SOIL AMELIORATION AND NUTRIENT MANAGEMENT OF RICE IN KOLE LANDS

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Soil amelioration and nutrient management of rice in Kole lands"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

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Introduction

I. INTRODUCTION

A wetland is an ecosystem that arises when inundation by water produces soils dominated by anaerobic processes, which in turn forces the biota, particularly rooted plants to adapt to flooding. Wetlands, facing several threats are highly fragile complex systems that provide variety of services to the society. However, the global area of wetlands has decreased at an ever increasing rate during the course of the country. Of the total wetland area lost, 87 per cent accounts for the diversion to agricultural development, 8 per cent to urban development and 5 per cent to other conversions (Barbier, 1977). As growing demand for food production accentuates preservation of wetlands and the interaction between rice cultivation and wetlands assume greater importance.

The Kole lands a unique wetland ecosystem of Kerala, is located 0.5-1.0m below mean sea level. Geologically, Kole is a low lying area with rich alluvium deposits brought along by Kecheri and Karuvannur rivers. It extends to an area of 13,632 hectares, spread over Thrissur and Malappuram districts of Kerala. This complex ecological system lies submerged under water for about six months in a year rendering the properties of both terrestrial and aquatic ecosystem. The cyclical nutrient recharging of the wetland during the flood season rendered the areas as one of the most fertile soils of Kerala. Based on the textural analysis, Kole land soil has been classified into clay, sandy loam, sandy clay loam and clay loam (Sheela, 1975).

Soil acidity, toxicity of iron and manganese and deficiency of potassium are the major soil factors limiting the productivity of rice in Kole lands. Use of chemical fertilizers per hectare of rice in Kole lands is found two times more than that of all Kerala average. While the quantity of chemical fertilizers used is 123 kg/ha for Kerala (CACP, 2010), it is as high as 282 kg ha^{-1} for Kole lands (Srinivasan, 2011). Large scale use of fertilizers containing only major nutrients can result in the deficiencies of secondary and micro nutrients (Ponnusamy, 2006). The incidence of micro nutrient deficiencies has increased markedly in recent years due to intensive cropping, loss of top soil by erosion, loss of micro nutrients through leaching, liming of acid soils and decreased proportion of manures compared to chemical fertilizers. Factors such as pH, redox potential, CEC and clay content are important in determining the availability of nutrients (Fageria *et al.*, 2002).

Magnesium has important role in photosynthesis due to primary constituent of chlorophyll. Application of silica and higher levels of potassium has been found to ameliorate the limiting influence of Fe and Mn enabling increased rice production (Lakshmikanthan, 2000). Magnesium alone and in combination with silica have been reported to increase the productive factors of rice. Several studies conducted revealed that application of boron to rice reduced panicle sterility and enhanced the yield.

By the time the deficiency symptoms of a particular nutrient appear on the plant, the crop might have undergone considerable damage in respect of its ultimate yield. It is therefore, desirable to test soils for their available nutrient status before sowing or transplanting a crop inorder to ensure timely corrective measures (Muralidharan and Jose, 1994). Application of higher dose of K along with secondary and micronutrients and silica will provide a nutrient management strategy for soil amelioration and balanced supply of nutrients to enhance the productivity of rice in Kole lands.

It is in this context, a holistic study on the comparative evaluation of soil ameliorants and nutrient management was taken up in Kole lands with the following objectives.

1) To study the effect of soil amelioration and nutrients *viz.* Ca, Mg, B and Si on growth, nutrient uptake and yield of rice in Kole lands.

2) To develop a nutrient management schedule for higher productivity of rice in Kole lands.

Review of Literature

II. REVIEW OF LITERATURE

Kerala, despite being a small land area of 38864 km^2, is bestowed with a vast network of backwaters, lagoons, natural lakes, rivers and canals. Occurrence of two distinct rainfall periods i.e., southwest and northeast monsoons, results in near water- logged conditions in almost 20 per-cent of the geographical area of the state. Thus as much as one fifth of the total land mass is wetlands (Freyfogle, 2007).

Wetlands in Kerala come under Central-Asian-Indian Flyway. Hence kole wetland is one such area with high importance. The Kole wetlands are spread over two districts, Thrissur and Malappuram and extends from northern banks of Chalakudy River to southern banks of Bharathapuza River in the north. Out of the total wetland area of 5.7 lakh ha identified in the state, 0.72 and 0.66 lakh hectares are located in Thrissur and Malappuram districts, respectively. Under this wetland area, 61 and 48 percent area is under rice in the respective districts. The Kole constitutes 4.09% of the total rice area in the state and the Kole area in Thrissur and Malappuram districts represents 23.2% and 10.9% of the total rice area of the respective districts. (F.I.B, 2002; K.S.I, 2000). The area lies between 10^0 20^1 and 10^0 40^1 N latitudes and 75^0 58^1 and 76^0 11^1 E longitudes. It forms the 'rice granary' of Thrissur and Malappuram districts (Binilkumar *et al.*, 2010).

A peculiar type of cultivation is carried out in Kole lands during the months from December to May. During June to November, i.e., for a period of almost six months, a major portion of this land lies submerged under water. These lands were formerly shallow lagoons that got silted up gradually. Kechery and Karuvannur are the two rivers which bring flood water into the area and finally it is emptied into the Arabian Sea (Sivaperuman and Jayson, 2000).

Rice is a major crop cultivated in this region after dewatering of fields. Cyclical nutrient recharging of the wetland during the flood season rendered these areas as one of the most fertile soils of Kerala.

Use of chemical fertilizers per hectare of rice in kole lands is found to be two times more than that of national average. While the quantity of chemical fertilizers used is 123 kg ha^{-1} for Kerala (CACP, 2010), it is as high as 282 kg ha^{-1} for kole land (Srinivasan, 2011).

Large scale use of fertilizers containing only major nutrients can result in the deficiencies of secondary and micro nutrients (Ponnusamy, 2006). The incidence of micro nutrient deficiencies has increased markedly in recent years due to intensive cropping, loss of top soil by erosion, loss of micro nutrients through leaching, liming of acid soils and decreased proportion of manures compared to chemical fertilizers etc. (Pushparajah, 1998).

Apart from major nutrients, Ca, Mg and S also play an important role in rice nutrition. Micro nutrients *viz.*, Fe, Zn, Cu, B, Mo, Mn and Cl are required by plants in very small amounts in comparison to major nutrients, but not in the sense of their minor importance in plant life (Bhatt, 2011). Silicon is also reported to be highly beneficial to rice. In this chapter an attempt is being made to trace the available research information on these lines of work. Since the study is mainly focused on soil amelioration and nutrient management of rice in kole lands, a more detailed review on nutrients K, Ca, Mg, Fe, B and Mn is given in this chapter.

2.1Crop growth and yield limiting factors of Kole lands

The productivity of rice in laterite soils is seriously affected because of several limiting factors associated with soils. These include the characteristic physico-chemical properties of the soils including nutrient toxicities. Soil acidity, toxicity of iron and manganese and potassium deficiency are the major soil factors limiting productivity of rice in kole lands (Johnkutty and Venugopal, 1993). Here comes the need to ameliorate the soil so as to supply balanced amounts of nutrients which enhance productivity of rice in kole lands.

2.1.1 Soil Acidity

Soils of kole lands are acidic in nature with pH ranging from 4.5-5.5. The low productivity of laterite and allied soils can generally be attributed to low pH, low base saturation, low available P and high P fixing capacity and toxicity of Fe and Al. Moderate to high acidity of laterite soils also causes serious problems in major rice growing areas especially in kole lands (Patnaik, 1971).

Jacob (1987) reported that because of low pH and lower organic carbon content, the N content, CEC and C: N ratio were low in laterite soils. He also observed very low total reserves of CaO, MgO, K_2O and P_2O_5 in Kole laterite soils.

2.1.2 Toxicity of iron and manganese

Iron is an important micronutrient but in excess concentration it affects the growth and yield of rice in laterite soils of Kerala. Pathirana *et al.* (1995) found that Fe uptake was positively correlated with Fe concentration and deposition was greater in roots than shoots. Das *et al.* (1997) reported that Fe content of plants significantly decreased in heavy textured soils indicating a positive influence of the soil clay content towards reducing Fe content in the plant.

Anilakumar *et al.* (1992) reported that high level accumulation of excess iron occurred in early stages of rice but the content declined as growth advanced, they also reported that high content of iron in plants led to degradation of chlorophyll 'a' which had been identified as physiological cause for low productivity of rice in laterite soils. Singh (1992) found that iron toxicity resulted in decreased number of panicles and filled grains, delayed crop maturity and yield reduction of 1-2 t ha^{-1}.

Mn content of Kerala state ranges from 0.2-20ppm (Rajagopal *et al.*, 1977). Excess Mn hindered the translocation of iron by causing iron in the plant root, which will be converted into an insoluble form (Somer and Shive, 1942). A study conducted by Moormann (1963) in acid sulphate soils showed that excess Mn concentration and its increased solubility caused toxicity to rice plant.

2.1.3 Deficiency of potassium

Iron toxicity is accompanied by potassium deficiency and high levels of iron depressed potassium absorption leading to low productivity of rice (Mengel and Krikby, 1982). Potassium deficiency led to decreased plant height during panicle initiation, flowering and harvesting stages. It also decreased panicle weight, filled grains per panicle and grain weight. Nogushi and Sugawara (1966) found that K deficiency reduced the accumulation of silicon in the epidermal cells making the plants more susceptible to pests to diseases.

2.2 Effect of primary nutrients on growth and yield of rice

2.2.1 Effect of nitrogen

The total N content in soil varies from traces to 1-2 per cent depending upon the C: N ratio of soil organic matter (Prasad, 2007). N is essential constituent of amino acids, nucleic acids, nucleotides and chlorophyll and is closely related to photosynthetic rate (Coumaravel *et al.*, 2004). It promotes increased plant height, number of tillers, spikelets per panicle, percentage of filled spikelets per panicle and yield (Dobermann and Fairhurst, 2000).

The optimum ranges of N content in rice at tillering, flowering and maturity are 2.9-4.2, 2.2-3.0 and 0.6-0.8 per cent respectively. The critical level of deficiency of nitrogen at tillering stage is less than 2.5 per cent (Dobermann and Fairhurst, 2000). Nitrogen is the most yield limiting nutrient in lowland rice production. Intensive agricultural production systems have increased the use of nitrogen fertilizer in order to sustain high crop yields (Fageria *et al.*, 2010). Yadav and Choudhary (2012) reported that Nitrogen Use Efficiency in water logged rice was 30-35 per cent. Low recovery of N is associated with its loss by volatilization, leaching, surface run off, immobilization and denitrification.

2.2.2 Effect of Phosphorous

The total P content in surface soil may vary from traces to over 3.58 mg kg^{-1} (Tomar, 2000). The forms of phosphorus in soil can be organic and inorganic. The source of organic P is inositol phosphates, nucleic acid, phospholipids *etc.* Inorganic P occurs as compounds of Ca, Fe and Al (Shujie, 2012). Dixit (2006) reported that phosphorus become immobile and unavailable to plants due to low pH and dominance of active forms of Al and Fe.

Phosphorus is an essential constituent of adenosine triphosphate (ATP), nucleotides, nucleic acids and phospholipids. Its major functions are in energy storage and transfer and membrane integrity. P is mobile within the plants and promotes tillering, root development, early flowering and ripening. Saleque *et al.* (2006) reported that about 2.5-3.5 kg P is required to produce one tonne of rice and it depletes about 7-8 kg P ha^{-1} when P fertilizer is not used.

Dobermann and Fairhurst (2000) reported that the optimum ranges of P content in rice at tillering, flowering and maturity are 0.20-0.40, 0.20-0.30 and 0.10-0.15 per cent respectively and the critical level of deficiency of P at tillering stage is less than 0.10 per cent. P deficient plants are stunted with reduced tillering. Cong *et al.* (2011) found that P fertilization increased grain yield significantly (up to 60 kg P_2O_5 ha^{-1}).

2.2.3 Effect of Potassium

Among the major plant nutrients, potassium is the most abundant plant nutrient in soils. It constitutes an average of 1.9 per cent of the earth's crust. As a result of its structural ionic nature, K^+ has functions particularly related to the ionic strength of solutions within plant cells (Tisdale *et al.*, 1993). Potassium is essential for the physiological functions of carbohydrate metabolism and synthesis of proteins, regulation of activities of various essential mineral elements, activation of various enzymes, promotion of meristamatic tissues growth and adjustment of stomatal movement and water relation (Havlin *et al.*, 2006).

Ravichandran and Sriramachandrasekharan (2011) reported that the optimum ranges of K content in rice at tillering, flowering and maturity are 1.8-2.6, 1. 4- 2.0 and 1.5- 2.0 per cent respectively and the critical level of deficiency of K at tillering stage is less than 0.15 per cent. Tanaka *et al.* (1997) reported that the rice plant was characterized by its high capacity of absorbing as well as exhausting K and thereby tend to maintain the K concentration of the plant at a constant level. When the K concentration in the rice plant was forced to be low, its relative growth increment decreased drastically. A positive response of rice to K application was observed by Su (1976).

Vijayan and Sreedharan (1972) and Venkatasubbaiah *et al.* (1982) observed significant increase in rice plant height with increase in the levels of potassium. A positive correlation between K application and leaf area index in rice was observed by Mandal and Dasmahapatra (1983). Ray and Choudhari (1980) reported increase in chlorophyll content in the flag leaf due to K application. Mengel *et al.* (1981) reported that potassium checked the chlorophyll degradation, promoted the synthesis of chlorophyll and increased the rate of translocation of amino acids to the grain and higher protein formation.

Potassium application positively influenced yield attributes in rice. Potassium absorbed at the maximum tillering stage increased the number of panicles, spikelets per panicle and weight of grain (Su, 1976; Mandal and Dasmahapatra, 1983). Verma *et al.* (1979) observed longer panicles with increased K rates. Mithra *et al.* (1990) evaluated the effects of higher levels of K (0 to 160 kg ha^{-1}) on rice in an iron toxic laterite soil and reported that Fe toxicity symptoms decreased with increasing K application.

