number of tillers m^{-2} was significantly influenced by silicon nutrition. The treatment T_6 had maximum number of tillers m^{-2} (657), which was on a par with T_7 (654), T_5 (651) and T_4 (609) and significantly higher than all other treatments.

Number of tillers m^{-2} were significant at harvest stage also. The treatment T_6 produced maximum number of tillers m^{-2} (488), which was on a par with T_7 (484), T_5 (479) and T_4 (473) and significantly higher than all other treatments.

4.1.3 Dry Matter Production (kg ha^{-1})

The results of the statistical analysis of the data on dry matter production (DMP) at various growth stages are furnished in Table 7.

The DMP at maximum tillering stage was not significantly influenced by silicon nutrition. However, at PI stage DMP varied significantly due to silicon nutrition. The highest DMP of 10340 kg ha^{-1} was recorded in T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%),which was on a par with T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) and T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) with DMP of 10120 and 9295 respectively and these treatments were significantly superior to the remaining treatments. Effect of silicon nutrition on DMP was significant at harvest stage also. The treatment T_6 resulted in the highest DMP of 11376 kg ha^{-1} and it was significantly superior to all other treatments.

Table 5. Effect of silicon nutrition on plant height at maximum tillering, panicle initiation and harvest stage

Treatments	Plant height (cm)		
	Maximum tillering	Panicle initiation	Harvest
T_1	45.30	75.47	110.99
T_2	44.70	75.36	110.73
T_3	45.12	75.50	108.13
T_4	45.88	74.50	111.23
T_5	44.68	76.68	112.60
T_6	46.94	76.78	113.90
T_7	46.00	76.70	112.75
S E m±	1.920	0.842	1.349
CD (0.05)	NS	1.836	2.940

Table 6. Effect of silicon nutrition on number of tillers at maximum tillering, panicle initiation and harvest stage

Treatments	Number of tillers m^{-2}		
	Maximum tillering	Panicle initiation	Harvest
T_1	273	594	464
T_2	252	569	439
T_3	263	589	461
T_4	265	609	473
T_5	275	651	479
T_6	285	657	488
T_7	281	654	484
S E m±	8.5	24.8	7.97
CD (0.05)	18.638	54.104	17.372

Table 7. Effect of silicon nutrition on dry matter production at maximum tillering, panicle initiation and harvest stage

Treatments	Dry matter production (kg ha^{-1})		
	Maximum tillering	Panicle initiation	Harvest
T_1	1115	8602	9643
T_2	935	8569	9611
T_3	1155	9295	9974
T_4	3520	9020	9546
T_5	1100	8745	10250
T_6	880	10120	11376
T_7	1155	10340	10270
S E m±	1280.6	516.4	471.1
CD (0.05)	NS	1125.328	1026.738

4.2 YIELD AND YIELD ATTRIBUTES

4.2.1 Productive Tillers m^{-2}

The results of the statistical analysis of the data with respect to number of productive tillers m^{-2} are given in Table 8. The highest number of productive tiller m^{-2} of 467 was recorded in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250kg ha^{-1}), which was on a par with T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) and T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) with 460 and 450 productive tillers m^{-2}, respectively. The treatment T_2, *i.e,* fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1} produced the lowest number of 411 tillers m^{-2}, which was on par with T_3, *i.e,* fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%.

4.2.2 Weight of Panicle (g)

The average panicle weight was recorded and the results of the statistical analysis of the data are presented in Table 8. The treatment T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) produced the highest panicle weight of 3.43 g and it was on a par with T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%), T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) and T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) with an average weight of 3.41, 3.30 and 3.23 g respectively.

4.2.3 Filled Grains Panicle^{-1}

The data on number of filled grains panicle^{-1} are furnished in Table 8. The highest number of filled grains panicle^{-1} of 128.92 was obtained in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}), which was on a par with T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) and T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) with 123.12 and 119.60 filled grains panicle^{-1} respectively.

4.2.4 Sterility Percentage

The data on sterility percentage are given in Table 8. Effect of silicon nutrition on sterility percentage was significant. The lowest sterility percentage of 12.33 was observed in treatment T_6 *i.e*, fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} and it was on a par with T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) and T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) with sterility percentages of 12.68 and 12.77, respectively. The highest sterility percentage of 13.85 was observed in T_2 (fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}), which was on a par with T_1 (fine silica @ 100 kg ha^{-1}), T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%), T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) which recorded sterility percentages of 13.73, 13.53 and 13.26 respectively.

4.2.5 Thousand Grain Weight (g)

The data on thousand grain weight are presented in Table 8. Significantly highest thousand grain weight of 24.36 g was obtained in the treatment T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1})

4.2.6 Grain and Straw Yield (t ha^{-1})

The data on grain yield and straw yield are furnished in Table 9. Grain yield was significantly influenced by the treatments and it ranged from 5.58 t ha^{-1} to 6.14 t ha^{-1}. The highest grain yield of 6.14 t ha^{-1} was obtained in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) and it was significantly superior to all other treatments. The lowest grain yield of 5.58 t ha^{-1} was observed in T_2 *i.e*, fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}.

The highest straw yield of 8.77 t ha^{-1} was recorded in T_6 and T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) and these treatments were on a par with T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}), T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%), T_1 (fine silica @ 100 kg ha^{-1}) with a straw yield of 8.75, 8.75 and 8.73 t ha^{-1} respectively. The lowest straw yield (8.57 t ha^{-1}) was recorded in T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%), which was on a par with T_2 (fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}).

4.2.7 Harvest Index

The results of the statistical analysis of the data on harvest index are furnished in Table 9. There was a significance influence of treatments on harvest index. The highest harvest index of 0.41 was observed in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) and it was on a par with T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) and these treatments were significantly superior to all other treatments. The lowest harvest index of 0.38 was observed in treatment T_2 (fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}).

Table 8. Effect of silicon nutrition on productive tillers, panicle weight, thousand grain weight, filled grains per panicle and sterility percentage

Treatments	Productive tillers m^{-2}	Panicle weight (g panicle^{-1})	Number of filled grains pancicle^{-1}	Sterility percentage	Thousand grain weight (g)
T_1	440	3.03	117.89	13.73	23.15
T_2	411	3.01	115.32	13.85	23.01
T_3	435	2.99	112.22	13.26	23.16
T_4	438	3.23	118.69	13.53	23.07
T_5	450	3.30	119.60	12.77	23.18
T_6	467	3.43	128.92	12.33	24.36
T_7	460	3.41	123.12	12.68	23.29
S E m±	11.8	0.152	4.360	0.298	0.349
CD (0.05)	25.848	0.337	9.502	0.651	0.762

Table 9. Effect of silicon nutrition on grain yield, straw yield and harvest index

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index
T_1	5.73	8.73	0.39
T_2	5.58	8.57	0.38
T_3	5.73	8.75	0.39
T_4	5.72	8.57	0.39
T_5	5.78	8.75	0.39
T_6	6.14	8.77	0.41
T_7	5.99	8.77	0.40
S E m±	0.057	0.063	0.000
CD (0.05)	0.128	0.143	0.010

4.3 MECHANICAL COMPOSITION OF SOIL

The data on mechanical composition of soil are given in Table 10. There was no significant variation among treatments regarding mechanical composition of the soil, after the experiment.

4.4 SOIL ANALYSIS AFTER THE EXPERIMENT

4.4.1 Soil Reaction (pH)

The data on the soil reaction (pH) are presented in Table 11. Soil pH after the harvest of the crop increased compared to the initial status (4.50). However the soil pH at fortnightly intervals was not influenced significantly, except at 3rd fortnight and at harvest.

At 3rd fortnight, the highest soil pH of 5.84 was recorded by T_6 *i.e*, fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} and it was significantly superior to all other treatments. The lowest soil pH value of 5.35 was observed in T_2 *i.e,* fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}, which was on a par with T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) and T_1 (fine silica @ 100 kg ha^{-1}). After the harvest, the highest soil pH was recorded in T_7 (5.71) and it was on a par with T_6 (5.68), T_1 (5.67), T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) (5.66) and T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) (5.66). The lowest soil reaction value of 5.59 was observed in T_2, which was on a par with T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%).

4.4.2 Organic Carbon (OC)

The data on organic carbon (OC) content of soil are presented in Table 12.

The soil OC was found to vary significantly by silicon nutrition. The highest soil OC of 1.39 was recorded in the treatment T_6 *i.e,* fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} and it was on a par with T$_5$ (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) and T$_7$ (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) and significantly higher than all other treatments. The lowest value of 1.14 was observed in T$_4$ *i.e.* (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%), and it was on a par with T$_1$ (fine silica @ 100 kg ha^{-1}), T$_2$ (fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}) and T$_3$ (fine silica @ 75 kg ha^{-1}+ foliar application of foliar application at maximum tillering stage @ 0.5%).

4.4.3 Electrical Conductivity

The data on electrical conductivity (EC) of soil after the harvest are given in Table 12.

The effect of silicon application on EC of soil after the harvest was not significant.

4.4.4 Available Nitrogen

The data on available Nitrogen (N) content in soil are presented in Table 12. The available N content in the soil was not significantly influenced by the treatments.

4.4.5 Available Phosphorus

The analytical data on available phosphorus (P) content in soil is presented in Table 12. Application of fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} (T$_6$) resulted in the highest available P content in soil (36.37 kg ha^{-1}), which was on a par with T$_5$ (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}), T$_7$ (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) with the available P content of 34.72 and 33.96 kg ha^{-1} respectively and these treatments were significantly superior to all other treatments. The lowest available P status of 31.87 kg ha^{-1} was observed in T_2 (fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}), which was on a par with T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) with a soil P status of (29.54 kg ha^{-1}).

4.4.6 Available Potassium

The data with respect to available potassium (K) in soil are presented in Table 12. The highest available K content in soil of 206.25 kg ha^{-1} was obtained in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}), which was on a par with T_7 *i.e,* fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%, T_1 (fine silica @ 100 kg ha^{-1}), T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) and T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) with available K content of 204.89, 199.10, 196.06 and 187.84 kg ha^{-1} respectively.

4.4.7 Available Silicon

The data with respect to available silicon (Si) in soil are furnished in Table 12. The highest available Si content of 83.61 kg ha^{-1} was recorded in treatment T_6 *i.e,* fine silica @ 50 kg ha-1 + rice husk ash @ 250 kg ha^{-1}, which was on a par with T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) with the available Si content of 80.76 kg ha^{-1} and significantly higher than all other treatments. The treatment T_4 *i.e,* fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5% had the lowest value of 74.06 kg ha^{-1}, which was on a par with T_1 (fine silica @ 100 kg ha^{-1}), T_2 (fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}) and T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) with available Si content of 75.40, 74.92 and 74.17 kg ha^{-1} respectively.

Table 10. Effect of silicon nutrition on mechanical composition of soil

Treatments	Sand (%)	Silt (%)	Clay (%)	Soil texture
T_1	51.50	5.70	43.20	Sandy clay loam
T_2	53.93	5.16	41.13	“
T_3	52.83	5.33	41.83	“
T_4	52.33	5.33	42.33	“
T_5	52.96	5.36	41.66	“
T_6	53.83	5.06	41.10	“
T_7	52.70	5.63	41.66	“
S E m±	0.876	0.346	0.687	-
CD (0.05)	NS	NS	NS	NS

Table 11. Effect of silicon nutrition on soil reaction (pH) at fortnightly intervals

Treatments	Soil reaction (pH)							
	1st FT*	2nd FT*	3rd FT*	4th FT*	5th FT*	6th FT*	7th FT*	Harvest
T_1	6.58	6.50	5.55	5.70	5.43	5.41	5.47	5.67
T_2	6.58	6.44	5.35	5.53	5.35	5.31	5.30	5.59
T_3	6.63	6.25	5.63	5.66	5.39	5.39	5.56	5.66
T_4	6.55	6.55	5.62	5.62	5.36	5.34	5.74	5.62
T_5	6.55	6.39	5.57	5.65	5.32	5.37	5.49	5.66
T_6	6.53	6.42	5.84	5.85	5.30	5.37	5.68	5.68
T_7	6.60	6.57	5.45	5.80	5.41	5.34	5.78	5.71
S E m±	0.044	0.150	0.089	0.109	0.044	0.063	0.141	0.025
CD (0.05)	NS	NS	0.195	NS	NS	NS	NS	0.066

*Fortnight

Table 12. Effect of silicon nutrition on OC, EC and available nutrients (N, P, K and Si) in soil

Treatments	OC (%)	EC (dS m^{-1})	Available nutrients (kg ha^{-1})			
			N	P	K	Si
T_1	1.18	0.14	356.10	32.58	199.10	75.40
T_2	1.18	0.14	323.33	31.87	183.40	74.92
T_3	1.17	0.16	363.43	29.54	177.87	74.17
T_4	1.14	0.13	315.53	27.49	187.84	74.06
T_5	1.32	0.16	370.99	34.72	196.06	80.76
T_6	1.39	0.14	377.73	36.37	206.25	83.61
T_7	1.31	0.14	366.68	33.96	204.89	79.33
S E m±	0.051	0.000	19.971	1.567	8.675	1.547
CD (0.05)	0.113	NS	NS	3.415	18.904	3.372

4.5 PLANT ANALYSIS

4.5.1 Nutrient Uptake

4.5.1.1 Nitrogen

The data with respect to N content in grain, straw and total N uptake are presented in Table 13. The N content in grain and straw were not significantly influenced by silicon nutrition, however, the total N uptake by the plant, varied significantly.

The total N uptake of 189.74 kg ha^{-1} was recorded in T_6 *i.e,* fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}, which was on a par with T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) with a total N uptake of 181.36 kg ha^{-1}. The lowest uptake value of 164.49 kg ha^{-1} was observed in T_2 *i.e,* fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}, which was on a par with T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) (169.3 kg ha^{-1}), T_1 (fine silica @ 100 kg ha^{-1}) and T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) with the total N uptake of 169.3, 166.73 and 166.02 kg ha^{-1} respectively.

4.5.1.2 Phosphorus

The data with respect to phosphorus (P) content in grain, straw and total P uptake are presented in Table 14. The phosphorus (P) content in grain, straw and total P uptake were significantly influenced by the treatments. The highest grain P content of 0.18 % was observed in T_6 *i.e,* fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} which was significantly superior to all other treatments. The lowest grain P content of 0.14 % was observed in T_2 *i.e,* fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1} and it was on a par with T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) with a P content of 0.14%. The highest straw P content of 0.07 % was observed in T_6 *i.e,* fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} and it was on a par with T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) with a P content of 0.06 % and these treatments were significantly superior to all other treatments. The lowest straw P content of 0.03% was observed in T_2 *i.e,* fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1} and it was on a par with T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) with a P content of 0.04%. The total uptake of P was highest in T_6 (17.19 kg ha^{-1}) and it was significantly superior to all other treatments.

4.5.1.3 Potassium

The data on potassium (K) content in grain, straw and total K uptake are presented in Table 15. The K content of grain was found to be the highest in T_7 (0.86%), which was significantly superior to all the other treatments. The treatment T_2 had recorded the lowest value (0.36%) and was on a par with T_1 (0.4 %), T_3 (0.39 %) and T_4 (0.37 %)

The K content in straw was found to be the highest in T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) *i.e*, 1.09 % which was on par with T_6 *i.e,* fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} with a K content of 1.06 % and these two treatments were significantly superior to all other treatments. The lowest K content (0.93 %) in straw was observed in T_2 (fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}), which was on a par with T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) (0.97 %), T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}), T_1 (fine silica @ 100 kg ha^{-1}), and T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%).

The total K uptake ranged from 99.82 kg ha^{-1} in T_2 to 147.07 kg ha^{-1} in T_7. The treatment T_7 was significantly superior to all the other treatments.

4.5.1.4 Silicon

The data on silicon (Si) content in grain, straw and total Si uptake are presented in Table 16. The highest grain Si content of 0.96 % was obtained due to the application of fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5% (T_7) and it was on a par with T_6 *i.e*, fine silica @ 50 kg ha^{-1} + 250 kg ha^{-1} with a grain Si content of 0.92 %. The lowest grain Si content of 0.59 % was observed in T_4 *i.e*, fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%, which was on a par with T_2 (fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}) and T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%). The treatment T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) recorded the highest straw Si content of 3.37%, which was on a par with T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ rice husk ash @ 250 kg ha^{-1}) with a Si content of 3.29% and these two treatments were significantly superior to the remaining treatments. The least straw Si content of 2.8% was noticed in T_2 i.e, fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-}1, which was on a par with T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%).

Similar trend was also observed in the case of total Si uptake by plant also, wherein T_7 had the highest Si uptake of 352.93 kg ha^{-1} and it was significantly superior to all other treatments.

4.6 INCIDENCE OF PESTS AND DISEASES

No major pests and diseases were found to infest the crop beyond the economic threshold level demanding control measures, and hence scoring was not done.

Table. 13. Effect of silicon nutrition on the nitrogen content in grain, straw and total N uptake by plant

Treatments	N content (%)		Total N uptake (kg ha^{-1})
	Grain	Straw	
T_1	1.46	0.97	166.73
T_2	1.45	1.01	164.49
T_3	1.45	0.95	166.02
T_4	1.42	1.03	169.30
T_5	1.51	0.97	175.25
T_6	1.55	1.04	189.74
T_7	1.56	0.99	181.36
S E m±	0.096	0.051	4.582
CD (0.05)	NS	NS	9.985

Table. 14. Effect of silicon nutrition on the phosphorous content in grain, straw and total P uptake by plant

Treatments	P content (%)		Total P uptake (kg ha^{-1})
	Grain	Straw	
T_1	0.15	0.04	12.08
T_2	0.14	0.03	10.39
T_3	0.14	0.04	11.52
T_4	0.15	0.05	12.86
T_5	0.16	0.06	14.49
T_6	0.18	0.07	17.19
T_7	0.17	0.06	15.44
S E m±	0.000	0.000	0.112
CD (0.05)	0.005	0.009	0.243

Table. 15. Effect of silicon nutrition on the potassium content in grain, straw and total K uptake by plant

Treatments	K content (%)		Total K uptake (kg ha^{-1})
	Grain	Straw	
T_1	0.40	0.95	105.81
T_2	0.36	0.93	99.82
T_3	0.39	0.97	107.25
T_4	0.37	0.95	104.84
T_5	0.50	0.96	113.10
T_6	0.56	1.06	127.38
T_7	0.86	1.09	147.07
S E m±	0.115	0.036	1.414
CD (0.05)	0.059	0.082	3.082

Table. 16. Effect of silicon nutrition on the silicon content in grain, straw and total Si uptake by plant

Treatments	Si content (%)		Total Si uptake (kg ha^{-1})
	Grain	Straw	
T_1	0.76	3.20	322.78
T_2	0.61	2.8	273.89
T_3	0.68	3.11	311.19
T_4	0.59	2.9	282.27
T_5	0.85	3.21	330.11
T_6	0.92	3.29	345.14
T_7	0.96	3.37	352.93
S E m±	0.051	0.057	2.192
CD (0.05)	0.108	0.125	4.778

4.7 ECONOMIC ANALYSIS

The data on gross income, net income and benefit cost ratio (B:C ratio) are presented in Table 17.