John *et al.* (2004) revealed that potassium influenced the use efficiency of other nutrients. They also reported that the ill effects of Fe can be reduced by K fertilization. High level of K was reported to decrease Fe uptake and helped to maintain K/Fe ratio in plants. Higher rate of K application increased the efficiency of N, P and Zn in laterite soils of Kerala (Mathew, 2002 and Deepa, 2002). Bridgit and Potty (2004) reported that increasing the levels of K increased the yield attributes and yield of rice. Manzoor *et al.* (2008) reported that the efficient potassium uptake by rice was obtained when potassium was applied at maximum tillering stage (25 DAT) and at panicle initiation stage (45 DAT).

Ravichandran and Sriramachandrasekharan (2011) reported that to produce the maximum number of spikelets per panicle, the K content of mature leaves should be more than 2 per cent at booting stage. They also reported that the critical level for K in straw at harvest is between 1.0 - 1.5 per cent but to obtain yields more than 7 t ha^{-1} requires more than 1.2 per cent of K in the in the flag leaf and straw at flowering and at harvest respectively.

Potassium application must be done to realize full yield potential of crops in soils with low levels of both exchangeable and non exchangeable K (Rao *et al.*, 2010). Arivazhagan and Ravichandran (2005) reported that nutrient uptake and grain and straw yields increased with increased levels of N and K. Muthukumararaja *et al.* (2009) reported that the addition of 50 kg K_2O ha^{-1} recorded the highest LAI, chlorophyll content, grain (5621 kg ha^{-1}) and straw yield (9077 kg ha^{-1}) in rabi season.

Dutta *et al.* (2013) reported that application of 37.5 kg K ha^{-1} recorded significantly higher growth, yield attributes, yield and nutrient uptake as compared to lower levels of potash at 27.5 kg K ha^{-1}. Further application of potassium in 3 equal split (1/3 as basal + 1/3 at maximum tillering + 1/3 at panicle initiation stage) resulted in 5.5 to 13.2 per cent increase in grain yield over the other application timings.

The interaction between nutrient elements can be synergistic or antagonistic and the type of interaction is usually characteristic of the plant species (Emmert, 1961). The main effect of nutrients is often unrelated to their interaction and interactive effect may not decline with increasing rates of addition of that nutrient (Mandal *et al.*, 2002).

Salplarinliana *et al.* (2006) reported that the combined application of N and K showed the highest percentage of soil organic matter with 60 kg N+ 40 kg K ha^{-1}, while 90 kg N + 60 kg K ha^{-1} gave the highest soil available NPK, grain yield and straw yield of rice.

Bahmaniar and Ranjbar (2007) found that the simultaneous application of N and K increased grain yield, plant height, shoot dry matter and harvest index under field conditions and plant height, length of flag leaf and shoot dry matter under pot culture in rice. Zhiming *et al.* (2007) found that the tiller number and dry weight of leaves of rice increased with the increased rate of N and K fertilizer application and they concluded that the optimum rates of application were 1.8 kg N and 1.6 kg K_2O for production of 100 kg grain in high fertile soil.

Kavitha *et al.* (2008) reported that the application of N and K in 4 equal splits at active tillering, panicle initiation, booting and flowering stages recorded higher yields of 7484 kg ha^{-1} in kharif and 7154 kg ha^{-1} in rabi, respectively.

Muthuswamy *et al.* (1974) indicated that potassium application was correlated with the uptake of N, P and K by rice. Sindhu (2003) reported that P at 17.5 kg ha^{-1} and K at 70 kg ha^{-1} interacted to produce highest content of 0.23 per cent of K in the kernel. Application of 35 kg ha^{-1} of K gave the highest Mg content of 0.08 per cent. The content remained same when P was applied at 35 kg ha^{-1} along with K at 70 kg ha^{-1}.

Krishnakumar *et al.* (2005) found that the application of 150:75:50 kg N: P_205: K_20 ha^{-1} gave the highest grain yield.of rice. The treatment with 150:50:50 kg N, P_20_5 and K_20ha^{-1} showed the highest total P and K uptake. The N: P_20_5: K_20 application rates of 200:75:75, 200:100:100 and 200:50:75 kg ha^{-1} respectively resulted to higher soil available N, P and K. in post harvest soils.

Kalita (2007) reported that the application of NPK at 40:20:20 kg ha^{-1} gave the highest nutrient uptake and grain yield of rice when compared to the other fertilizer treatments. Sangwan *et al.* (2007) found that the higher grain yield of 68.0 q ha^{-1} was obtained with the application $N_{150}P_{60}K_{60}$ over N_{150} alone (61.5 q ha^{-1}) and the uptake of N, P and K were also increased with the same treatment.

Singh and Singh (1987) studied the effect of applied K on Fe toxicity and found that K content was increased with K application and was more pronounced at flowering stage. P content was increased with K application while Fe concentration reduced drastically indicating K-P synergism and K-Fe antagonism.

Tanaka *et al.* (1997) reported that an interaction existed between Fe and K in plant; plants exhibiting bronzing symptoms were usually low in K and application of K remedied the disorder. Mathew and John (2004) reported that higher dose of K (70 kg ha^{-1}) was found to have no appreciable effect on yield of paddy. Yield advantage with application of higher K dose in iron rich soils was reported due to its indirect effect on adsorption of other elements like iron. Mehraban *et al.* (2008) indicated that iron toxicity induced greater oxidative stress in rice plants and supplemental potassium was ineffective in preventing iron accumulation in shoots and consequently did not ameliorate plant growth under iron toxic levels.

2.3 Effect of secondary nutrients on growth and yield of rice

Ca, Mg and S are referred to as secondary nutrients. Panda (2005) reported that these secondary nutrients are added to the soil through some commercial fertilizers and are supplied to the plants incidentally by the application of NPK fertilizers as well as amendments.

2.3.1 Effect of Calcium

Calcium makes up to about 3.64 per cent of earth's crust (Mengel and Kirkby, 1987). Calcium is absorbed as Ca^{+2} from the soil. Content of calcium ranges from 0.2-1.0 per cent (Samui and Mandal, 2003). Large amount of Ca is present in soil as exchangeable Ca on silicate minerals in soils having pH 6 or above.

Calcium is referred to as 'Liming Element' because it is added to ammend soil pH and plays a greater role in neutralizing the acid forming effects of H^+. Prasad and Power (1997) reported that exchangeable Ca in soils can range from less than 25mg kg^{-1} to more than 5000 mg kg^{-1} and that in soil solution may range from 68-778 mg kg^{-1}. Dobermann and Fairhurst (2000) stated that critical level of Ca at tillering stage of rice is less than 0.15 per cent and critical level of deficiency of neutral normal ammonium acetate extractable Ca in soil for rice is less than 1.0 c mol (p^+) kg^{-1} for optimum growth of rice, Ca: Mg ratio should be more than 3- 4:1 for exchangeable soil form and 1:1 in soil solution. They also observed that Ca: Mg ratio of 1-1.5:1 in rice shoots from tillering to panicle initiation was optimal. The concentration of Ca in soil solution tends to increase after flooding because of the displacement of exchangeable Ca^{+2} by Fe^{+2}.

Ca is necessary for cell division and cell elongation and is present as calcium pectate in lamella of cell wall which maintains cell wall integrity. It is an enzyme activator and is required for osmoregulation.

Havlin *et al.* (2006) reported that soil acidity affected the availability of not only Ca but almost all plant nutrients and therefore the effects of Ca deficiency due to acidity were compounded with the deficiency and toxicity of other nutrients. Liming of acidic red and laterite soil not only ameliorated soil acidity related problems but also supply Ca and increased the uptake of Ca (Fox *et al.*, 1991; Samui and Mandal, 2003).

Alam *et al.* (2003) found that the application of calcium phosphate and calcium sulphate to rice increased N, P, K and Ca and decreased Na and Mg concentrations compared to control plants. Guanghui *et al.* (2003) found that the lime amendment in the acid soil improved P availability and promoted absorption of phosphorus, calcium and magnesium leading to increase in yield. Vallalkannan (2004) reported that excessive lime reduced absorption of potassium, zinc, copper, manganese and iron for upland rice.

Chang and Sung (2004) found that amelioration of soil with lime significantly increased the yield components of rice like number of panicle per ha, grains per panicle and 100 grain weight. Krasaesindhu and Sims (1972) reported increased grain yield, decreased straw weight and markedly increased grain: straw ratio by the application of Ca. Suswanto *et al.* (2007) reported that the best yield of rice of 14.15 t ha^{-1} was obtained for treatment with 4 t ha^{-1} lime with 120 kg N ha^{-1} + 16 kg P ha^{-1} + 120 kg K ha^{-1}. This also showed liming with prudent fertilizer management improved rice production in acid sulphate soil.

Deguchi and Ota (1957) reported that Ca stimulated the absorption of P and K under certain concentration ranges of ions in nutrient solutions. Padmaja and Varghese (1966) observed an increase in phosphorus content of the grain and straw by the application of calcium. Seng *et al.* (2008) found that the increase in shoot dry matter of rice with lime and P application in non - flooded soil was associated with a significant decline in soluble Al in the soil and an increase in plant P uptake.

Deguchi and Ota (1957) observed increase in absorption of K by the addition of Ca. According to Bridgit (1999) calcium application narrowed K/Ca. K/Mn, K/Fe, K/Zn and K/Cu ratios in plants. She also observed that (Ca + Mg)/K ratio in the plant showed a negative correlation with yield and total biomass. Though the application of Ca reduced Fe content, it failed to improve yield. Fernandez *et al.* (1973) found that K was negatively correlated with Ca and Mg in all stages of rice crop.

According to Erdei and Zsoldos (1977) calcium stimulated the absorption of P and K and accelerated more effectively the translocation of photosynthetic products compared to K and Mg.

2.3.2 Effect of Magnesium

The Magnesium content in earth's crust is about 2.07 per cent (Mengel and Kirkby, 1987). The exchangeable form of Mg is about 4-20 per cent of CEC. Magnesium in soil solution may range from 50-120 mg L^{-1} (Prasad, 2007). The critical level of deficiency of neutral normal ammonium acetate extractable Mg in soil for rice is less than 1.0 c mol (p^+) kg^{-1}. A Ca: Mg ratio in soil solution greater than 7:1 was found to be undesirable (Dobermann and Fairhurst, 2000).

Magnesium is a primary constituent of chlorophyll and its absorption by soil depends on soil pH, quantity of other exchangeable ions and the type of clay (Havlin *et al.*, 2006). Magnesium is required for grana stacking and formation of light-harvesting chlorophyll a/b complexes (Obatolu, 1999). Magnesium is also a necessary activator for many critical enzymes in carbon fixation. Scott and Robson (1990) found that depending upon the nutritional status, a range of 6- 35 per cent of the total Mg is bound to chlorophyll.

Ding *et al.* (2006) reported that Mg is fairly mobile in plants and highly reactive. Magnesium is absorbed as Mg^{+2} by plants. The Mg level in rice plants was in the order leaf > stem > panicle > root. Yan and Chu (1996) reported that the Mg uptake is peak at tillering and panicle development stages. Mg uptake in cereal is about 3 mg kg^{-1} of grain (Shrotriya, 2007). Fageria (1976) reported that the critical and adequate value of Mg for a 100 days old rice plant were 0.12-0.17 per cent and 0.17-0.30 per cent respectively.

Deficiency of magnesium in rice is a widespread problem, affecting productivity and quality of rice (Hermans *et al.*, 2004). Dobermann and Fairhurst (2000) stated that the deficiency also reduced the number of spikelets, thousand grain weight, grain yield and quality. In an experiment conducted by Ding *et al.* (2006) Mg deficiency in rice (less than 1.1 mg g^{-1} dry weight in the shoot) resulted in significant reduction in shoot biomass, total chlorophyll concentration and net photosynthetic rate.

Fenn *et al.* (1981) stated that if soluble salts of Mg were applied with urea, it prevented the volatilization of NH_3 by forming ammonium chloride or nitrate. Choudhury and Khanif (2002) reported that grain yield of rice increased significantly due to the application of 20 kg ha^{-1} of Mg. They also reported that Mg application significantly increased total Mg uptake both at 10 and 20 kg $ha^{-1}$of Mg application.

For Mg deficient soils, application of 15 kg ha^{-1} of magnesium as calcium magnesium phosphate or magnesium sulphate was recommended (Yan and Chu, 1996). Application of Mg as basal dose in the form of $MgSO_4$ (10 per cent MgO) or Magnesite (40%) @ 20 kg

MgO ha^{-1} is effective in giving significant increase in grain and straw yield of rice in Mg deficient soil (KAU, 2011).

Cakmak and Engels (2002) reported that the harvest index of rice decreased due to the application of Mg as magnesium carbonate @ 50 kg ha^{-1} of Mg. Brohi *et al.* (2000) reported that application of P alone or in combination with Ca and Mg significantly increased the grain and straw yields. Sahrawat *et al.* (1999) found that the application of Mg generally improved the plant status with regard to N, Ca, Mg and Fe.

Kobayashi *et al.* (2005) reported that in rice, the excess Mg treatment increased the Mg content of shoots and roots and potassium content of roots but slightly decreased the Ca and K contents of shoots. In an experiment conducted in KAU, Padmaja and Verghese (1966) observed that magnesium alone and in combination with silicon increased the productive factors such as tillering, height of the plant, leaf width, root weight and spread as well as the test weight of grain. Yamauchi and Winslow (1989) reported that Mg is involved in the protection of rice plants against grain discoloration and its application increased grain yield by an average of 34 per cent.

In an experiment conducted, Latheef (2013) showed that $MgSO_4$ either as soil application or foliar spray along with NPK as per package of practice recorded significantly increased height, productive tillers, thousand grain weight and dry matter at harvest.

A Ca: Mg ratio in soil solution greater than 7:1 is considered undesirable (Havlin *et al.*, 2006). Continuous liming of soils can thus create Mg deficiency, on the other hand a Ca: Mg ratio less than about 2:1 can cause Ca deficiency. K^+ also antagonizes Mg uptake (Ologunde and Sorenson, 1982) and desirable K: Mg ratios of less than 5: 1 was found to be optimum for field crops (Havlin *et al.*, 2006). Ding *et al.* (2006) found the antagonistic and moderately synergistic effects between K and Mg, but the effects of K were much more significant than those of Mg on their uptake, translocation and net photosynthetic rate in the leaves.