4.7.1 Gross Income

The silicon application had significant effect on gross income. Significantly higher gross income (₹ 164470 ha^{-1}) was obtained in T_6 *i.e,* fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}. This was followed by T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}), where gross income of ₹ 161075 ha^{-1} was obtained. The lowest gross income (₹ 151270 ha^{-1}) was obtained in T_2 (fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}), which was on a par with T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) with a gross income of ₹ 154335 ha^{-1}.

4.7.2 Net Income

The silicon application significantly influenced net income also. Significantly higher net income (₹ 72503 ha^{-1}) was recorded in T_6 (fine silica @ 50 kg ha^{-1}+ rice husk ash @ 250 kg ha^{-1}), compared to all the other treatments. The lowest net income (₹ 56837 ha^{-1}) was recorded in T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%), which was on a par with T_3 (fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) and T_2 (fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}) with a net income of ₹ 57574 ha^{-1} and ₹ 59315 ha^{-1} respectively.

4.7.3 Benefit Cost Ratio

Benefit cost ratio (B:C ratio) also showed significant difference among the treatments. The highest B:C ratio (1.78) was recorded due to the application of fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} (T_6) which was significantly higher than all the other treatments. The lowest B:C ratio of 1.54 was recorded in T_3 *i.e,* fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%, which was on a par with T_4 (fine silica @ 50 kg ha^{-1} + rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%) with a B:C ratio of 1.58.

Table 17. Effect of silicon nutrition on gross income, net income and B:C ratio

Treatments	Gross income (₹ ha^{-1})	Net income (₹ ha^{-1})	B:C ratio
T_1	155030	62963	1.68
T_2	151270	59315	1.64
T_3	155185	57574	1.54
T_4	154335	56837	1.58
T_5	156235	64218	1.69
T_6	164470	72503	1.78
T_7	161075	63514	1.65
S E m±	1420.2	1420.2	0.000
CD (0.05)	3094.713	3094.713	0.033

DISCUSSION

5. DISCUSSION

The results generated from the study "Silicon nutrition for rice in iron toxic laterite soils of Kollam district" are discussed hereunder.

5.1. EFFECT OF SILICON ON GROWTH ATTRIBUTES

Effect of silicon nutrition on plant height was found significant at panicle initiation (PI) stage and at harvest. At both these stages, plant height was found to be the highest in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}), which might be due to gradual and steady supply of sufficient quantity of silicon from the two silicon sources *viz.* rice husk ash and fine silica. However this treatment was statistically on a par with all the other treatments, except T_2, in which fine silica @ 75 kg ha^{-1} and rock dust @ 25 kg ha^{-1} were applied. Similar results have been reported by Gholami and Falah (2013), Sunilkumar (2000), Bhaskaran (2014) and Ahmad *et al.* (2013) in rice.

There was significant increase in the number of tillers m^{-2} with silicon application in rice at all growth stages. At tillering stage application, treatments receiving a combination of different sources of silicon *viz.* T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%), T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) and T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) were found to be as effective as silicon supplied as single source as fine silica (T_1) in increasing tiller number. However as the crop reached PI and harvest stage, only the treatments wherein different sources of silicon were combined {T_6, T_7, T_5 and T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%)} were found to be effective in enhancing tiller number. The higher number of tillers at later stages of crop growth might be due to the higher silicon availability to plants through the various sources of silicon. This is in confirmative with the findings of Savant *et al.* (1997a) and Singh and Singh (2005). Silicon fertilization increased the number of tillers, when applied at transplanting stage (IRRI, 1965; Burbey *et al.,* 1988). Pawar and Hegde (1978) also observed that foliar spray of 100-400 ppm silicon applied twice per week to rice up to the booting stage increased tillering, vegetative growth and photosynthetic efficiency.

Significant impact of silicon nutrition on dry matter production (DMP) in rice was observed in the present study, except at maximum tillering stage. The highest DMP was noticed in T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) at PI stage and T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) at harvest stage. The increased DMP in these treatments could be attributed to the higher silicon uptake by the rice plants. According to Savant *et al.* (1994), application of rice hull ash (0.5-2.0 kg m^{-2}) resulted in healthy and strong rice seedlings with increased biomass. In the present study also the treatments receiving rice husk ash (T_6 and T_7) showed significant effect on DMP endorsing the above result.

The favorable effect of silicon nutrition on growth attributes of rice *viz*. plant height, number of tillers and DMP could be due to the fact that silicon nutrition maintained the rice leaves in an erect position, which helps to capture more sunlight that leads to enhanced photosynthetic efficiency (10% increase) as reported by Yoshida *et al.* (1969). This was supported by the observations of Gong *et al*. (2003) who stated that there was an increased plant height, leaf area and DMP of wheat even in drought conditions with silicon application. Vaculik *et al*. (2009) reported that the silicon application had positive effects on most of the observed growth parameters in cereal crops. Application of 100 mg Si kg^{-1} soil increased the plant height, DMP and leaf area ratio (Rani *et al.,* 1997). The improvement in growth parameters in rice by silicon application was reported earlier by Padmaja and Verghese (1966), Sunilkumar (2000), Gong *et al.* (2003), Batty and Younger *et al.* (2003), Li *et al.* (2009), Murali *et al.* (2007), Ahmad *et al.* (2013) and Bhaskaran (2014) also. Si is not yet proven to be an essential element, its significant role in improving the growth of rice is evident from the results.

5.2 EFFECT OF SILICON ON YIELD ATTRIBUTES AND YIELD

The results indicated that higher number of productive tillers m^{-2} was noticed in those treatments, where rice husk ash was included as one of the silicon source. The treatment produced higher number of productive tillers (14.16) and it was on a par with T_7 (13.96), and T_5 (13.66). The increase in the number of productive tillers might be attributed to the higher silicon uptake and dry matter production in rice in these treatments. Other yield parameters like number of filled grains $panicle^{-1}$ and sterility percentage also followed a similar trend as that of number of productive tillers m^{-2}. However, with respect to thousand grain weight, the treatment T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) was found to be significantly superior to all other treatments, which might be due to the highest quantity of silicon (200 kg) applied in this treatment. The better expression of yield attributes could be due to adequate silicon availability, which increased the number of panicles, the number of grains $panicle^{-1}$.

Silicon has a positive effect on the number of spikelets on secondary branches of panicles and the ripening of grains (Seo and Ota, 1983). After transplanting, silicon application increased the number of panicles (IRRI, 1965). According to Prakash (2002) application of rice husk ash @ 2 to 4 t ha^{-1} increased rice yields to an extent of 15-20 per cent. In the present study also, the treatments receiving rice husk ash *i.e,* T_5, T_6 and T_7 exhibited significantly higher yield attributes. The favorable effect of silicon nutrition on yield attributes of rice were reported earlier (Sunikumar, 2000; Gholami and Falah, 2013; Ahmad *et al.,* 2013 and Bhaskaran, 2014).