2.4 Effect of micronutrients on growth and yield of rice

The efforts to enhance the food grain production from shrinking land resources magnified the depletion of limited micronutrient reserves and would cause the deficiency of micronutrients (Zayed *et al.*, 2011). The essential micronutrients for field crops are iron, zinc, copper, boron, manganese, chlorine and molybdenum (Papadopoulos *et al.*, 2009).

Narrow range between deficiency and toxicity limits may cause poor use efficiency of added micronutrients (Katyal *et al.*, 2004). Micronutrient deficiencies are location specific. Among micronutrients, deficiency was found widespread in Indian soils with boron followed by zinc. The deficiencies of Cu, Fe, Mn and Mo are of lesser magnitude than Zn (Sakal, 2001). The chloride deficiency rarely occurs in nature (Ray, 2011). In this context a detailed review of works done on Fe, Mn, B are studied and presented.

2.4.1 Effect of Iron on growth and yield of rice

Iron makes up 5 per cent by weight of the earth's crust and it is larger in ultisols and oxisols (Prasad, 2007). It is one of the three essential elements that causes major limitations to rice grain yield in tropical environment- the other two being nitrogen and phosphorus (Panda *et al.*, 2012). Sahrawat *et al.* (2000) reported that Fe toxicity reduces rice yields in wetlands by 12-100 per cent depending on the intensity of toxicity and tolerance of the rice cultivar.

Benckiser *et al.* (1984) reported that Fe toxicity is mainly experienced in rice which is grown on acid sulfate soils, ultisols and sandy soils with a low CEC, moderate to high acidity and active Fe and low to moderately high in organic matter. The iron toxicity inducing factors reported were release of iron from parent material to soil solution, reduction in oxidation reduction potential, increase in ionic strength, low soil fertility, low soil pH, soil organic matter content, high reactivity and content of Fe (III) oxide hydrates, increased salt content, microbial activities, interaction with other nutrients and plant genetic variability (Fageria *et al.*, 2008). Range of oxidation-reduction potential values at which reduction of Fe^{3+} to Fe^{2+} occur is +180 to +150 (Patrick, 1996).

Santos and Oliveira (2007) stated that flooding of red and laterite soils caused reduction of Fe^{3+} to Fe^{2+} and ferrous form was maintained for long period of time which created a high concentration of plant available Fe^{2+} in soil solution and led to iron toxicity. Similar findings were reported by Singh *et al.* (2003) and Fageria *et al.* (2011). Flooding increased the availability of Fe from 0.1 to 50-100 mg kg^{-1}soil (Ponnamperuma, 1978). The critical level of toxicity of DTPA extractable Fe in rice is more than 300 mg kg^{-1} (Samui and Mandal, 2003).

Antagonistic interaction between iron and manganese in rice plants was observed by Olsen and Watanabe (1979). Panda *et al.* (2012) reported that when the concentration level of Fe increased the concentration of Cu and Mn decreased.

Samui and Mandal (2003) reported that critical level of toxicity of Fe in rice at tillering stage is 300-500 mg kg^{-1}. Dobermann and Fairhurst (2000) stated that excessive uptake of Fe resulted in increased polyphenol oxidase activity leading to the production of oxidized polyphenols, which cause leaf bronzing. Abu *et al.* (1989) reported that cultural practices such as planting date, ridge planting, water management and pre submergence of soil can be manipulated to reduce Fe toxicity in rice. Application of Zn @ 10 kg ha^{-1} as ZnO along with NPK decreased iron toxicity and also increased yield in rice (Audeberta and Sahrawata, 2000). The shoot biomass, plant height and chlorophyll content decreased at 10 mg L^{-1} of Fe concentration of soil solution in rice (Panda *et al.*, 2012).

2.4.2 Effect of Manganese on growth and yield of rice

Manganese serves as an activator of several enzymes. This element also occurs in excess concentration in soils of many parts of the state and hence important in limited rice productivity. Hariguchi and Kitagishi (1976) reported that more than 60 per cent of Mn contained in the plant leaves is in chloroplast and Mn along with Fe and Cu take part in indispensable roles in the electron transport system.

Cheng and Quellete (1971) reported that critical tissue content for Mn toxicity was 7000 ppm and rice has a high degree of tolerance for high Mn concentration in its tissue.

According to De Datta (1981) the critical limits of deficiency and toxicity of Mn rice plants are 20 ppm and 2500 ppm respectively. Singh *et al.* (1995) reported that manganese in Indian soils is adequate varying from 37 to 11500 mg kg^{-1} and available status of 0.6 - 164 mg kg^{-1} to support optimum crop growth. Tadano and Yoshida (1978) suggested that a high Mn content in rice tissue was frequently associated with high yields possibly indicating that a high Mn content in the plant was associated with various favorable soil conditions.

Mn interacts negatively with a number of plant nutrients. Reduced uptake of Mn by plants has been reported by application of Fe (Baxter and Osman, 1988) and Zn (Haldar and Mandal, 1979). Bulbule and Despande (1989) reported that tolerant varieties maintained a high nutrient ratio of N/Fe, P/Fe, K/Fe, Mg/Fe and Mn/Fe. They also stated that excess Fe absorption was related with multiple nutritional stress and the resulting low K/Fe and P/Fe ratios led to more serious yield reduction than Ca/Fe and Mg/Fe ratios.

Pendias and Pendias (2001) reported that Mn-Fe antagonism is widely known and is observed mainly in acidic soils that contain large amounts of available Mn. In general, Fe and Mn are interrelated in their metabolic functions and their appropriate level (the Fe: Mn ratio should range from 1.5 to 2.5) is necessary for the healthy plant.

2.4.5 Effect of Boron on growth and yield of rice

Boron primarily occurs in the soil as H_3BO_3. Available B is derived from decomposition of organic matter and release from clay minerals. The H_3BO_3 form of B is highly mobile in the soil (Dunn *et al.*, 2005). Rao *et al.* (2013) reported that soil application of boron led to fixation and unavailability. Boron is a nonmetal micronutrient. It is amongst the important micronutrients required for rice from start till physiological maturity.

Rashid *et al.* (2004) reported that the range of B deficiency and toxicity is narrow. Deficiency occurs at less than 0.5 mg kg^{-1} of hot water soluble B while toxicity could occur at more than 5.0 mg kg^{-1}. Critical level of deficiency of B in rice at tillering to panicle initiation is less than 5 mg kg^{-1} (Dobermann and Fairhurst, 2000). The critical limit of B at active vegetative stage in third leaf of rice plant is 12 mg kg^{-1} (Debnath and Ghosh, 2012).

According to Rao *et al.* (2013) boron is associated with a wide range of morphological alterations, tissue differentiation, pollen germination and metabolite transfer which will greatly influence the yield and productivity. The main functions of B in plant relate to sugar transport, flower production and retention, pollen tube elongation and germination and translocation of carbohydrate and sugars to reproductive organs, which in turn improved the spikelet number and fertility that influenced the yield and productivity (Ahamad *et al.*, 2009). Aslam *et al.* (2002) reported that boron is responsible for better pollination, seed setting, low spike sterility and more grain formation in different varieties of rice.

Rao *et al.* (2013) reported that rice crop, when grown on a wide range of soil types such as calcareous, clayey laterite, acid, *etc.* with varying soil pH levels, boron availability, uptake and mobilization became limiting and led to reduced productivity and poor rice yields. The boron requirement is much higher for reproductive growth than for vegetative growth in most plant species. Hence the reproductive stage is known as a sensitive period to low B stress (Uraguchi and Fujiwara, 2011).

Boron is immobile in plant. Severe deficiency symptoms in rice include thinner stems, shorter and fewer tillers, death of growing point and failure to produce viable seeds (Dunn *et al.*, 2005). Sakal *et al.* (2002) suggested that the application of boron through soil or foliar spray was found to be beneficial in simulating plant growth and increasing yield of rice.

According to Dunn *et al.* (2005) rice receiving soil applied boron produced significantly greater yields than rice with foliar applied B. The dry matter yield increase at higher B levels may be ascribed to B toxicity because a slight increase in B levels markedly increased the B concentration in shoots (Debnath and Ghosh, 2012).

Boron application at higher level adversely affected chlorophyll pigments (Rehman *et al.*, 2012). Debnath *et al.* (2009) reported that the application of 1.5 kg B ha^{-1} increased the plant height, number of tillers, dry weight and spikelet fertility. Several studies conducted have shown that application of boron to rice reduced panicle sterility and enhanced the yield (Jana *et al.*, 2005; Rashid *et al.*, 2006 and Hussain *et al.*, 2012)

Hosseini *et al.* (2005) reported that increasing levels of B up to 10 kg borax ha^{-1} significantly increased B content in grain (27.3 mg kg^{-1}) and straw (43.1 mg kg^{-1}) over control (19.3 mg kg^{-1} and 33 mg kg^{-1}). A positive interaction existed between P and B when boron was applied at higher dose (Gaur and Singh, 2010). A significant increase in straw yield was obtained by the application of boron in red loam soils of Kerala (Sreedharan and George, 1969).

Saleem *et al.* (2011) reported that by application of boron, increased the yield due to the role of B in plant physiological functions especially during plant reproductive phase. These findings are in conformity with those of Ehsan-Ul-Haq *et al.* (2009) and Dunn *et al.* (2005). They reported that soil-applied B produced significantly higher yields over the control.

Gupta (1993) revealed that yield of paddy straw increased due to boron application because boron improved the membranes function which could positively affect the transport of all metabolites required for normal growth and development, as well as the activities of membrane bound enzymes. Borax produced high straw yield because B was readily available for plant uptake and act as a slow-release B sources (Rashid *et al.*, 2007). Rao *et al.* (2013)

observed that the application of 0.4 ppm B at anthesis decreased the number of unfilled spikelets compared to control.

Latheef (2013) reported that application of boron as borax 20 kg ha^{-1} along with NPK as per Package of practice and FYM increased the LAI and filled grain percentage. In an experiment conducted, Santosh (2013) showed that maximum grain yield of 8.07 t ha^{-1} was recorded with 6 kg ha^{-1} borax followed by 4 kg ha^{-1}.

2.5 Effect of beneficial elements on growth and yield of rice

In addition to the 16 elements (C, H, O, N, P, K, S, Ca, Mg, Fe, Mn, Cu, Zn, B, Mo, Cl) that are considered essential for plant growth, according to the criteria proposed by Arnon and Stout (1939), a number of other elements have been reported to be essential or at least beneficial, by way of increased growth or improved resistance to diseases or pests for some species. These elements, which include Na, Si, Co, Ni, La, Ce, V, and even Al are currently considered as beneficial plant nutrients (Epstein and Bloom, 2005).

2.5.1 Effect of Silicon on growth and yield of rice

Silicon (Si) is one of the most abundant elements in the earth's crust. Soils generally contain 5 to 40 per cent Si (Kovda, 1973). Silicon (Si) is a beneficial element for crop growth and it plays an important role in the growth and development of crop, especially for gramineae crops (Hodson *et al.*, 2005). Most of the beneficial effects of Si are realized through Si deposition in cell walls of the epidermal surfaces of leaves, stems and hulls (Melo *et al.*, 2010). Deposition of Si enhanced the strength and rigidity of cell walls and thus increased the resistance of plants to various stresses (Ma *et al.*, 2004).

Rice is considered as a silicon accumulator and is prone to various stresses if the available soil silicon is low for absorption (Takahashi,1995). Koendoefer *et al.* (2001) reported that adequate supply of silicion to rice from tillering to elongation stage increased the number of grains per panicle and the percentage of ripening.

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

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

Silicon uptake has been reported to mitigate the aluminium (Al) and iron (Fe) toxicity and a wide range of stresses in rice and other crops (Ma and Takahashi, 2002). Many scientists working on role of silicon on plant growth concluded that reduced amount of silicon in plant developed necrosis, disturbance in leaf photosynthetic efficiency, growth retardation and reduced grain yield in cereals (Shashidhar *et al.*, 2008). Mandal *et al.* (2002) revealed that although silicon has not been considered important for vegetative growth it helped the plant in healthy development under stresses in different grasses especially in rice. Plant tissue analysis revealed that the optimum amount of silicon is necessary for cell development and differentiation (Liang *et al.*, 2006).

Mobasser *et al.* (2008) reported that plant height, number of tillers per plant and number of productive tillers performed better when silicon was applied as foliar, while straw yield, spikelets per panicle, 1000 grain weight and yield were better when silicon was soil applied. These findings were near to Mauad *et al.* (2003) and Wang *et al.* (2010), who reported that silicon was not directly involved in quality enhancement but it controlled diseases and stresses to maximize the quality. Silicon has been implicated as a factor influencing the degree of plant resistance to biotic and abiotic stresses (Singh *et al.*, 2005). Application of 120 kg potash/ ha + lime 150kg ha^{-1} + silica 100 kg ha^{-1} is recommended for iron toxicity in laterite soils (KAU, 2011).

Ahmad *et al.* (2007) reported that among the different doses of silica tried in rice, maximum straw yield of 12.61 t ha^{-1} was produced at 1.00 per cent silicon while 10.49 t ha^{-1} straw yield was found in control. In an experiment conducted, Lakshmikanthan, (2000) showed that application of silica and higher levels of potassium was found to ameliorate the limiting influences of Fe and Mn enabling increased rice production.

Ma and Takahashi (1989) reported that the application of Si at various growth stages of rice increased the plant height and root dry weight. But Si applied at ripening stage has no effect on growth attributes. Malidareh (2009) reported that application of sodium silicate combined with magnesium carbonate increased all the productive factors such as ear head length, 1000 grain weight, grain and straw yield. Ca in combination with silica has reduced the proportion of immature to mature ear heads.

According to Bridgit (1999), application of sodium silicate at 250 kg ha^{-1} in laterite soil significantly increased the yield of grain and the increase was to the tune of 619 kg ha^{-1} compared to control. Malidareh (2009) found that the Si fertilizer application decreased the straw and grain nitrogen content. Si_0 and Si_{500} (kg ha^{-1}) had maximum and minimum grain nitrogen with 1.93 and 1.91 per cent and straw nitrogen with 1.02 and 0.92 respectively. Junior *et al.* (2009) reported that the soil-applied silicon increased the foliar silicon content and reduced the severity of brown spot, in contrast to the results observed in the foliar-applied silicon treatments.

In an experiment conducted by Kumara *et al.* (2013) the highest grain yield was recorded with the application of calcium silicate at 2 t ha^{-1} + 90 Kg N ha^{-1} and it was on par with 60 Kg N ha^{-1} compared to recommended N (100 Kg N ha^{-1}) under aerobic rice.

Materials and Methods

III. MATERIALS AND METHODS

The present study entitled "Soil amelioration and nutrient management of rice in Kole lands" was carried out in farmer's field at Ponnamutha Kole padavu of Venkitangu Panchayath in Thrissur District during November, 2013 to March, 2014. The details of materials used and methods adopted for the study are described in this chapter.

3.1 General details

3.1.1 Location

The Kole lands are low lying wetland tracts, located at 0.5 to 1m below the mean sea level covering an area of 13,000 ha and spread over two districts *viz.*, Thrissur and Malappuram. The area lies between $10^0 20^1$ and $10^0 40^1$ N latitudes and $75^0 58^1$ and $76^0 11^1$ E longitudes and extends from northern banks of Chalakudy River to southern banks of Bharathapuza River in the north.

3.1.2 Climate and weather conditions

The experimental site enjoys typical humid tropical climate. The maximum and minimum temperature during the cropping period varied from 22.3°C to 36.7°C respectively. The mean monthly averages of important meteorological parameters observed during the experimental period are presented in Appendix I.

3.1.3 Soil characters

The soils of Kole lands are clayey in texture and come under the soil order Inceptisol. The physico-chemical characteristics of the soils of the experimental field are presented in Table 3.1.

Table 3.1. Physico-chemical characteristics of the soil prior to the field experiment

Properties	Value
a. Physical properties	
Bulk density (Mg m^{-3})	1.42
Particle density (Mg m^{-3})	2.46
Porosity (%)	45.00
Water holding capacity (%)	85.62
Particle size composition	
Sand (%)	20.5
Silt (%)	22.3
Clay (%)	57.2
Texture	Clayey
b. Chemical properties	
Soil reaction (pH)	4.50
Electrical conductivity (dS m^{-1})	0.74
Organic Carbon (%)	1.25
Available N (kg ha^{-1})	427.55
Available P_2O_5 (kg ha^{-1})	6.75
Available K_2O (kg ha^{-1})	85.56
Available Ca (mg kg^{-1})	340.6
Available Mg (mg kg^{-1})	25.14*
Available S (mg kg^{-1})	6.12
Available Fe (mg kg^{-1})	1090.06
Available Zn (mg kg^{-1})	1.75
Available B (mg kg^{-1})	0.18*
Available Mn (mg kg^{-1})	81.40
Available Si (mg kg^{-1})	12.24

* Deficient

3.1.4 Crop and Variety

The rice variety Uma (Mo-16), a red kernelled, medium duration variety released from KAU was used for the experiment. The variety is suitable for all the three seasons with medium tillering, resistant to BPH and capable of producing a yield of over 5 t ha^{-1} under favorable situations.

3.1.5 Cropping history of the experimental site

The experimental area belongs to a typical single cropped wet land where rice is grown during October-November to February-March. The land remains submerged during the rest of the year. The field was under bulk cropping of rice in the previous season.

3.2 Experimental methods

The experiment was conducted in the field of farmer Mr. Parameswaran during second crop season (*Mundakan*) from November 2013 to March 2014. The experimental design was RBD with three replications. The plot size was 5.0 m x 4.0 m and direct seeding was adopted as method of planting. The layout of the experiment is depicted in Fig.3.1.

3.2.1 Treatment details

The treatment details are given in Table 3.2

3.2.1.1 Fertilizers

Urea, Rajphos, Muriate of potash, Magnesium sulphate, Sodium silicate, Calcium silicate and Borax were used as the sources for different nutrients and ameliorants. The nutrient content of the fertilizers used in the experiment is given in Table 3.3

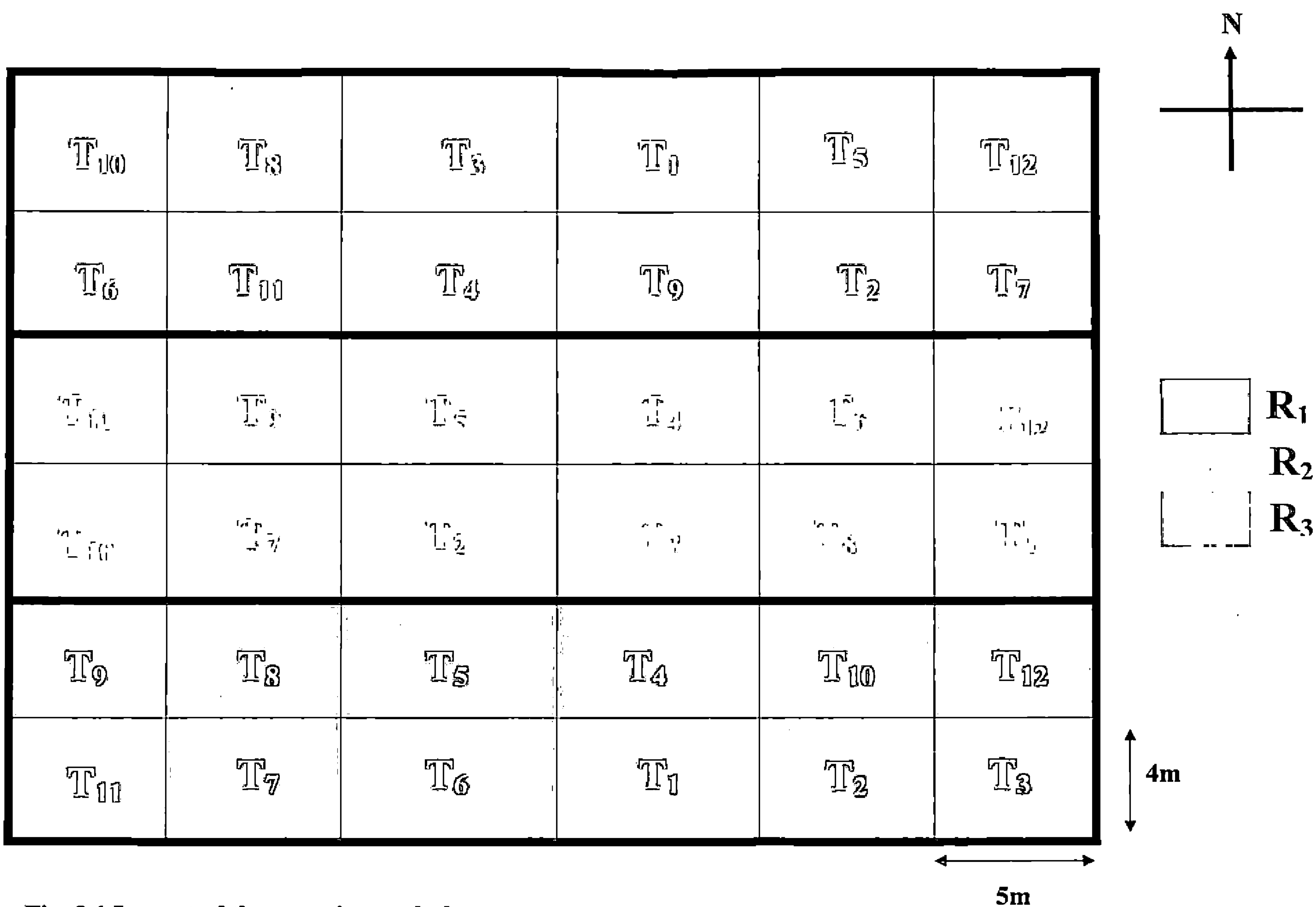

Fig. 3.1 Layout of the experimental plot

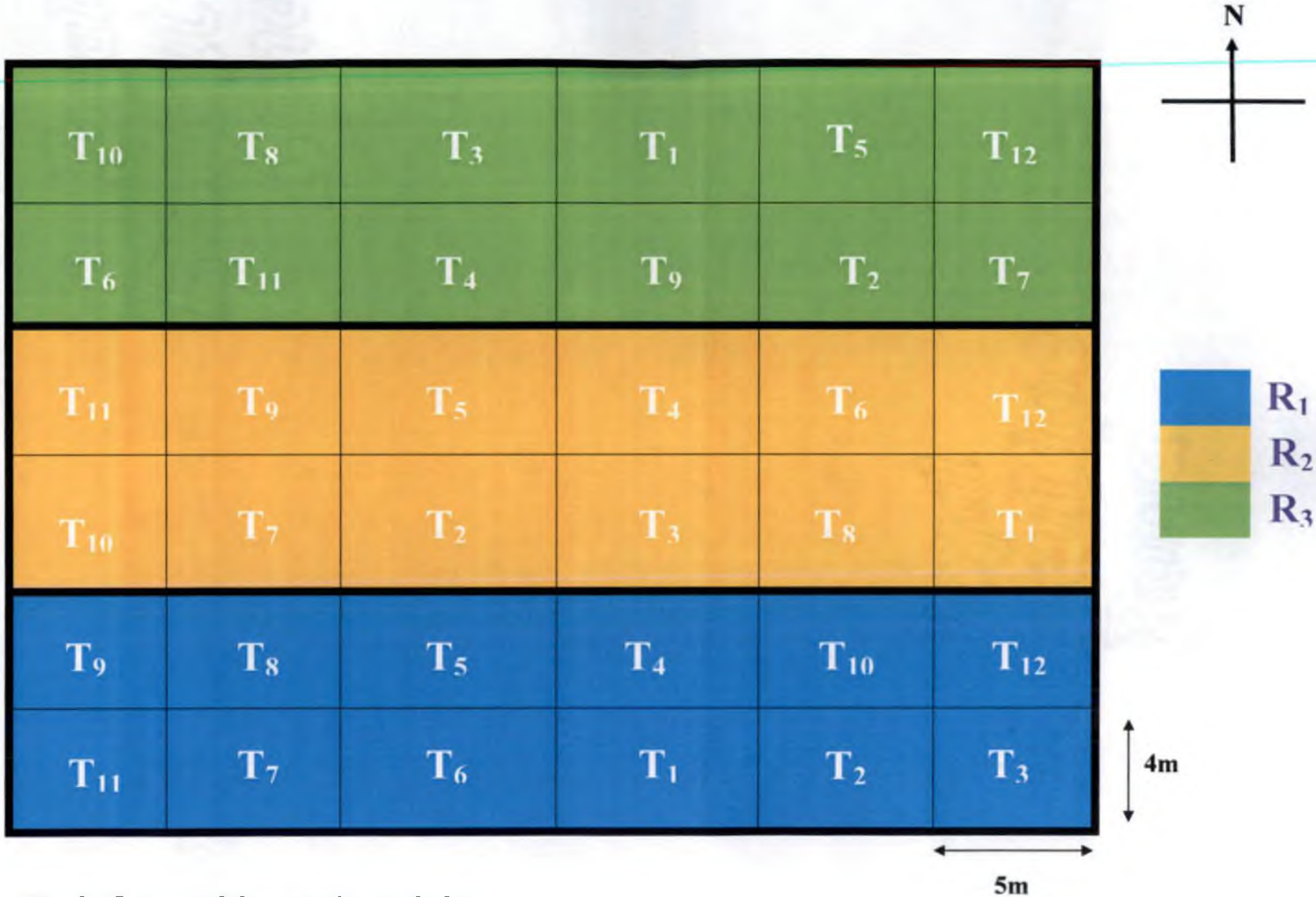

Fig. 3.1 Layout of the experimental plot

Table 3.2 Treatment details

Treatments	
T_1	**FYM @ 5t/ha + Soil test based nutrient package + lime600kg/ha** [STNP+ FYM+ lime]
T_2	**FYM @ 5t/ha + 110:45:55kg NPK/ha + lime 600kg/ha (Existing POPR)** [POPR]
T_3	**110:45:55kg NPK/ha + lime 600 kg/ha** [POPR without FYM]
T_4	**FYM @ 5t/ha + 110:45:85kg NPK/ha + lime 600 kg/ha** [110:45:85 kg NPK+FYM+lime]
T_5	**FYM @ 5t/ha + 110:45:110kg NPK/ha + lime 600kg/ha** [110:45:110kg NPK+FYM+lime]
T_6	**FYM @ 5t/ha + POP NPK + MgO 20 kg /ha + lime 600 kg/ha** [POP+ MgO]
T_7	**FYM @ 5t/ha + POP NPK + Silica (sodium silicate) 100 kg/ha + lime 600 kg/ha** [POP+ sodium silicate]
T_8	**FYM @ 5t/ha + POP NPK + Silica (calcium silicate) 100 kg/ha + lime 600 kg/ha** [POP+ calcium silicate]
T_9	**FYM @ 5t/ha + POP NPK+ Silica (sodium silicate) 100kg/ha** [POP+ sodium silicate without lime]
T_{10}	**FYM @ 5t/ha + POP NPK + Borax 10 kg/ha + lime 600kg/ha** [POP+ borax]
T_{11}	**FYM @ 5t/ha + POP NPK + MgO 20 kg /ha + Silica 100 kg/ ha + Borax 10 kg/ ha + lime 600kg/ha** [POP+ MgO+ silica(sodium silicate)+borax]
T_{12}	**Absolute control**

* The soil test based nutrient requirement was estimated as 93:48:59 kg N, P_2O_5 and K_2O ha^{-1}.

Table 3.3 Sources of nutrients

Nutrients	Fertilizer	Nutrient content (%)
Nitrogen	Urea	46
Phosphorous	Rajphos	18
Potassium	Muriate of potash	60
Magnesium oxide (MgO)	Magnesium sulphate	45
Silica	Sodium silicate	20
	Calcium silicate	24
Boron	Borax	11

3.3 Crop culture

3.3.1 Land preparation, sowing and fertilizer application

Plots of 5m x 4m were taken after ploughing and leveling the field. The lime @ 350 kg ha^{-1} and silica in respective treatments as per the technical programme were applied basally at the time of first ploughing. Remaining dose of lime @250kg/ha was applied one month after sowing. FYM was applied after 10 days. Urea, Rajphos Muriate of potash, Magnesium sulphate and Borax were applied 15 days after ploughing and before sowing as per the treatments in the experiment. N was applied in three equal splits as basal, maximum tillering and at panicle initiation stage, K was applied in two equal splits at basal and at panicle initiation and borax was applied in two equal split doses at basal and at flowering.