The highest grain yield of 6.14 t ha^{-1} was recorded in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) and it was significantly superior to all the

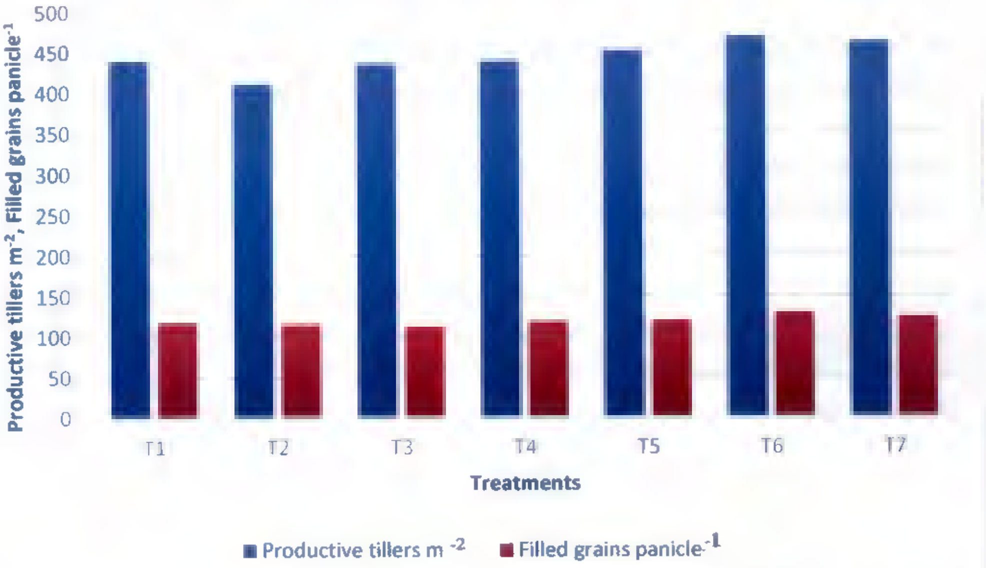

Fig. 3. Effect of silicon nutrition on number of productive tillers m^{-2} and filled grains $panicle^{-1}$

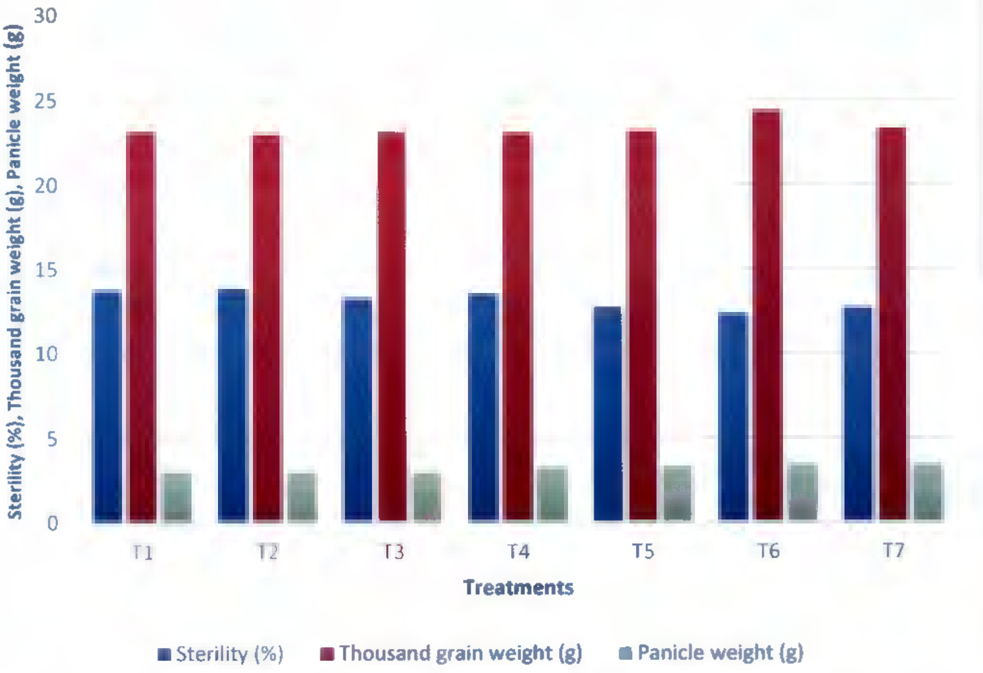

Fig. 4. Effect of silicon nutrition on sterility (%), thousand grain weight (g) and panicle weight (g)

other treatments. The better realization of grain yield in this treatment could be due to the fact that maximum quantity of silicon (200 kg ha^{-1}) was applied in this treatment compared to 100 kg in T_1, 83.75 kg in T_2, 76.08 kg in T_3, 59.83 in T_4, 150 in T_5 and 126.08 in T_7. The higher quantity of silicon supplied in T_6 enhanced the yield attributes like number of productive tillers m^{-2}, thousand grain weight, number of filled grains panicle^{-1} and reduced sterility percentage which inturn resulted in higher yield in T_6. Sunilkumar (2000) reported that translocation of photosynthates from straw to ear head, increased the thousand grain weight and yield by the application of silicon. Moreover the application of silicon might have improved light receiving posture of rice plants, thereby enhancing photosynthetic rate and yield.

The favorable effect of silicon nutrition on the grain yield of rice in the iron toxic laterite soils of the experimental field, could be due to the increase in the oxidizing power of the roots by silicon which converts ferrous ion into ferric ion thereby preventing large scale uptake of Fe reducing its toxicity, as reported by Ma and Takahashi (2002) and Yuan and Chang (1978). Ahmad *et al.* (2013) reported that foliar application of 1% silicon solution produced the highest paddy yield (4.88 t ha^{-1}). However the three rates of applications (0.25, 0.5 and 1%) were statistically similar and differed from control. Corroboratory results on the favourable effect of silicon nutrition on grain yield of rice were reported by IRRI (1964), Padmaja and Verghese (1966), Lian (1976), Synder *et al.* (1986), Sunilkumar (2000), Murali *et al.* (2007) and Bhaskaran (2014).

Japanese and Korean rice farmers are able to sustain high yields in the range of 6 to 9 t ha^{-1} probably because their nutrient management systems include a practice of silicate slag application @ 1.5 to 2.0 t ha^{-1} especially for degraded lowland paddy soils (IRRI, 1993). Silicon applied basally @ 47 kg ha^{-1} as calcium magnesium silicate significantly increased grain yield by more than 500 kg ha^{-1} in the Maahas clay, which was believed to have sufficient silicon (IRRI, 1964). Silicate slag application at the rate of 1.5 to 2.0 t ha^{-1} is now mostly used in degraded paddy fields and peaty paddy fields in Japan (Kono, 1969). Synder *et al.*

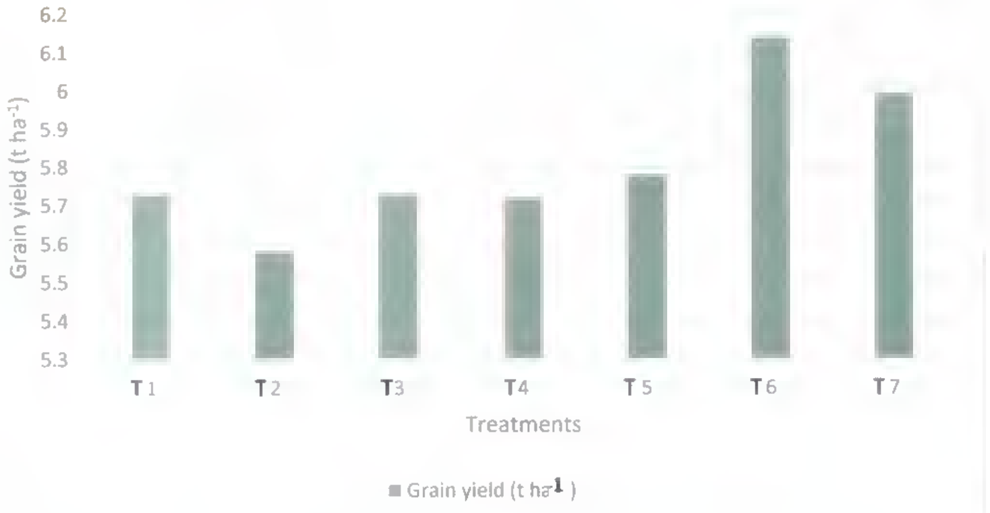

Fig. 5. Effect of silicon nutrition on grain yield (t ha^{-1})

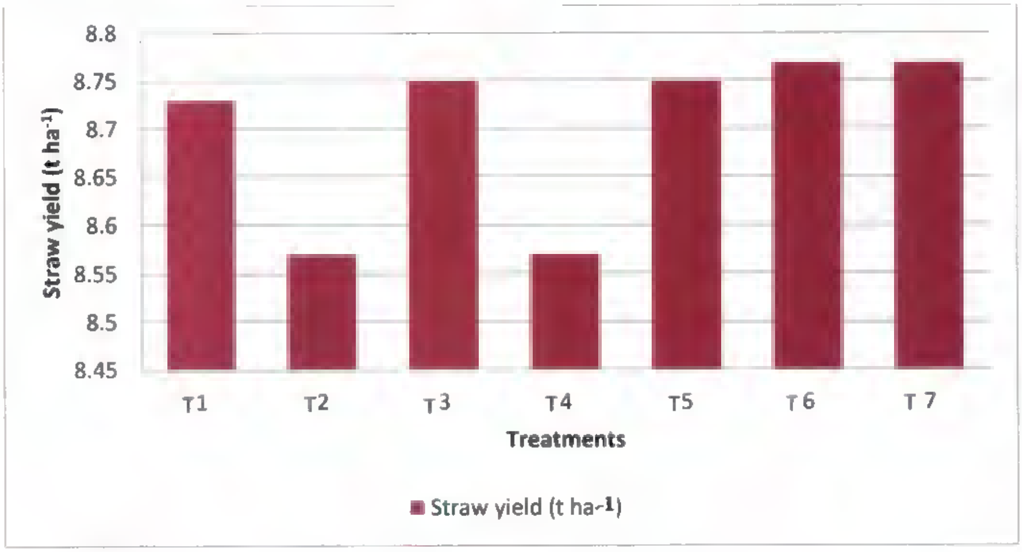

Fig. 6. Effect of silicon nutrition on straw yield (t ha^{-1})

(1986) showed that silicon application increased rice yields on Histosols mainly due to the supply of plant available silicon. Increased rice yields have been reported due to recycling of silicon in rice hulls and straw in the Philippines (IRRI, 1966). This explains why higher yield in the range of 5.58 to 6.14 t ha^{-1} could be realized in the iron toxic laterite soils of experimental site compared to 4.5 t ha^{-1} in the surrounding farmers' field. According to Savant *et al.* (1997a) intensive cropping (two or more crops per year) resulted in rapid depletion of all nutrients, including that of silicon. The short fallow periods between two successive crops in a year may not be sufficient for replenishing plant available silicon (PAS) in soil when the dissolution rate of soil silicon is very slow and, addition of large amount of NPK fertilizers alone could gradually reduce their effectiveness. Savant *et al.* (1997b), also reported that in continuous monocropping with high silicon accumulator crops such as rice, the removal of plant available silicon, could be greater than the supply via natural processes, releasing it into the soil, unless fertilized with silicon.