The seeds of the variety Uma were soaked in water for 12 hrs and treated with of *Pseudomonas fluorescens* @10g per litre of water per kg of seed. The water was drained after 12 hours and the seeds were incubated in moist cloth bag for sprouting. The germinated seeds were used for sowing. The seeds were broadcasted at the rate of 100 kg/ha. Date of sowing was on 14.11.2013.

3.3.2 After cultivation and plant protection

The cultural operations were carried out as per the Package of Practices recommendations of the Kerala Agricultural University (KAU, 2011). The plots and bunds were kept weed free by hand weeding. Plant protection measures were taken up against leaf folder and Ekalux @2ml lit^{-1} was sprayed when incidence of leaf folder was noticed.

3.3.3 Harvesting

The crop was harvested on 20.3.2014. Plants in the two border rows from all sides of each plot were harvested first and net plot area was harvested. Threshing was done with mechanical thresher (Redlands mechanical thresher and winnower) and grain and straw were separated and the weight was recorded. The weight of grain is expressed at 12 per cent moisture content and that of straw as air dry weight in kg ha^{-1}.

3.4 Observations recorded

3.4.1 Biometric observations

3.4.1.1 Plant height

Height of five plants was measured in cm from ground level to the tip of the longest leaf at 30 and 60 days after sowing (DAS) and height of 10 plants were measured at harvest.

3.4.1.2 Tiller count/m^2

The number of tillers per m^2 was counted at five random places from each plot using a quadrant and the mean was worked out, at 30 and 60 DAS and at harvest.

3.4.1.3 Dry matter production

Five plants were uprooted, cleaned and oven dried at 80±5 ^{0}C and dry weight was recorded at 30 and 60 DAS and at harvest.

3.4.1.4 Leaf Area Index (LAI)

Leaf area index is the ratio of leaf area to ground area. The leaf area was measured using Leaf Area Meter (CI-202 Area Meter) from the randomly selected plants at 60 DAS and leaf area was worked out using the formula

$$\text{Leaf area index (LAI)} = \frac{\text{Total leaf area of plant}}{\text{Land area}} \times 100$$

3.4.1.5 Number of panicles per m^2

Number of panicles per m^{-2} was counted from five random places per plot using a quadrant and the mean was worked out.

3.4.1.6 Number of spikelets per panicle

The number of spikelets per panicle was counted from twenty five randomly selected panicles and mean was worked out.

3.4.1.7 Percentage of filled grain

Grains were collected from randomly selected twenty five plants and separated into filled grains and chaff. The number of filled grains was counted and expressed as percentage of total grain.

3.4.1.8 Thousand grain weight

One thousand filled grains taken randomly were weighed to get the test weight.

3.4.1.9 Grain and Straw yield

The crop was harvested from each plot, threshed, winnowed and grain and straw were separated. The weight of grain and straw from each plot was recorded separately and expressed in t ha^{-1}.

3.4.2. Physiological characters

3.4.2.1 Chlorophyll content

The top most fully opened leaves were collected from five randomly selected plants for chlorophyll estimation. For analysis, 0.2 gm of finely cut sample of leaf was taken in a beaker and 10 ml DMSO (Dimethyl Sulphoxide) solution was added. This was kept in dark place overnight and then made up to 25 ml in a volumetric flask after filtering on the next day. The chlorophyll content was estimated colorimetrically (Yoshida *et al.*, 1972) in a Spectronic- 20 Spectrophotometer at two wave lengths i.e.

663 and 645 nm. Using the equation given below, chlorophyll a, chlorophyll b and total chlorophyll contents were computed at 60 DAS and expressed as mg g^{-1} fresh weight.

Chlorophyll a = 12.7x OD @ 663nm- 2.69.\OD@ 645nm x V/Wx1000

Chlorophyll b = 22.9x OD @ 645nm- 4.63\OD@ 663nm x V/Wx1000

Total chlorophyll = 8.02x OD @ 663nm + 20.2xOD@ 645nm x V/Wx1000

OD - Optical Density, V - Volume made up, W- Weight of sample

3.4.3 Scoring of diseases

In each treatment diseased samples were collected from one m^2 area and the number of infected plants and total number of plants were recorded.

Scoring was done based on the Standard Evaluation Systems (SES) of Rice (IRRI, 1996) as detailed below:

Sl. No.	Description (% diseased leaf area)	Grade/ scale
1	1 – 5	1
2	6-12	3
3	13-25	5
4	26 – 50	7
5	51 – 100	9

The percent of disease incidence (PDI) was calculated using the formula.

$$\text{PDI} = \frac{\text{Total no. of infected plants}}{\text{Total no. of plants observed}} \times 100$$

3.4.4 Scoring of pests

Ten plants were randomly selected from each treatment and incidence of pests was noticed. The number of damaged leaves along with undamaged ones was recorded and per cent infestation was determined using the following formula

$$\%\ \text{Infestation} = \frac{\text{Number of damaged leaves}}{\text{Total number of leaves}} \times 100$$

% infestation was converted to a 0-9 score as follows (Shah *et al.*, 2008)

% Infestation	Scores
0	0
1-10	1
11-30	3
31-50	5
51-75	7
More than 75	9

3.4.5. Chemical analysis

3.4.5.1 Soil analysis

Samples were collected from the experimental plots following standard procedures- Soil samples air dried, powdered and passed through 2 mm sieve, were used for analyzing physico- chemical characteristics of the soil. Soil samples were collected from each plot and were analyzed before and after the experiment. pH and EC of soil were measured at two weeks interval. The various methods used for the analysis are given in Table 3.5

3.4.5.2 Plant analysis

For plant analysis five plants were selected at random from each plot. Plant samples were collected at 30 and 60 DAS and at harvest for analysis. After cleaning the samples, leaf blades and sheath were separated, dried in a hot air oven at 60 ± 5°C, powdered well and analyzed for different nutrients. The method used for the analysis of different nutrients are given in Table 3.6

3.4.6 Uptake of nutrients

Uptake of nutrients for each nutrient is calculated by multiplying the particular nutrient content in grain and straw at harvest with dry matter production at harvest.

3.4.7 Economics of cultivation

The cost of cultivation, gross returns and benefit: cost ratio (gross return/cost of cultivation) was calculated on the basis of prevailing market price of different inputs and outputs. The price of paddy and that of straw at current local market prices were taken as Rs. 19 and Rs. 2 per kg respectively. Benefit cost ratio was worked out by dividing the gross return with total expenditure per hectare.

3.4.8 Statistical analysis

Statistical packages such as MSTAT - C and Microsoft excel spread sheets were used for computation and analysis (Freed, 1986). Duncan's multiple range test (DMRT) was used to compare means (Duncan, 1955; Gomez and Gomez, 1984).

Table 3.4 Method used for soil analysis

No.	Particulars	Method
1	Particle size analysis	International Pipette Method (Robinson, 1922)
2	Soil reaction (pH)	Soil water suspension of 1:2.5 and read in pH meter (Jackson,1958)
3	Electrical conductivity	Soil water suspension of 1:2.5 and read in pH meter (Jackson,1958)
4	Organic carbon	Walkley and Black method (Walkley and Black, 1934)
5	Available N	Alkaline permanganate method (Subbiah and Asija, 1956)
6	Available P	Ascorbic acid reduced molybdophosphoric blue colour method (Bray and Kurtz, 1945; Wattanabe and Olsen, 1965)
7	Available K	Neutral normal ammonium acetate extract using flame photometer (Jackson, 1958)
8	Available Ca	Neutral normal ammonium acetate extract using Atomic Absorption Spectrophotometer (Jackson, 1958)
9	Available Mg	Neutral normal ammonium acetate extract using Atomic Absorption Spectrophotometer (Jackson, 1958)
10	Available S	$CaCl_2$ extract- turbidimetry method (Chesnin and Yien, 1951)
11	Available Fe, Zn & Mn	0.1M HCl acid extract method using Atomic Absorption Spectrophotometer (Sims and Johnson, 1991)
12	Available B	Hot water extraction and Azomethine- H method using Spectrophotometer (Berger and Truog, 1945; Gupta, 1967)
13	Available Si	Rapid microdetermination of silicon (Nayar *et al.*, 1975)

Table 3.5 Method used for plant analysis

No.	Nutrient	Method
1	N	Microkjeldhal digestion and distillation method (Jackson, 1958)
2	P	Diacid digestion of leaf sample followed by filtration. Vandadomolybdate phosphoric yellow colour in nitric acid system (Piper, 1966)
3	K	Diacid extract using Perkin-Elmer Atomic Absorption Spectrophotometer (Piper, 1966)
4	Ca	Diacid extract using Atomic Absorption Spectrophotometer (Piper, 1966)
5	Mg	Diacid extract using Atomic Absorption Spectrophotometer (Piper, 1966)
6	Fe, Zn &Mn	Diacid extract using Perkin- Elmer Atomic Absorption Spectrophotometer (Piper, 1966)
7	B	By dry ashing (Gaines and Mitchell, 1979) and Azomethine-H method (Bingham, 1982)
8	Si	Blue silico molybdous acid method (Ma *et al.*, 2002)

Plate 1. Bunds preparation after land preparation

Plate 2. Basal application of fertilizers

Plate 3. General view of experimental plot at 30 DAS

Plate 4. General view of experimental plot at 80 DAS

Plate 5. Manual harvesting of the crop at harvest

Plate 6. Threshing and winnowing of harvested produce with mechanical thresher cum winnower

Results

IV. RESULTS

A field experiment on "Soil amelioration and nutrient management of rice in kole lands" was conducted during the second crop season of 2013-2014 in farmer's field at Ponnamutha Kole padavu of Venkitangu Panchayath in the Kole lands of Thrissur district. The data obtained from the experiment are described here with appropriate tables after statistical analysis.

4.1 Biometric characters

4.1.1 Plant height

The data revealed that application of nutrients and soil ameliorants had significant effect on plant height of rice compared to control (Table 4.1). Even though plant height did not show much variation among the treatments at 30 days after sowing (DAS), the tallest plants (67.53 cm) were produced by combined application of magnesium, boron and silica (T_{11}) which had comparable height with application of sodium silicate (T_7) at 60DAS. The plant height at harvest showed comparable values for treatments T_7, T_{10} and T_{11}. Application of highest dose of K (T_5) produced taller plants at all stages of growth compared to lower doses. Among the sources of silica, no considerable variation was noticed. The soil test based nutrient package (T_1) as well as POPR (T_2) recorded lower values for plant height during all growth stages of rice.

4.1.2 Tiller count/m^2

The data on tiller count at 30 and 60 DAS and at harvest are presented in Table 4.2. Tiller count at 30 DAS was the highest (331.8 m^{-2}) by combined application of magnesium, boron and silica (T_{11}) followed by boron application (T_{10}). Application of nutrients as per soil test (T_1) produced more number of tillers compared to POPR (T_2). Highest dose of K (T_5) recorded higher number of tillers than the lower dose (T_4). Both the sources of silica, sodium silicate (T_7) and calcium silicate (T_8) produced comparable number of tillers at 30 DAS. Sodium silicate without lime (T_9) showed comparatively lesser tiller count than that with lime. Lowest tiller count (177.0 m^{-2}) was recorded in control plot (T_{12}).

Table 4.1 Effect of nutrients and soil ameliorants on plant height (cm) of rice

Treatments		30 DAS	60 DAS	Harvest
T_1	STNP+ FYM+ lime	35.00^c	56.87^e	81.57^{cd}
T_2	POPR	36.53^{bc}	59.00^{de}	80.47^{cd}
T_3	POPR without FYM	37.67^b	56.67^e	78.80^d
T_4	110:45:85 kg NPK+FYM+lime	40.73^a	62.00^{cd}	82.27^c
T_5	110:45:110kg NPK+FYM+lime	41.60^a	62.93^c	85.33^b
T_6	POPR+ MgO	41.60^a	63.07^c	86.40^b
T_7	POPR+ sodium silicate	41.27^a	67.47^a	90.33^a
T_8	POPR+ calcium silicate	40.47^a	63.80^{bc}	87.63^b
T_9	POPR+ sodium silicate without lime	40.07^a	63.33^c	86.70^b
T_{10}	POPR+ borax	41.47^a	66.80^{ab}	91.23^a
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	41.27^a	67.53^a	90.93^a
T_{12}	Absolute control	21.47^d	45.77^f	66.60^e

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Table 4.2 Effect of nutrients and soil ameliorants on tiller count/m^2

Treatments		30 DAS	60 DAS	Harvest
T_1	STNP+ FYM+ lime	221.20^{c}	530.90^{ab}	371.80^{ab}
T_2	POPR	210.10^{cd}	545.60^{ab}	365.50^{b}
T_3	POPR without FYM	158.40^{e}	453.50^{c}	253.70^{c}
T_4	110:45:85 kg NPK+FYM+lime	228.60^{c}	541.90^{ab}	359.20^{b}
T_5	110:45:110 kg NPK+FYM+lime	280.20^{b}	538.30^{ab}	359.20^{b}
T_6	POPR+ MgO	272.80^{b}	545.60^{ab}	371.80^{ab}
T_7	POPR+ sodium silicate	294.90^{ab}	538.30^{ab}	381.30^{ab}
T_8	POPR+ calcium silicate	294.90^{ab}	553.00^{a}	378.20^{ab}
T_9	POPR+ sodium silicate without lime	280.20^{b}	519.80^{b}	365.50^{b}
T_{10}	POPR+ borax	309.70^{ab}	538.30^{ab}	382.80^{ab}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	331.80^{a}	534.60^{ab}	400.30^{a}
T_{12}	Absolute control	177.00^{de}	309.70^{d}	211.70^{d}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

At 60 DAS tiller count increased compared to 30 DAS. Calcium silicate application (T_8) recorded the highest tiller count (553.0 m^{-2}) at 60 DAS. Soil test based nutrient application (T_1), POPR (T_2), different doses of K (T_4 and T_5), magnesium application (T_6), sodium silicate application (T_7), application of boron (T_{10}) and combined application of magnesium, boron and silica (T_{11}) did not influence the tiller count and were on par with each other. Sodium silicate application without lime (T_9) was better in tiller production when compared to POPR without FYM (T_3). Tiller count at 60 DAS was the lowest (309.7 m^{-2}) in control treatment (T_{12}).

In the case of tiller count at harvest, the scenario had changed and there was a decline in tiller count at harvest. Combined application of magnesium, boron and silica recorded the highest tiller count (400.3 m^{-2}) at harvest followed by boron application (T_{10}). POPR (T_2) and sodium silicate application without lime (T_9) produced more number of tillers compared to POPR without FYM (T_3). Lowest number of tillers (211.7 m^{-2}) was recorded in control plot (T_{12}).

4.1.3 Leaf area index (LAI)

The data on LAI are given in Table 4.3. In case of LAI, combined application of magnesium, boron and silica (T_{11}) showed highest LAI (4.84) followed by calcium silicate treatment (T_8) and sodium silicate (T_7) which were comparable. Soil test based nutrient package (T_1) and POPR (T_2) was better in LAI than POPR without FYM (T_3). Higher doses of K (T_4 and T_5) recorded more LAI than the recommended dose (T_2). Sodium silicate application with lime (T_7) gave better results for LAI than that without lime application. Least LAI was observed in control treatment (2.89).

4.1.4 Chlorophyll content

The treatment effects on chlorophyll 'a', chlorophyll 'b' and total chlorophyll at 60 DAS are presented in Table 4.4. The chlorophyll a content of leaves was highest (1.447 mg g^{-1} tissue) for T_{10} which was comparable with T_{11} and the lowest (0.846 mg g^{-1} tissue) was recorded by T_{12}. Application of FYM showed significant effect on chlorophyll 'a' content of leaves. Application of higher doses of K and magnesium did not influence the chlorophyll 'a' content while the application of silica as sodium silicate (T_7) recorded more chlorophyll 'a'

Table 4.3 Effect of nutrients and soil ameliorants on LAI

Treatments		LAI
T_1	STNP+ FYM+ lime	4.20[d]
T_2	POPR	4.28[d]
T_3	POPR without FYM	3.99[e]
T_4	110:45:85 kg NPK+FYM+lime	4.35[cd]
T_5	110:45:110 kg NPK+FYM+lime	4.48[c]
T_6	POPR+ MgO	4.65[b]
T_7	POPR+ sodium silicate	4.67[ab]
T_8	POPR+ calcium silicate	4.81[ab]
T_9	POPR+ sodium silicate without lime	4.65[b]
T_{10}	POPR+ borax	4.75[ab]
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	4.84[a]
T_{12}	Absolute control	2.89[f]

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Table 4.4 Effect of nutrients and soil ameliorants on chlorophyll content at 60 DAS (mg kg^{-1})

Treatments		Chl. a	Chl. B	Total Chl.
T_1	STNP+ FYM+ lime	1.183^{bc}	0.456^{abc}	2.660^{cd}
T_2	POPR	1.227^{bc}	0.530^{ab}	2.827^{bc}
T_3	POPR without FYM	0.950^{d}	0.320^{c}	2.093^{e}
T_4	110:45:85 kg NPK+FYM+lime	1.127^{c}	0.440^{abc}	2.547^{d}
T_5	110:45:110 kg NPK+FYM+lime	1.223^{bc}	0.513^{abc}	2.803^{bc}
T_6	POPR+ MgO	1.287^{b}	0.420^{bc}	2.823^{bc}
T_7	POPR+ sodium silicate	1.283^{b}	0.433^{abc}	2.827^{bc}
T_8	POPR+ calcium silicate	1.243^{bc}	0.586^{ab}	2.917^{b}
T_9	POPR+ sodium silicate without lime	1.250^{bc}	0.450^{abc}	2.777^{bc}
T_{10}	POPR+ borax	1.447^{a}	0.543^{ab}	3.243^{a}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	1.437^{a}	0.633^{a}	3.323^{a}
T_{12}	Absolute control	0.8467^{d}	0.406^{bc}	2.000^{e}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

content in leaves than as calcium silicate application (T_8). The application of silica as sodium silicate without lime (T_9) did not have any significant effect on chlorophyll 'a' content.

The chlorophyll 'b' content of leaves also followed a similar trend to that of chlorophyll 'a' content with highest content in T_{11}(0.633 mg g^{-1} tissue) and lowest in T_{12}. Application of FYM (T_2) showed a positive effect while application of higher dose of K (T_4 and T_5) did not produce significant effect with respect to chlorophyll 'b' content. Application of magnesium (T_6) and silica had profound influence on chlorophyll 'b' content but considerable variation was not noticed due to sources of silica (T_6 and T_7).

The total chlorophyll content also had similar trend as that of chlorophyll 'a' and 'b' with highest content in T_{11} (3.323 mg g^{-1}). Application of POPR (T_2), highest dose of K (T_5), magnesium application (T_6) and both source of silica (T_7 and T_8) recorded comparable total chlorophyll content. POPR without FYM (T_3) recorded lower amounts of total chlorophyll content.

4.1.5 Dry matter production

The dry matter production at 30 DAS, 60 DAS and at harvest by the application of various treatments is presented in Table 4.5. The dry matter production at 30 DAS was highest by combined application of magnesium, boron and silica (T_{11}) followed by application of calcium silicate (T_8), sodium silicate (T_7) and boron application (T_{10}). Highest dose of K (T_5) recorded better dry matter production than lower dose (T_4). POPR (T_2) and magnesium application (T_6) showed similar effect on dry matter production at 30 DAS. POPR with FYM had significant effect on dry matter production compared to that without FYM (T_3). The lowest dry matter content of 0.58 t ha^{-1} was noted in control treatment (T_{12}) at 30 DAS.

Dry matter production at 60 DAS was highest (4.97 t ha^{-1}) by combined application of magnesium, boron and silica (T_{11}) and sodium silicate applied treatment (T_7). POPR (T_2) was better than soil test based nutrient application (T_1) at 60 DAS and both showed better results than T_3. Higher doses of K (T_4 and T_5) produced higher dry matter compared to T_2. Among the sources of silica, application of silica as sodium silicate (T_7) produced higher dry matter than as calcium silicate (T_8).

Table 4.5 Effect of nutrients and soil ameliorants on dry matter production (t ha^{-1})

Treatments		30 DAS	60 DAS	Harvest
T_1	STNP+ FYM+ lime	1.46^{d}	3.69^{d}	13.75^{d}
T_2	POPR	1.51^{b}	4.02^{c}	13.68^{d}
T_3	POPR without FYM	1.32^{e}	3.37^{e}	11.43^{e}
T_4	110:45:85 kg NPK+FYM+lime	1.55^{c}	3.98^{cd}	14.42^{c}
T_5	110:45:110 kg NPK+FYM+lime	1.66^{b}	4.15^{bc}	14.85^{c}
T_6	POPR+ MgO	1.50^{c}	4.77^{a}	14.51^{c}
T_7	POPR+ sodium silicate	1.66^{b}	4.97^{a}	15.75^{ab}
T_8	POPR+ calcium silicate	1.68^{b}	4.17^{bc}	15.37^{b}
T_9	POPR+ sodium silicate without lime	1.46^{c}	4.13^{c}	14.83^{c}
T_{10}	POPR+ borax	1.66^{b}	4.46^{b}	15.57^{b}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	1.82^{a}	4.97^{a}	16.14^{a}
T_{12}	Absolute control	0.58^{f}	2.25^{f}	8.27^{f}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Boron application (T_{10}) resulted in dry matter production of 4.46 t ha^{-1} and least dry matter production of 2.25 t ha^{-1} was observed in control treatment (T_{12}) at 60 DAS.

Dry matter production at harvest also showed the same trend as that at 60 DAS with the highest (16.14 t ha^{-1}) dry matter by combined application of magnesium, boron and silica (T_{11}). Boron applied treatment (T_{10}) and calcium silicate applied treatment (T_8) produced comparable dry matter production at harvest. Soil test based nutrient application (T_1) and POPR (T_2) showed higher dry matter than POPR without FYM (T_3). Higher doses of K (T_4 and T_5) and magnesium application (T_6) did not show variation in dry matter production and had comparable values. Among sources of silica, sodium silicate (T_7) was better than calcium silicate (T_8) in dry matter production. Lime application with sodium silicate was comparatively better for dry matter production than that without lime. Least (8.27 t ha^{-1}) dry matter at harvest was observed in control treatment (T_{12}).

4.2 Yield attributes

4.2.1 Number of Panicles/m^2

The effect of application of nutrients and soil ameliorants on number of panicles/ m^2 is shown in Table 4.6. The highest number of panicles/m^2 was obtained by combined application of magnesium, borax and silica (T_{11}) followed by boron (T_{10}) and sodium silicate application (T_7). POPR with FYM (T_2) produced more number of tillers compared to POPR without FYM (T_3). Lowest number of panicles/m^2 (211.7 m^{-2}) was recorded in control plot (T_{12}).

4.2.2 Number of spikelets per panicle

The effect of application of nutrients and soil ameliorants on number of spikelets per panicle is shown in Table 4.6. Number of spikelets per panicle was highest (100.4) with combined application of magnesium, boron and silica (T_{11}). Soil test based nutrient application (T_1) and POPR (T_2) produced higher number of spikelets compared to application of nutrients as per POPR without FYM (T_3). Highest dose of K (T_5) resulted in significantly more number of spikelets than lower dose (T_4). Among the sources of silica, sodium silicate application (T_7) gave better results in spikelet number compared to calcium silicate. Application of lime with silica (T_7) was better option for higher number of spikelets than without lime application (T_9). Boron application (T_{10}) also resulted in increased spikelets

Table 4.6 Effect of nutrients and soil ameliorants on yield attributes of rice

	Treatments	Panicles/ m^2 (No.)	Spikelets/ panicle (No.)	Filled grain/ panicle (%)	1000 grain wt. (g)
T_1	STNP+ FYM+ lime	371.80^{ab}	87.63^{e}	85.68^{de}	23.57^{d}
T_2	POPR	365.50^{b}	87.60^{e}	85.45^{de}	24.61^{bc}
T_3	POPR without FYM	253.70^{c}	68.63^{f}	84.64^{e}	23.38^{d}
T_4	110:45:85 kg NPK+FYM+lime	359.20^{b}	88.84^{e}	88.35^{cd}	24.48^{c}
T_5	110:45:110 kg NPK+FYM+lime	359.20^{b}	94.99^{c}	88.38^{cd}	25.34^{ab}
T_6	POPR+ MgO	371.80^{ab}	90.32^{de}	88.29^{cd}	25.39^{ab}
T_7	POPR+ sodium silicate	381.30^{ab}	98.79^{ab}	90.92^{bc}	25.71^{a}
T_8	POPR+ calcium silicate	378.20^{ab}	91.61^{d}	90.20^{bc}	25.76^{a}
T_9	POPR+ sodium silicate without lime	365.50^{b}	90.32^{de}	88.06^{cd}	22.90^{d}
T_{10}	POPR+ borax	382.80^{ab}	96.41^{bc}	94.30^{a}	26.07^{a}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	400.30^{a}	100.40^{a}	92.67^{ab}	26.00^{a}
T_{12}	Absolute control	211.70^{d}	52.07^{g}	64.94^{f}	21.05^{e}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

number compared to POPR. Number of spikelets per panicle (52.07) was lowest in control treatment (T_{12}).

4.2.3 Per cent of Filled grains

The effect of treatments on per cent filled grains per panicle is given in Table 4.6. Significantly highest percentage of filled grains (94.3%) was observed with application of boron (T_{10}) followed by combined application of magnesium, boron and silica (T_{11}). Soil test based nutrient application (T_1) and POPR (T_2) showed lower per cent for filled grain but higher than POPR without FYM (T_3). Higher doses of K (T_4 and T_5) and magnesium application (T_6) did not show much variation for filled grain percentage. Both the sources of silica, sodium silicate (T_7) and calcium silicate (T_8) had comparable effect on grain filling, but it was higher than sodium silicate without lime (T_9). The lowest amount of filled grains was recorded by the control plot (64.94 %).

4.2.4 Thousand grain weight

The data on thousand grain weight are shown in Table 4.6. Combined application of magnesium, boron and silica (T_{11}), application of boron (T_{10}), sodium silicate (T_7) and calcium silicate applications (T_8) recorded significantly higher thousand grain weight which was on par with higher dose of K (T_5) and magnesium application (T_6). POPR (T_2) was better than soil test based nutrient application (T_1) with respect to weight of thousand grains. POPR without FYM (T_3) and sodium silicate application without lime (T_9) showed comparatively less thousand grain weight and thousand grain weight in these treatments were less than POPR. The control treatment resulted in the lowest thousand grain weight of 21.05 g.

4.3 Yield

4.3.1 Grain yield

The effect of nutrients and soil ameliorants on grain yield is shown in Table 4.7. Application of nutrients and soil ameliorants had significant effect on yield. Grain yield was the highest (7.95 t ha^{-1}) in combined application of magnesium, boron and silica (T_{11}) followed by boron applied treatment (T_{10}) and sodium silicate applied treatment (T_7). Soil test based nutrient application (T_1), POPR (T_2) and higher doses of K (T_4 and T_5) and magnesium

Table 4.7 Effect of nutrients and soil ameliorants on grain and straw yield (t ha^{-1}) and Harvest index (HI)

Treatments		Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	HI
T_1	STNP+ FYM+ lime	6.45^{c}	7.11^{c}	0.47^{abc}
T_2	POPR	6.32^{c}	7.35^{d}	0.45^{cde}
T_3	POPR without FYM	5.36^{d}	6.07^{f}	0.46^{bcd}
T_4	110:45:85 kg NPK+FYM+lime	6.42^{c}	8.00^{bc}	0.43^{fg}
T_5	110:45:110 kg NPK+FYM+lime	6.56^{c}	8.28^{a}	0.43^{fg}
T_6	POPR+ MgO	6.23^{c}	8.27^{a}	0.42^{g}
T_7	POPR+ sodium silicate	7.62^{a}	8.13^{ab}	0.47^{ab}
T_8	POPR+ calcium silicate	7.18^{b}	8.18^{ab}	0.47^{ab}
T_9	POPR+ sodium silicate without lime	6.55^{c}	8.28^{a}	0.44^{efg}
T_{10}	POPR+ borax	7.67^{a}	7.89^{c}	0.48^{a}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	7.95^{a}	8.19^{ab}	0.48^{a}
T_{12}	Absolute control	3.77^{e}	4.50^{g}	0.45^{def}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

(T_6) recorded comparable yield and they were better when compared to POPR without FYM application. Sodium silicate (T_7) was noticed to be a better source for higher grain yield than calcium silicate application (T_8). The grain yield (3.77 t ha^{-1}) was the lowest in control treatment (T_{12}).