With respect to straw yield, T_6 and T_7 resulted in the highest value of 8.77 t ha^{-1} and these treatments were on a par with T_5, T_3 and T_1. The DMP at harvest also followed almost a similar trend with T_6 recording the highest value followed by T_7, T_5, T_3 and T_1. Rice hull is not harmful to the soil but is slightly beneficial as a fertilizer (IRRI, 1966). Agarie *et al.* (1992), also stated that the maintenance of photosynthetic activity due to silicon nutrition could be one of the reasons for the increased DMP and yield in rice.

A similar trend as that of yield was observed in the case of harvest index also. The treatment T_6 produced the highest harvest index of 0.41 and it was on a par with T_7.

5.3. EFFECT OF SILICON ON PHYSIO-CHEMICL PROPERTIES OF SOIL

Silicon application has not shown significant change in soil texture in any of the treatments. Silicon in soil increases soil reaction, slightly increases electrical

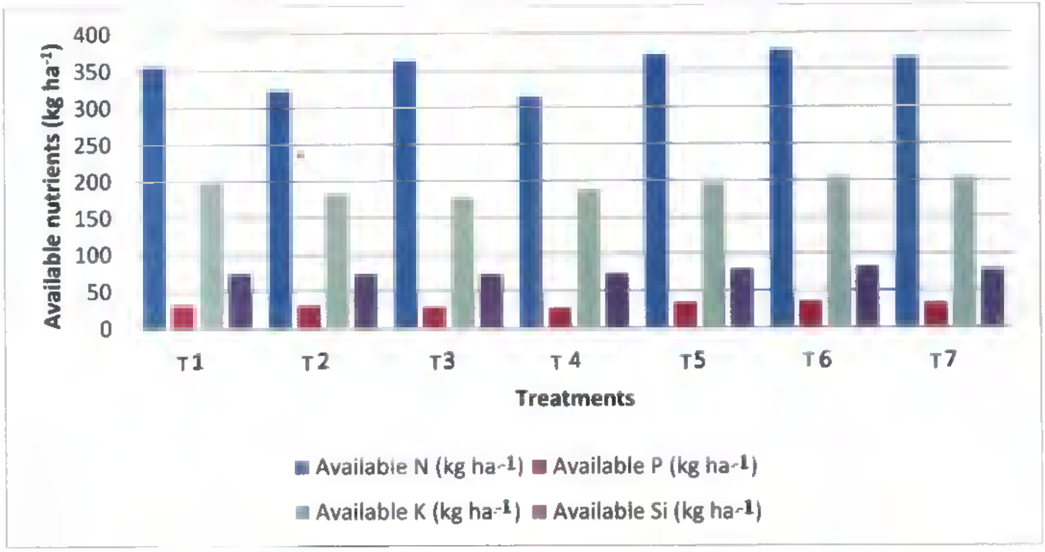

Fig. 9. Effect of silicon nutrition on available soil N, P, K and Si (kg ha^{-1})

conductance, improves physico-chemical soil properties and maintains nutrients in plant available form but will not change soil texture (Devanur, 2015). Similar results have been reported by Berthelsen *et al.* (2003).

The soil reaction (pH) was not significantly influenced by the silicon application, except at 3rd fortnight and after the harvest. Soil reaction increased in all the treatments after the harvest compared to the initial value (4.50). This increase in soil reaction could be attributed to the fact that silicate materials can increase soil reaction and also help in correcting soil acidity by neutralizing exchangeable Fe, Al and Mn and other toxic elements (Sandhya, 2013). These results were also in line with that reported by Wallace (1993) and Qiang *et al.* (2012).

The organic carbon content was significantly influenced by silicon application. Treatments with rice husk ash (T_5, T_6, T_7) resulted in significant increase in organic carbon content in soil compared to the other treatments. The increase in soil organic carbon was due to the reason that organic materials like rice husk ash has direct impact on mineralization rate and increases soil carbon directly. This is in agreement with the findings of Njoku *et al.* (2011) who observed the highest organic carbon content in the unburnt rice husk amended plots compared to the burnt rice husk ash.

Silicon application in soil has not shown significant effect on soil electrical conductivity (EC), but there has been a slight increase in soil EC after the experiment. This might be attributed to submergence, increase in solubility of salts present in the soil and also due to the dissolution of silicon fertilizers as reported by Sandhya (2013).

5.4. EFFECT OF SILICON ON AVAILABLE NUTRIENT STATUS OF SOIL

The treatments had not shown significant effect on available N in soil, but when compared to initial soil N status, there was a decline in soil N status in all the treatments. This decrease in available N in soil might be due to enhanced uptake of soil N, because silicon in soil has the ability to raise the optimum N rate, thus enhancing the productivity of existing lowland paddy fields. These results are in confirmation with the work done by Yoshida *et al.* (1969), Ho *et al.* (1980) and Chanchareonsook *et al.* (2002).

The available P content in soil was significantly higher in the case of application of fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} (T_6), followed by T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) and T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}). This increase in P might be due to the possibility of replacing the phosphate anion $[HPO_4]^{2-}$ from Al and Fe phosphates by monosilicic acid $[Si(OH)_3]^-$ of silicon sources. Guntzer *et al.* (2012) observed that there was an increase in the response of applied phosphorus in rice, when applied along with silicon fertilizers. Similar results were also reported by Eneji *et al.* (2008), Savant *et al.* (1997a) and Ma and Takahashi (1990).

The available potassium content in soil was significantly influenced by the silicon application. The highest available K was found in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}), which was followed by T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%), T_1 (fine silica @ 100 kg ha^{-1}), T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) and T_4 (fine silica @ 50 kg·ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%). The production of hydrogen ions during reduction of Fe and Al might have helped in the release of K from the exchange sites or from the fixed pool to the soil solution. Devanur (2015) stated that beside yield enhancement in rice, silicon also has many fold advantages of increasing availability of major nutrients and also alleviating iron toxicity problems in soils. These results are confirmative with the findings of Burbey *et al.* (1988), Liang (1999) and Mali and Aery. (2008).

Silicon nutrition significantly influenced soil silicon status also. The soil silicon was found to be higher in all the treatments after harvest compared to the initial status, but the highest soil available silicon was found in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) followed by T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}). The silicon applied through various silicon sources, would have prevailed in soil as monosilicic acid (H_4SiO_4) due to its residual activity and enhanced soil silicon availability. These findings are in agreement with those reported by Singh *et al.* (2006) and Korndorfer *et al.*, (2001). Prasanta and Heinz (2009) reported that changes in the pH of soils due to soil flooding significantly influence the solubility of Fe, P and Si in soil; so also plant available soil silicon increases due to increase in soil reaction. In the present study also, the increase in soil reaction compared to the initial value might have resulted in significantly higher silicon content in soil.

5.5. EFFECT OF SILICON ON NUTRIENT CONTENT IN RICE STRAW, GRAIN AND TOTAL NUTRIENT UPTAKE

The silicon nutrition had no shown significant influence on N content in grain and straw, but total N uptake increased significantly by silicon nutrition. With respect to total N uptake, T_6 (Fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) was superior with the uptake of 189.74 kg ha^{-1}. This treatment had registered the highest DMP of 11376 kg ha^{-1} also. The available N content of soil was also low for the above treatment after harvest compared to the initial soil N. This might naturally be due to enhanced absorption of N by the crop ultimately leading to higher N uptake by plant, resulting in low available N status in soils. Similar results have also been reported by Devanur (2015) and Chanchareonsook *et al.*, (2002).

Phosphorus concentration in plant and uptake of P were positively influenced by silicon application. Treatment T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) produced significantly higher content of P in grain and total P uptake, probably because this treatment received the highest quantity of silicon *i.e.* 200 kg ha^{-1}. The P content of straw was also found to be the highest in T_6 (0.07 %),

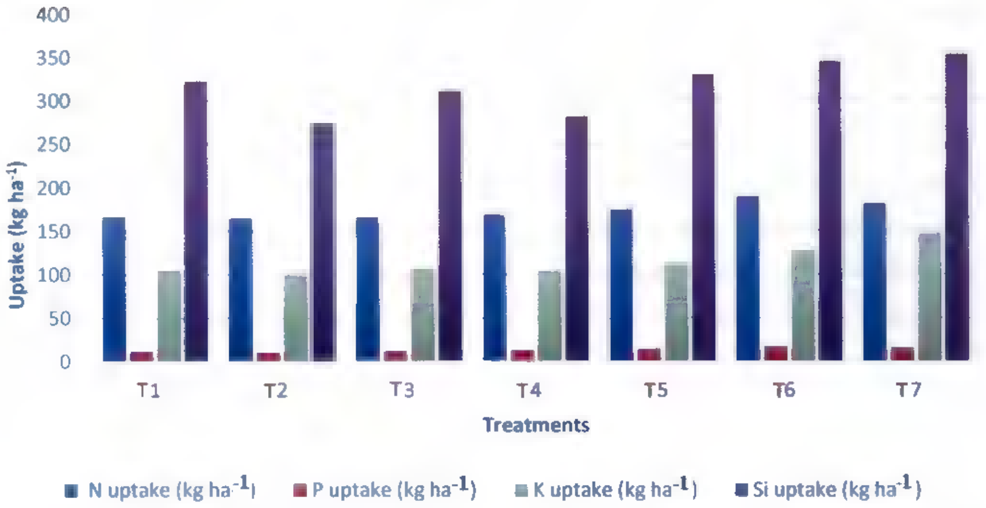

Fig. 7. Effect of silicon nutrition on total plant uptake of N, P, K and Si (kg ha^{-1})

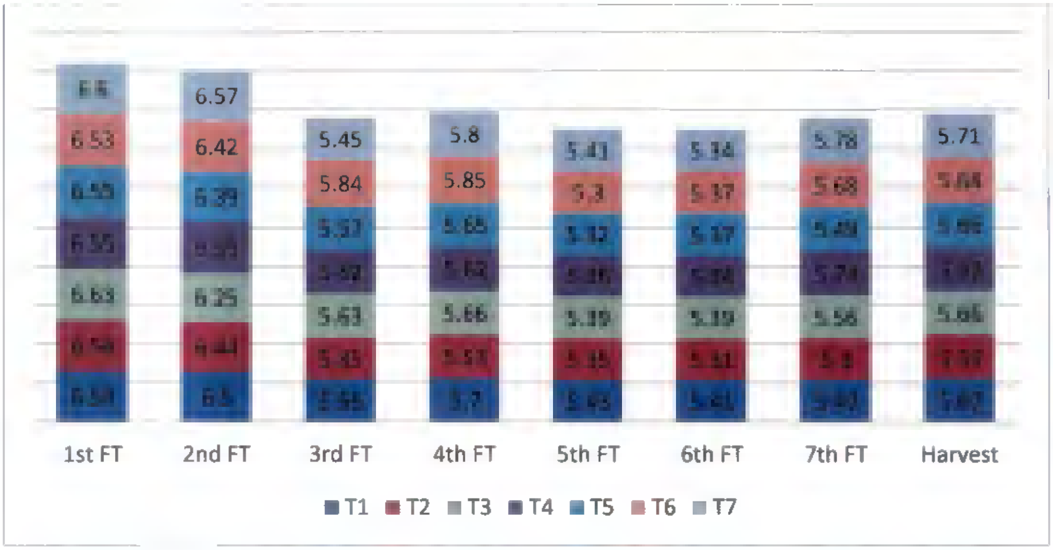

Fig. 8. Effect of silicon nutrition on soil reaction (pH)

followed by T_7 (0.06 %). The available P content in the soil after the experiment was also high in the above treatments. The monosilicic acid anions released from silicon sources might have replaced the phosphate anions released from Fe and Al phosphate, which might have resulted in higher P content and uptake by the plants. Increase in P uptake by the rice crop increased from 26 to 34% when P as single superphosphate was applied along with a silicate fertilizer (Savant *et al.* 1997a and Ma and Takahashi (1990, 1991). Tavakkoli *et al.* (2011) reported that overall beneficial effect of silicon may be attributed to a higher P: Mn ratio in the plant shoot due to the decreased Mn and Fe uptake, and thus indirectly improving P utilization within the rice plants. Addition of silicon fertilizers also increased the pH in acid soils which will release P from Fe-P and Al-P complexes (Suekisha *et al.*, 1963). Ma and Takahashi (1990), noticed significant increase in shoot dry weight with increased application of P when silicon was applied suggesting silicon application raised the optimum P level in rice.

The content of K in grain, straw and total uptake of K by rice crop increased with silicon application. Fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5 % spray (T_7) and fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} (T_6) were significantly superior with respect to K content in straw. However, T_7 was found to be the treatment with highest grain K and total K uptake. Soil application of silicon has synergistic interaction with applied K and also promotes the release of K from the exchange sites to the soil solution by the hydrogen ions produced during the oxidation of Fe and Al compounds (Savant *et al.*, 1997a). Silicon application increased yield response to applied potassium in upland rice (Burbey *et al.*, 1988). Similar beneficial effect of silicon fertilizers on K content in plant and K uptake are reported by Singh and Singh (2005), Liang (1999) and Sunilkumar (2000).

5.6. SILICON CONTENT IN RICE STRAW, GRAIN AND TOTAL UPTAKE

The silicon nutrition of rice evaluated in terms of concentration and uptake of silicon was influenced by silicon fertilization. With respect to silicon content in grain and straw, T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) and T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250kg ha^{-1}) were significantly superior to other treatments. Silicon supply in T_7 was less, but foliar application of potassium silicate helped to improve silicon uptake. However, with respect to available silicon in soil, T_6 was superior to T_7. According to Ma and Yamaji (2008), the increase in plant available silicon in the soil was usually accompanied by increased silicon accumulation in the plant, which might have result in increased growth and productivity in several crops, especially rice. Silicon content of rice straw shows large variations from 1.7 to 9.3%. (Yoshida, 1978) and is influenced by several factors such as soil, irrigation water quality, amount of fertilizers applied, rice cultivars and season (Ponnamperuma, 1984). The straw silica content of rice at harvest ranged from 4.8 to 13.5% in dry season and from 4.3 to 10.3%, in wet season (Devanur, 2015). Similar observations were also reported by Pawar and Hegde (1978), Savant *et al.* (1997a) and the result of present study is in agreement with this.

5.7. ECONOMIC ANALYSIS.

Silicon application significantly influenced the economics of rice cultivation. The treatment T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) resulted in significant increase in the gross income, net income and B:C ratio. This might be due to the increased grain and straw yield in these treatments. The gross income, net income and B:C ratio of T_6 were ₹ 164470 ha^{-1}, ₹ 72503 ha^{-1} and 1.78 respectively. The combination of fine silica (50 kg ha^{-1}) and rice husk ash (250 kg ha^{-1}) can be considered as most suitable silicon sources for iron toxic laterite soils. as they are cheap, readily availability, with high content of available silicon (Marafon and Endres, 2013). Yadav *et al.* (2017) reported that there was an

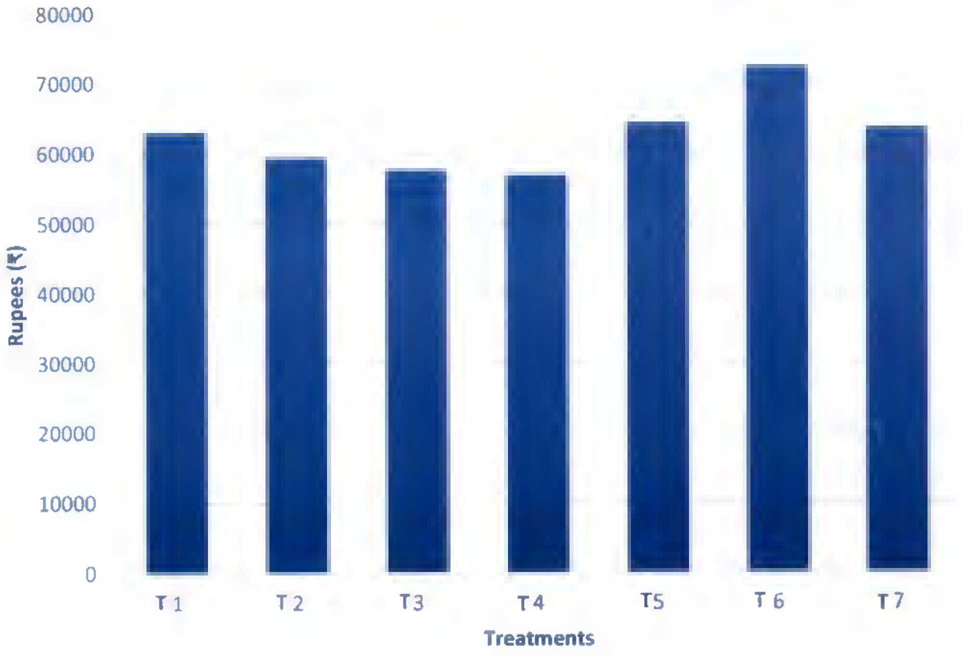

Fig. 10. Effect of silicon nutrition on net income (₹ ha^{-1})