4.3.2 Straw yield

The effect of nutrients and soil ameliorants on straw yield is shown in Table 4.7. In case of straw yield a different trend was noticed. The highest straw yield of 8.28 t ha^{-1} was recorded in two treatments i.e. highest dose of K (T_5) applied plot and sodium silica without lime treatment (T_9). POPR recorded better straw yield compared to soil test based nutrient applied treatment (T_1) and POPR without FYM (T_3). Both the sources of silica (T_7 and T_8) and combination of magnesium, boron and silica (T_{11}) showed comparable straw yield. There was a profound decrease in straw yield in control treatment (T_{12}) and it recorded the lowest straw yield of 4.50 t ha^{-1}.

4.4 Harvest index (HI)

The effect of various treatments on harvest index is shown in Table 4.7. Combined application of magnesium, boron and silica (T_{11}) and application of boron (T_{10}) recorded significantly highest harvest index (0.48) which was on par with sodium silicate (T_7) and calcium silicate applications (T_8). Soil test based nutrient application (T_1) recorded more HI than POPR (T_2). Higher doses of K (T_4 and T_5) recorded comparable harvest index and were relatively lower than POPR. Magnesium application (T_6) recorded least HI (0.42).

4.5 Nutrient status of plants

4.5.1 Nitrogen content of plant

The nitrogen contents of plant at 60 DAS and in grain and straw at harvest is presented in Table 4.8. The combined application of magnesium, boron and silica (T_{11}), application of boron (T_{10}) and both sources of silica, sodium silicate (T_7) and calcium silicate (T_8) did not produce significant difference in N content of plant (2.82 %) at 60 DAS. It was followed by magnesium application (T_6) and higher doses of K (T_4 and T_5). Soil test based

Table 4.8 Effect of nutrients and soil ameliorants on nitrogen content of rice (%)

Treatments		60 DAS	Harvest	
			Grain	Straw
T_1	STNP+ FYM+ lime	2.45^{cd}	1.35^{ab}	0.72^{abc}
T_2	POPR	2.38^{d}	1.29^{cde}	0.69^{cd}
T_3	POPR without FYM	1.88^{e}	1.07^{f}	0.53^{e}
T_4	110:45:85 kg NPK+FYM+lime	2.50^{c}	1.24^{e}	0.72^{abc}
T_5	110:45:110 kg NPK+FYM+lime	2.55^{bc}	1.28^{cde}	0.75^{ab}
T_6	POPR+ MgO	2.64^{b}	1.31^{bcd}	0.75^{ab}
T_7	POPR+ sodium silicate	2.78^{a}	1.38^{a}	0.74^{abc}
T_8	POPR+ calcium silicate	2.74^{a}	1.32^{abc}	0.77^{a}
T_9	POPR+ sodium silicate without lime	2.45^{cd}	1.09^{f}	0.64^{d}
T_{10}	POPR+ borax	2.80^{a}	1.26^{de}	0.70^{bc}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	2.82^{a}	1.38^{a}	0.75^{abc}
T_{12}	Absolute control	1.72^{f}	0.77^{g}	0.41^{f}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

nutrient application (T_1) was found better in N content compared to POPR (T_2) and POPR without FYM (T_3).

In the case of N content of grain at harvest, combined application of magnesium, boron and silica (T_{11}) and sodium silicate application along with POPR (T_7) recorded the highest N content of 1.38%, which was on par with soil test based nutrient application (T_1). Application of higher dose of K (T_5) increased the N content of grain than lower dose (T_4). Boron application and application of sodium silicate without lime (T_9) resulted in lower N content in grain compared to POPR.

The N content in straw was highest (0.77 %) in calcium silicate applied treatment (T_8), followed by highest dose of K (T_5). Soil test based nutrient application (T_1), sodium silicate application (T_7) and combined application of magnesium, boron and silica (T_{11}) were also found to be better in N content compared to POPR. The absolute control treatment resulted in the lowest N content of 1.72%, 0.77% and 0.41% in plant at 60 DAS, in grain and straw at harvest respectively.

4.5.2 Phosphorous content of plant

The phosphorous content of plant analyzed at 60 DAS and in grain and straw at harvest is shown in Table 4.9. P content varied from 0.07% to 0.43% at 60 DAS due to various treatments. The highest P content of 0.43% at 60 DAS was observed in combined application of magnesium, boron and silica (T_{11}) treatment followed by boron application (T_{10}). Soil test based nutrient application (T_1), POPR (T_2) and higher doses of K (T_4 and T_5) recorded comparable P content of plant. Both the sources of silica (T_7 and T_8) did not show variation in P content and had comparable values. The content of P in plant at 60 DAS was lowest (0.07%) in control treatment (T_{12}).

At harvest, P content of grain did not show much variation among the treatments. P content in grain ranged from 0.19% to 0.40%. All the treatments were on par with each other for P content except POPR without FYM (T_3) and control (T_{12}). The lowest P content in plant was recorded in control treatment (T_{12}).

In the case of straw, P content varied from 0.14% to 0.40%. Highest P content in straw was noticed in soil test based nutrient applied treatment (T_1). All other treatments except control recorded comparable P content in straw. The control plot showed lowest P content of 0.14%.

Table 4.9 Effect of nutrients and soil ameliorants on phosphorous content of rice (%)

Treatments		60 DAS	Harvest	
			Grain	Straw
T_1	STNP+ FYM+ lime	0.27[bc]	0.39[a]	0.40[a]
T_2	POPR	0.22[bc]	0.39[ab]	0.30[ab]
T_3	POPR without FYM	0.16[cd]	0.30[b]	0.26[b]
T_4	110:45:85 kg NPK+FYM+lime	0.26[bc]	0.38[ab]	0.27[b]
T_5	110:45:110 kg NPK+FYM+lime	0.26[bc]	0.40[a]	0.30[ab]
T_6	POPR+ MgO	0.29[b]	0.32[ab]	0.33[ab]
T_7	POPR+ sodium silicate	0.27[bc]	0.34[ab]	0.31[ab]
T_8	POPR+ calcium silicate	0.26[bc]	0.38[ab]	0.28[b]
T_9	POPR+ sodium silicate without lime	0.21[bc]	0.39[ab]	0.27[b]
T_{10}	POPR+ borax	0.30[b]	0.36[ab]	0.32[ab]
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	0.43[a]	0.39[ab]	0.33[ab]
T_{12}	Absolute control	0.07[d]	0.19[c]	0.14[c]

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

4.5.3 Potassium content of plant

The potassium content of plant at 60 DAS and in grain and straw at harvest is presented in Table 4.10. The application of magnesium along with POPR (T_6) recorded the highest K content of 2.70 % at 60 DAS. Higher doses of K (T_4 and T_5) and combined application of magnesium, silica and boron (T_{11}) were on par with highest K content. POPR (T_2) application was found better in K content compared to soil test based nutrient application (T_1) and POPR without FYM (T_3). Both sources of silica, sodium silicate (T_7) and calcium silicate (T_8) did not show much variation in K content and were better. Boron (T_{10}) application also recorded relatively more K content compared to POPR (T_2).

The K content in grain was highest (0.28%) in magnesium applied treatment (T_6) and . Soil test based nutrient application (T_1), POPR (T_2) and POPR without FYM (T_3) recorded comparable K contents of grain and was low. Highest dose of K (T_5) recorded higher K content than POPR. Among the sources of silica, sodium silicate without lime (T_9) was better in K content of grain when compared to calcium silicate (T_8) and sodium silicate with lime application (T_7). The lowest K content in grain was recorded by control treatment (T_{12}).

At harvest, sodium silicate application without lime (T_9), soil test based nutrient application (T_1), highest dose of K (T_5), magnesium application (T_6) and combined application of magnesium, silica and boron (T_{11}) recorded higher K content in case of straw. POPR (T_2) and higher dose of K (T_4) showed better K content when compared to POPR without FYM (T_3). Both the sources of silica sodium silicate (T_7) and calcium silicate (T_8) as well as boron application (T_{10}) showed comparable values for K content in plant.

4.5.4 Calcium content of plant

The effect of various treatments on Ca content in plant at 60 DAS and in grain and straw at harvest is shown in Table 4.11. At 60 DAS the calcium content in the plant ranged from 3498 to 4336 mg kg^{-1} due to various treatments. Application of calcium silicate (T_8) recorded highest Ca content of 4336 mg kg^{-1} which was on par with highest dose of K application (T_5). Soil test based nutrient application (T_1), higher dose of K (T_4), sodium silicate application (T_7) and boron application (T_{10}) recorded comparable values for Ca content in plant at 60 DAS and were better compared to POPR (T_2). However POPR application recorded higher value for Ca content compared to POPR without FYM application (T_3). Absolute control (T_{12}) had the lowest Ca content of 3498 mg kg^{-1}.

Table 4.10 Effect of nutrients and soil ameliorants on potassium content of rice (%)

Treatments		60 DAS	Harvest	
			Grain	Straw
T_1	STNP+ FYM+ lime	2.13[de]	0.24[h]	2.56[a]
T_2	POPR	2.15[cde]	0.24[h]	2.43[ab]
T_3	POPR without FYM	1.99[e]	0.24[h]	2.11[c]
T_4	110:45:85 kg NPK+FYM+lime	2.51[ab]	0.17[i]	2.47[ab]
T_5	110:45:110 kg NPK+FYM+lime	2.60[ab]	0.25[f]	2.59[a]
T_6	POPR+ MgO	2.70[a]	0.28[a]	2.60[a]
T_7	POPR+ sodium silicate	2.39[bcd]	0.24[g]	2.28[bc]
T_8	POPR+ calcium silicate	2.38[bcd]	0.26[d]	2.23[bc]
T_9	POPR+ sodium silicate without lime	2.45[abc]	0.28[b]	2.61[a]
T_{10}	POPR+ borax	2.41[abcd]	0.25[e]	2.23[bc]
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	2.56[ab]	0.27[c]	2.59[a]
T_{12}	Absolute control	1.53[f]	0.12[j]	1.49[d]

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Table 4.11 Effect of nutrients and soil ameliorants on calcium content of rice (mg kg^{-1})

Treatments		60 DAS	Harvest	
			Grain	Straw
T_1	STNP+ FYM+ lime	4132.00^{bc}	146.70^{ab}	4270.00^{bc}
T_2	POPR	4041.00^{c}	153.20^{ab}	4297.00^{bc}
T_3	POPR without FYM	3638.00^{e}	101.90^{d}	3908.00^{de}
T_4	110:45:85 kg NPK+FYM+lime	4115.00^{bc}	143.80^{ab}	4296.00^{bc}
T_5	110:45:110 kg NPK+FYM+lime	4203.00^{ab}	154.00^{a}	4492.00^{ab}
T_6	POPR+ MgO	3645.00^{e}	115.00^{cd}	3591.00^{f}
T_7	POPR+ sodium silicate	4096.00^{bc}	139.30^{b}	4277.00^{bc}
T_8	POPR+ calcium silicate	4336.00^{a}	157.60^{a}	4672.00^{a}
T_9	POPR+ sodium silicate without lime	3787.00^{d}	118.80^{c}	3902.00^{de}
T_{10}	POPR+ borax	4085.00^{bc}	148.60^{ab}	4072.00^{cd}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	4192.00^{abc}	153.40^{ab}	4308.00^{bc}
T_{12}	Absolute control	3498.00^{f}	108.70^{cd}	3770.00^{ef}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Application of silica as calcium silicate (T_8) and highest dose of K (T_5) showed the highest Ca content (157.6 mg kg^{-1}) in grain at harvest which was on par with T_{10}. There was no considerable variation in Ca content of grain recorded by soil test based nutrient application(T_1), POPR (T_2), higher dose of K (T_4), boron application and combined application of magnesium, boron and silica (T_{11}). Silica application without lime (T_9) and magnesium applied treatment recorded lesser content of Ca in grain. The lowest Ca content of 101.9 mg kg^{-1} was observed in T_3.

Ca content in straw was significantly higher (4672 mg kg^{-1}) in calcium silicate (T_8) applied treatment which was on par with highest dose of K (T_5). Soil test based nutrient application (T_1), POPR (T_2), higher dose of K (T_4), sodium silicate application (T_7) and combined of magnesium, boron and silica (T_{11}) showed comparable amounts of calcium content in straw and were better than POPR without FYM (T_3) and sodium silicate application without lime (T_9). Magnesium application (T_6) recorded lowest amount of Ca content in straw (3591mg kg^{-1}).

4.5.5 Magnesium content of plant

The data pertaining to Mg content of rice plant at 60 DAS and at harvest in grain and straw is presented in Table 4.12. Highest Mg content of 1032.0 mg kg^{-1} was noted in magnesium applied plot (T_6) at 60 DAS. Soil test based nutrient application (T_1) recorded relatively more Mg content at 60 DAS compared to POPR (T_2). Application of higher dose of K (T_4 andT_5) and sources of silica, sodium silicate (T_7) and calcium silicate (T_8) did not produce significant variation in Mg content of plant but were better than POPR (T_2). POPR without FYM (T_3) recorded lower Mg content and it was least (533.0 mg kg^{-1}) in control plot (T_{12}).

Combined application of magnesium, boron and silica (T_{11}) showed the highest Mg content (972 mg kg^{-1}) in grain at harvest. Magnesium application (T_6) also resulted in better Mg content followed by sodium silicate (T_7) and calcium silicate application (T_8). Soil test based nutrient application (T_1) and POPR (T_2) recorded lower Mg content in grain. The lowest Mg content of 514.7 mg kg^{-1} was observed in T_3.