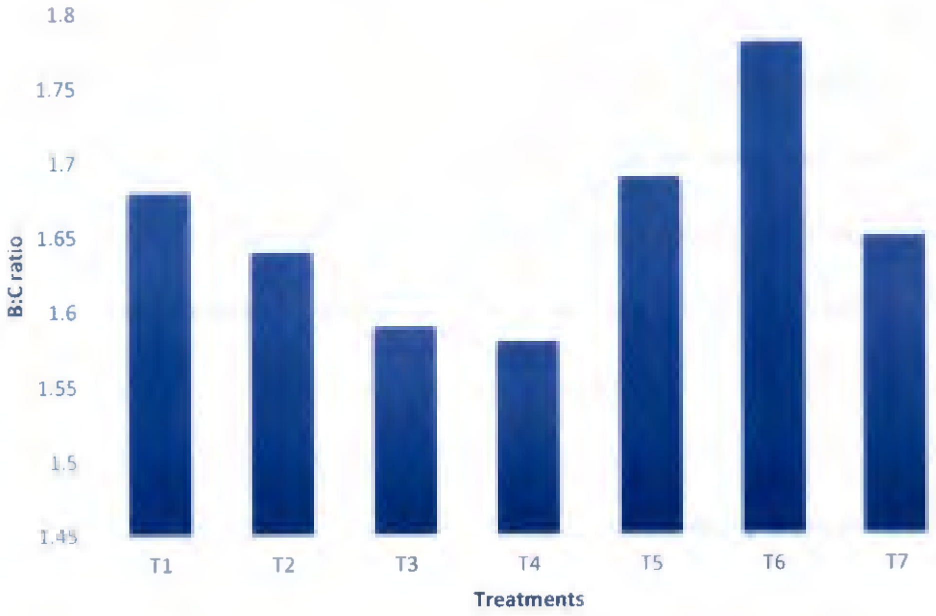

Fig. 11. Effect of silicon nutrition on B:C ratio

increase in net income, gross income and B:C ratio with silicon application, which was due to the increase in the straw yield and grain yield with increased silicon uptake by rice. Similar results were reported by Jawahar and Vaiyapuri (2012), Sunilkumar (2000) and Bhasakaran (2014).

SUMMARY

6. SUMMARY

The salient findings emanated from the field entitled “Silicon nutrition for rice in iron toxic laterite soils of Kollam district” are summarised in this chapter.

The experiment was laid out in RBD with three replications and the variety used was Uma. The treatments consisted of four sources of silicon *viz.* fine silica, rock dust, rice husk ash and potassium silicate at varying levels. The treatments were: T_1- fine silica @ 100 kg ha^{-1}, T_2 - fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}, T_3 - fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%, T_4 - fine silica @ 50 kg ha^{-1} + rock dust @ 25 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%, T_5 - fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}, T_6 - fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}, T_7 - fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%. All the treatments were given a uniform dose of lime @ 150 kg ha^{-1}, farm yard manure @ 5 t ha^{-1} and NPK @ 90:45:120 kg ha^{-1}. From the results of the present investigation the following conclusions were derived.

Silicon application had significant effect on plant height, number of tillers m^{-2} and DMP at all stages of crop growth. The highest plant height of 76.78 cm was recorded in T_6 at panicle initiation stage, which was on a par with T_1, T_3, T_5, T_7. At harvest, the highest plant height of 113.90 cm was obtained in T_6, which was on a par with T_1, T_4, T_5 and T_7. Regarding the number of tillers m^{-2} at maximum tillering stage, T_6 produced the maximum value (285) and was on a par with T_1, T_5 and T_7. At panicle initiation stage also, T_6 had the highest number of tillers m^{-2} (657) and was on a par with T_4, T_5 and T_7. With respect to number of tillers m^{-2} at harvest also, T_6 resulted in the highest number (488) which was on a par with T_4, T_5 and T_7. Dry matter production (DMP) had no significant variation due to treatments at maximum tillering stage. However, the treatment T_7 produced the highest DMP (10340 kg ha^{-1}) at panicle initiation stage, which was on a par with T_3 and T_6. The highest DMP at harvest stage was recorded in T_6 (11376 kg ha^{-1}).

Yield attributes like productive tillers m^{-2}, panicle weight, thousand grain weight and number of filled grains panicle^{-1} were significantly influenced by silicon application. More number of productive tillers m^{-2} (467.50) was found in T_6 and this treatment was on a par with T_7 and T_5. Average panicle weight was the highest in T_6 (3.43 g), and it was on a par with T_7, T_5 and T_4. Thousand grain weight was found to be highest in T_6 (24.36 g); however, it was on a par with all other treatments. The highest number of filled grains per panicle was also recorded by T_6 (128.92), and it was on a par with T_5 and T_7.

Grain yield, straw yield and harvest index were significantly influenced by silicon application. The highest grain yield of 6.14 t ha^{-1} was obtained in T_6 and it was significantly superior to all the other treatments. Straw yield was also the highest (8.77 t ha^{-1}) in T_6 and T_7, however these treatments were statistically on par with T_5, T_3 and T_1. With respect to harvest index also, T_6 had the highest value of 0.41 and it was on a par with T_7.

The different treatments did not impart any influence on soil EC and soil texture after harvest, but slight increase in soil EC was noticed compared to the initial value.

Significant variation due to treatments, was not observed with regard to soil organic carbon content. The highest organic carbon content was observed in T_6 (1.39 %), which was on a par with T_5 and T_7.

Soil pH was not significantly influenced by silicon application, except at 3rd fortnight and after the harvest. At 3rd fortnight, the highest pH was noticed in T_6 (5.84) and it was significantly different from the other treatments. After harvest, the highest pH was found in T_7 (5.71), which was superior to all other treatments.

However, compared to the initial pH of 4.50, pH values of all the treatments were higher and it sustained throughout the crop period.

Available nutrient content of soil, *viz.*, P, K and Si were significantly influenced by silicon application, except available N. The highest soil available P (36.37 kg ha^{-1}) was noticed in T_6, which was on a par with T_5 and T_7. With respect to available K, T_6 (206.25 kg ha^{-1}) resulted in the highest value and it was on a par with T_1, T_4, T_5 and T_7. The highest available Si was found in T_6 (83.61 kg ha^{-1}), which was on a par with T_7.

Silicon application had significance influence on N, P, K, Si content in grain and straw and total uptake of these nutrients by plant. The N content in grain and straw were not significantly influenced by silicon nutrition, except total N uptake by the plant. The total N uptake was found to be the highest in T_6 (189.79 kg ha^{-1}), which was on a par with T_7. The highest grain P content was noticed in T_6 (0.18 %) compared to all the other treatments. The straw P content was found to be higher in T_6 (0.07 %), which was on a par with T_7. More P uptake was observed in T_6 (36.48 kg ha^{-1}) and it was significantly superior to all the other treatments. The highest grain K content was noticed in T_7 (0.86 %) compared to all the other treatments. The highest K content in straw was observed in T_7 (1.09 %), which was on a par with T_6. Total K uptake was also more in T_7 (147.07 kg ha^{-1}) compared to the remaining treatments. The highest grain Si content of 0.96 % was noticed in T_7 and it was on a par with T_6. The highest Si content in straw (3.37%) and total Si uptake (352.93) were observed in T_7, which was on a par with T_6.

The gross income, net income and B:C ratio were influenced significantly by silicon application. The highest gross income, net income and B:C ratio were found in T_6 and this treatment was significantly superior to all the other treatments. The results, thus revealed the superiority of the treatment receiving fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} *i.e,* T_6, which was adjudged as the most cost effective package for rice in iron toxic laterite soils, along with the present KAU POP recommendation of FYM @ 5 t ha^{-1}, lime @ 150 kg ha^{-1} and NPK @ 90:45:120 kg ha^{-1}.

FUTURE LINE OF WORK:

1. Extensive survey of intensively cultivated rice tracts of the region should be conducted to assess silicon content of soil and plant for delineating the Si deficient areas.
2. Location specific integrated nutrient management system (INMS) involving silicon nutrition for sustainable rice production and breaking yield barriers.
3. Detailed investigations to evaluate cheaper and efficient alternate Si sources for aerobic and wetland rice.
4. Studies on silicon management for reducing methane emission from lowland rice fields.

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ABSTRACT

SILICON NUTRITION FOR RICE IN IRON TOXIC LATERITE SOILS OF KOLLAM DISTRICT

by

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ABSTRACT

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ABSTRACT

The study entitled “Silicon nutrition for rice in iron toxic laterite soils of Kollam district” was carried out at College of Agriculture, Vellayani, to assess the possibility of partially substituting fine silica with alternate silicon sources and to find out the effect of these sources on growth and productivity of rice for formulating a cost effective nutrient package for rice in iron toxic laterite soils. The field experiment was laid out in randomized block design with seven treatments and three replications, using rice variety Uma, during *Virippu*, 2016 at farmer’s field in Vilakkudy panchayath, Kollam district.

The treatments consisted of four sources of silicon *viz*. fine silica, rock dust, rice husk ash and potassium silicate at varying levels. The treatments were: T_1- fine silica @ 100 kg ha^{-1}, T_2 - fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}, T_3 - fine silica @ 75 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%, T_4 -fine silica @ 50 kg ha^{-1} + rock dust @ 25 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%, T_5 - fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}, T_6 - fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}, T_7 - fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%. All the treatments were given a uniform dose of lime @ 150 kg ha^{-1}, farm yard manure @ 5 t ha^{-1} and NPK @ 90:45:120 kg ha^{-1}. The result of the investigation are summarised below.

Application of silicon significantly influenced the growth attributes like plant height at panicle initiation stage (PI) and at harvest and the number of tillers m^{-2} at maximum tillering, PI and at harvest with T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) resulting in the highest value. With respect to dry matter production (DMP) also, at harvest stage T_6 showed the highest value. At PI stage T_7 produced the highest DMP; however it was on par with T_6 and T_3.

Yield attributing characters like productive tillers m^{-2}, thousand grain weight and number of filled grains panicle^{-1} were also significantly influenced by the silicon nutrition, T_6 resulting the highest values. Sterility percentage was the lowest in T_6 and it was on a par with T_5 and T_7. Silicon application significantly

influenced grain yield, straw yield, harvest index, net income and B:C ratio. The treatment T_6 produced the highest grain yield (6.14 t ha^{-1}), net income (₹ 72,503 ha^{-1}) and B:C ratio (1.78) and it was significantly superior to all the other treatments. Treatments T_6 and T_7 were on a par and superior to the other treatments with respect to straw yield and harvest index.

Soil physico-chemical properties such as soil texture and electrical conductivity were not significantly influenced by silicon application, but there was an improvement in soil reaction (pH) compared to the initial status. Significant increase in the soil organic carbon status was noticed in the treatments receiving rice husk ash (T_6, T_5, T_7).

Considering the growth and yield parameters as well as grain yield, net income and B:C ratio, application of fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} (T_6) was found to be cost effective package for rice in iron toxic laterite soils, along with the present KAU Package of Practices recommendation of lime @ 150 kg ha^{-1} + FYM @ 5 t ha^{-1} + NPK @ 90:45:120 kg ha^{-1}.

സംഗ്രഹം

കൊല്ലം ജില്ലയിലെ ഇരുമ്പിന്റെ ആധിക്യമുള്ള വെട്ടുകൽ പ്രദേശങ്ങളിലെ നെൽകൃഷിയ്ക്ക് സിലിക്കൺ പോഷണം എന്ന ശീർഷകത്തിൽ ഒരു പരീക്ഷണം ജില്ലയിലെ വിളക്കുടി പഞ്ചായത്തിൽ കർഷക പങ്കാളിത്തത്തോടെ 2016 വിരിപ്പ് സീസണിൽ നടത്തുകയുണ്ടായി. വെട്ടുകൽ മണ്ണിലെ നെൽകൃഷിയിൽ ഇരുമ്പിന്റെ അധിക ആഗിരണം കുറച്ചു ഉയർന്ന വിളവു ലഭിക്കുവാൻ കേരള കാർഷിക സർവ്വകലാശാല ശുപാർശ ചെയ്തിരിക്കുന്ന ഫൈൻ സിലിക്ക (100 കി.ഗ്രാം/ഹെ.) എന്ന സിലിക്ക വളത്തിന്റെ അളവിനെ വിവിധ സിലിക്കൺ ഉറവിടങ്ങളിലൂടെ ഭാഗികമായി കുറയ്ക്കുക എന്നതായിരുന്നു ഗവേഷണ പദ്ധതിയുടെ മുഖ്യലക്ഷ്യം. കൂടാതെ പുതിയ രീതി എങ്ങനെ നെല്ലിന്റെ വളർച്ചയെയും വിളവിനെയും ആദായത്തെയും ബാധിക്കു എന്നതും പഠനവിധേയമാക്കിയിരുന്നു.

പ്രസ്തുത പരൂക്ഷണത്തിനായി റാൻഡമൈസ്ഡ് ബ്ളോക്ക് ഡിസൈൻ എന്ന സ്റ്റാറ്റിസ്റ്റിക്കൽ രീതിയാണ് അവലംബിച്ചത്. ഫൈൻ സിലിക്കയുടെ അളവിനെ ഭാഗികമായി കുറയ്ക്കുന്നതിനായി പാറപ്പൊടി, ഉമിച്ചാരം, പൊട്ടാസ്യം സിലിക്കേറ്റ് എന്നീ സിലിക്കൺ വളങ്ങൾ വിവിധ അളവുകളിൽ നെല്ലിൽ പരീക്ഷിക്കുകയുണ്ടായി. പൊട്ടാസ്യം സിലിക്കേറ്റ് 0.6 ശതമാനം വീര്യത്തിൽ പത്രപോഷണമായി, വീര്യത്തിൽ നെല്ലിന്റെ ചിനപ്പു പരമാവധി പൊട്ടുന്ന അവസ്ഥയിൽ നൽകി. പരീക്ഷിക്കപ്പെട്ട ഏഴുരീതിയിലും കേരള കാർഷിക സർലവ്വകലാശാല, ഇരുമ്പിന്റെ ആധിക്യമുള്ള വെട്ടുകൽ മണ്ണിലെ നെൽകൃഷിക്ക് ശുപാർശ ചെയ്തിരിക്കുന്ന വള പാക്കേജിലെ കുമ്മായം - 150 കി.ഗ്രാം/ഹെ, ജൈവ വളം -5 ടൺ/ഹെ, പാക്യജനകം ഭാവകം, ക്ഷാരം പൊട്ടാസ്യം-90 45 120 കി.ഗ്രാം/ഹെ എന്നിവ നൽകിയിരുന്നു.

ഫൈൻ സിലിക്ക (50 കി.ഗ്രാം/ഹെ.) ഉമിച്ചാരം (250 കി.ഗ്രാം/ഹെ.) ഇവ സംയുക്തമായി ഉപയോഗിച്ച പ്ലോട്ടുകളിൽ നെൽച്ചെടിയുടെ ഉയരം, ചിനപ്പുകളുടെ എണ്ണം, കതിരുകളുടെ എണ്ണം, കതിരുകളുടെ ഭാരം, നെൽമണികളുടെ ഭാരം എന്നീ മാനദണ്ഡങ്ങൾ കൂടിയതായി കണ്ടു. പ്രസ്തുത വളപ്രയോഗത്തിലൂടെ നെല്ലിന്റെ വിളവ്, വൈക്കോലിന്റെ അളവ്, അറ്റാദായം, വരവ്ചെലവു അനുപാതം എന്നിവ വർധിക്കുന്നതായും കണ്ടെത്തി. കൂടാതെ പരീക്ഷിക്കപ്പെട്ട എല്ലാ വളപ്രയോഗ രീതികളും മണ്ണിന്റെ സ്വഭാവത്തിൽ യാതൊരു മാറ്റവും വരുത്താതെ അമ്ല-ക്ഷാര സൂചികയെ ഉയർത്തുകയും ചെയ്തു.

കൊല്ലം ജില്ലയിലെ, ഇരുമ്പിന്റെ ആധിക്യം ഉള്ള വെട്ടുകൽ മണ്ണുള്ള പ്രദേശങ്ങളിലെ നെൽകൃഷിയ്ക്ക് കേരള കാർഷിക സർവ്വകലാശാല ശുപാർശ ചെയ്തിരിക്കുന്ന വളപ്രയോഗ രീതിയിൽ ഫൈൻസിലിക്കയുടെ അളവ് ഭാഗികമായി കുറച്ച് (50 കി.ഗ്രാം/ഹെ.), അതോടൊപ്പം 250 കി.ഗ്രാം/ഹെ. എന്ന അളവിൽ ഉമിച്ചാരവും കൂടി നൽകുന്ന പുതിയ വളപ്രയോഗ രീതി ഉയർന്ന വിളവും കൂടുതൽ ആദായവും നലകുന്നതായി ബോധ്യപ്പെട്ടു.

APPENDICES

APPENDIX-I

Weather parameters during the cropping period (June – October, 2016)

Sl. No	Standard week	Rainfall (mm)	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)
1	24	294	30.00	23.00	91.00
2	25	63.00	31.00	23.00	86.00
3	26	32.20	31.00	23.00	86.00
4	27	46.20	31.98	23.41	84.00
5	28	8.40	30.88	23.74	87.28
6	29	37.10	30.98	23.37	82.57
7	30	46.90	31.17	23.68	86.14
8	31	24.50	32.04	23.68	81.07
9	32	18.90	31.95	23.57	81.78
10	33	31.50	32.98	23.25	69.28
11	34	28.40	31.87	23.90	82.5
12	35	51.10	31.91	23.65	70.85
13	36	8.40	31.41	20.08	80.14
14	37	2.80	32.64	22.46	65.28
15	38	19.60	32.37	23.58	81.35
16	39	14.70	32.37	23.45	77.35
17	40	13.30	31.41	22.57	81.35
18	41	0.00	33.65	21.71	74.07
19	42	51.80	33.17	23.24	87.21
20	43	14.70	32.22	23.52	80.57