Table 4.12 Effect of nutrients and soil ameliorants on magnesium content of rice (mg kg^{-1})

Treatments		60 DAS	Harvest	
			Grain	Straw
T_1	STNP+ FYM+ lime	873.00^{de}	735.00^{f}	968.30^{cd}
T_2	POPR	865.00^{e}	733.30^{f}	939.30^{efg}
T_3	POPR without FYM	721.00^{g}	514.70^{h}	765.30^{i}
T_4	110:45:85 kg NPK+FYM+lime	933.30^{b}	875.30^{cd}	961.70^{cde}
T_5	110:45:110 kg NPK+FYM+lime	949.30^{b}	894.70^{c}	975.70^{c}
T_6	POPR+ MgO	1032.00^{a}	959.70^{ab}	1055.00^{b}
T_7	POPR+ sodium silicate	920.00^{bc}	945.00^{b}	946.30^{def}
T_8	POPR+ calcium silicate	899.70^{cd}	936.30^{b}	933.70^{fg}
T_9	POPR+ sodium silicate without lime	812.00^{f}	823.00^{e}	831.30^{h}
T_{10}	POPR+ borax	889.70^{cde}	868.70^{d}	916.70^{g}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	1016.00^{a}	972.00^{a}	1080.00^{a}
T_{12}	Absolute control	533.00^{h}	684.00^{g}	663.30^{j}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Mg content in the straw ranged from 663.30 mg kg^{-1} to 1080.00 mg kg^{-1} and it showed the same trend as in case of grain. It was highest in combined application of magnesium, boron and silica (T_{11}) and lowest in control plot (T_{12}).

4.5.6 Sulphur content of plant

The sulphur content at 60 DAS and in grain and straw at harvest is presented in Table 4.13. The application of highest dose of K (T_5) recorded significantly higher S content of 2338 mg kg^{-1}. All the other treatments except control recorded comparable S content of plant at 60 DAS. The control plot showed the lowest S content of 1056 mg kg^{-1}.

At harvest, in case of grain the highest S content (684.1 mg kg^{-1}) was recorded in grain by application of magnesium (T_6), which was on par with sodium silicate application (T_7). Soil test based nutrient application (T_1) and POPR (T_2) did not produce variation in S content and was better than POPR without FYM (T_3). The doses of K (T_4 and T_5) recorded comparable values and they were more than POPR. The sulphur content of grain was not influenced by sources of silica and recorded comparable S content (T_7 and T_8).

The S content of straw was the highest (3003 mg kg^{-1}) in boron applied treatment (T_{10}) followed by magnesium applied treatment (T_6). There was no significant variation in S content with respect to soil test based nutrient application (T_1) and POPR (T_2), variation in doses of K (T_4 and T_5) and sources of silica (T_7 and T_8). Sodium silicate application without lime and combined application of magnesium, boron and silica recorded comparable S content in straw. The lowest S content was recorded in control treatment (T_{12}) in all the stages i.e. 1056, 1272 and 474.2 mg kg^{-1} at 60 DAS, in straw and grain at harvest respectively.

4.5.7 Iron content of plant

The effects of various treatments on Fe content of rice at 60 DAS and in grain and straw at harvest are shown in Table 4.14. The content of Fe was higher in the plant compared to grain and straw. At 60 DAS the Fe content ranged from 643.3 to 993.7 mg kg^{-1} due to application of nutrients and soil amendments. The higher Fe contents were noted in plot where POPR was applied without FYM (T_3) and in control plot (T_{12}). POPR, higher dose of K (T_4) and sodium silicate application (T_9) without lime recorded relatively higher Fe content. Highest dose of K (T_5) showed lower Fe content than POPR. Magnesium applied plot (T_6) and

Table 4.13 Effect of nutrients and soil ameliorants on sulphur content of rice (mg kg^{-1})

Treatments		60 DAS	Harvest	
			Grain	Straw
T_1	STNP+ FYM+ lime	2142.00^{ab}	626.50^{d}	2344.00^{bc}
T_2	POPR	2129.00^{ab}	628.40^{d}	2431.00^{bc}
T_3	POPR without FYM	1545.00^{bc}	532.80^{f}	1753.00^{d}
T_4	110:45:85 kg NPK+FYM+lime	2198.00^{ab}	625.70^{d}	2297.00^{bc}
T_5	110:45:110 kg NPK+FYM+lime	2338.00^{a}	645.90^{cd}	2413.00^{bc}
T_6	POPR+ MgO	1693.00^{abc}	684.10^{a}	2622.00^{b}
T_7	POPR+ sodium silicate	2126.00^{ab}	672.10^{ab}	2448.00^{bc}
T_8	POPR+ calcium silicate	2133.00^{ab}	664.80^{abc}	2413.00^{bc}
T_9	POPR+ sodium silicate without lime	2076.00^{ab}	563.10^{e}	2135.00^{c}
T_{10}	POPR+ borax	2159.00^{ab}	655.10^{bc}	3003.00^{a}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	2129.00^{ab}	646.10^{cd}	2274.00^{c}
T_{12}	Absolute control	1056.00^{c}	474.20^{g}	1272.00^{e}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Table 4.14 Effect of nutrients and soil ameliorants on iron content of rice (mg kg^{-1})

Treatments		60 DAS	Harvest	
			Grain	Straw
T_1	STNP+ FYM+ lime	766.10^{bcd}	182.50^{de}	423.30^{cd}
T_2	POPR	866.60^{ab}	193.30^{cde}	455.30^{bc}
T_3	POPR without FYM	993.70^{a}	247.40^{ab}	524.20^{b}
T_4	110:45:85 kg NPK+FYM+lime	874.20^{ab}	213.50^{bcde}	403.30^{cd}
T_5	110:45:110 kg NPK+FYM+lime	810.80^{bc}	191.90^{cde}	374.70^{cde}
T_6	POPR+ MgO	767.00^{bcd}	221.80^{bcd}	398.20^{cd}
T_7	POPR+ sodium silicate	782.70^{bcd}	195.60^{cde}	350.00^{def}
T_8	POPR+ calcium silicate	694.40^{cd}	177.40^{ef}	282.00^{f}
T_9	POPR+ sodium silicate without lime	879.70^{ab}	233.10^{abc}	401.50^{cd}
T_{10}	POPR+ borax	689.30^{cd}	175.30^{ef}	339.60^{def}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	643.30^{d}	139.20^{f}	294.80^{ef}
T_{12}	Absolute control	977.80^{a}	271.30^{a}	635.90^{a}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

sodium silicate applied plot (T_7) had lower Fe values compared to POPR. Calcium silicate application (T_8) and boron application (T_{10}) showed still lower values for Fe content. The lowest Fe content of (643.3 mg kg^{-1}) was noticed in combined application of magnesium, boron and silica applied plot (T_{11}).

In case of grain it was significantly highest (271.3 mg kg^{-1}) in control plot (T_{12}), which was on par with POPR application without FYM (T_3). POPR (T_2) showed higher Fe content than soil test based nutrient application (T_1). Highest dose of K (T_5) recorded lower Fe content than lower dose (T_4). But magnesium application (T_6) recorded more Fe content than POPR. Among sources of silica, sodium silicate application (T_7) showed more Fe content than calcium silicate (T_8) application. Combined application of magnesium, boron and silica (T_{11}) recorded the least Fe content in grain (139.2 mg kg^{-1}).

The Fe content in straw also showed the same trend as that of grain. The content of Fe was highest (635.9 mg kg^{-1}) in control plot (T_{12}) followed by POPR application without FYM (T_3). Fe content was decreased by combined application of magnesium, boron and silica (T_{11}) and it was lowest (282.0 mg kg^{-1}) by calcium silicate (T_8) application.

4.5.8 Manganese content of plant

The Manganese content of rice analyzed at 60 DAS and in grain and straw at harvest is presented in Table 4.15. The Mn content was relatively higher in control plot (T_{12}) and by application of POPR without FYM at 60 DAS. The Mn content recorded by control plot (T_{12}) at 60 DAS and at harvest in grain and straw was 235.40 mg kg^{-1}, 100.7 mg kg^{-1} and 216.9 mg kg^{-1} respectively. Among higher doses of K (T_4 and T_5), T_4 showed higher Mn content than T_5 but lower than POPR. Among the sources of silica, sodium silicate without lime (T_9) noted higher Mn content followed by calcium silicate application (T_8) and sodium silicate application (T_7) at all the stages. Application of boron (T_{10}) at all stages recorded lower Mn content than POPR. The lowest Mn content at 60 DAS was recorded by combined application of magnesium, boron and silica while in case of both grain and straw, it was by application of magnesium (T_6). The lowest Mn content recorded by T_{11} at 60 DAS and by T_6 at harvest (grain and straw) was 191.80 mg kg^{-1}, 61.92 mg kg^{-1} and 153.30 mg kg^{-1} respectively.

Table 4.15 Effect of nutrients and soil ameliorants on manganese content of rice (mg kg^{-1})

Treatments		60 DAS	Harvest	
			Grain	Straw
T_1	STNP+ FYM+ lime	208.80^{cd}	87.50^{c}	179.90^{b}
T_2	POPR	213.30^{bc}	85.33^{c}	185.90^{b}
T_3	POPR without FYM	230.00^{a}	93.67^{b}	241.70^{a}
T_4	110:45:85 kg NPK+FYM+lime	204.10^{def}	72.50^{d}	171.10^{c}
T_5	110:45:110 kg NPK+FYM+lime	201.00^{def}	68.00^{def}	160.20^{de}
T_6	POPR+ MgO	196.30^{fg}	61.92^{g}	153.30^{e}
T_7	POPR+ sodium silicate	196.50^{fg}	66.75^{efg}	166.30^{cd}
T_8	POPR+ calcium silicate	198.90^{fg}	70.75^{de}	167.40^{cd}
T_9	POPR+ sodium silicate without lime	220.90^{efg}	90.17^{bc}	187.90^{b}
T_{10}	POPR+ borax	205.90^{cde}	69.08^{de}	167.60^{cd}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	191.80^{g}	63.25^{fg}	160.30^{de}
T_{12}	Absolute control	235.40^{a}	100.70^{a}	216.90^{a}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

4.5.9 Zinc content of plant

The data on Zn content of plant at 60 DAS and at harvest in grain and straw are shown in Table 4.16. At 60 DAS, the combined application of magnesium, boron and silica (T_{11}) recorded significantly higher Zn content (53.67 mg kg^{-1}), which was on par with boron application (T_{10}). Soil test based nutrient application (T_1), POPR (T_2), higher dose of K (T_4), magnesium application (T_6) and sodium silicate application without lime (T_9) showed comparable Zn content in plant which was higher than POPR without FYM application (T_3). Among sources of silica, sodium silicate application (T_7) recorded higher Zn content than calcium silicate application (T_8). Lowest Zn content (23.33 mg kg^{-1}) was recorded in control plot (T_{12})

At harvest, Zn content of grain did not show much variation among the treatments. Zn content in grain ranged from 6.61 mg kg^{-1} to 11.27 mg kg^{-1} due to treatments. All the treatments were on par with each other for Zn content except POPR without FYM and control. The lowest content was recorded in control plot (T_{12}).

In case of straw, combined application of magnesium, boron, silica (T_{11}) recorded the highest Zn content of 66.25 mg kg^{-1} followed by boron application (T_{10}). Soil test based nutrient application (T_1) showed higher Zn content than POPR (T_2). The Zn content of straw recorded was almost same irrespective of source of silica. Magnesium application (T_6) had higher Zn content than POPR. The lowest content of (26.83 mg kg^{-1}) Zn was recorded by control plot (T_{12}).

4.5.10 Boron content of plant

The data on boron content in rice at 60 DAS and in grain and straw at harvest are shown in Table 4.17. Combined application of magnesium, boron and silica (T_{11}) and boron alone treatment (T_{10}) recorded significantly higher B content (7.29 mg kg^{-1} and 7.17 mg kg^{-1}) at 60 DAS. Soil test based nutrient applied plot (T_1) and silica application irrespective of source (T_7 and T_8) recorded comparable B content and was on par with POPR. Among the doses of K, higher dose of K (T_5) was better for B content compared to lower dose (T_4) and the content was less than that with POPR. Magnesium application (T_6) also recorded less B content than POPR.

In case of grain the highest B content (5.92 mg kg^{-1}) was recorded by the application of combination of magnesium, boron and silica (T_{11}) and boron applied treatments (T_{10}). The

Table 4.16 Effect of nutrients and soil ameliorants on zinc content of rice (mg kg^{-1})

Treatments		60 DAS	Harvest	
			Grain	Straw
T_1	STNP+ FYM+ lime	42.75^{cd}	10.22^{a}	51.75^{bc}
T_2	POPR	44.42^{cd}	10.34^{a}	43.33^{de}
T_3	POPR without FYM	36.17^{e}	7.88^{b}	34.08^{f}
T_4	110:45:85 kg NPK+FYM+lime	42.17^{cd}	10.37^{a}	41.83^{e}
T_5	110:45:110 kg NPK+FYM+lime	46.33^{bcd}	10.50^{a}	49.42^{bcde}
T_6	POPR+ MgO	42.75^{cd}	10.69^{a}	48.17^{cde}
T_7	POPR+ sodium silicate	47.08^{bc}	11.00^{a}	50.67^{bcd}
T_8	POPR+ calcium silicate	41.25^{d}	11.05^{a}	50.92^{bcd}
T_9	POPR+ sodium silicate without lime	45.08^{cd}	10.87^{a}	49.42^{bcde}
T_{10}	POPR+ borax	50.75^{ab}	10.91^{a}	56.50^{b}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	53.67^{a}	11.27^{a}	66.25^{a}
T_{12}	Absolute control	23.33^{f}	6.61^{c}	26.83^{g}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Table 4.17 Effect of nutrients and soil ameliorants on boron content of rice (mg kg^{-1})

Treatments		60 DAS	Harvest	
			Grain	Straw
T_1	STNP+ FYM+ lime	6.27^{c}	4.46^{d}	6.65^{c}
T_2	POPR	6.89^{b}	4.58^{d}	7.03^{b}
T_3	POPR without FYM	4.69^{g}	4.12^{e}	5.53^{g}
T_4	110:45:85 kg NPK+FYM+lime	5.81^{de}	5.16^{c}	6.18^{de}
T_5	110:45:110 kg NPK+FYM+lime	6.06^{cd}	5.42^{b}	6.33^{d}
T_6	POPR+ MgO	5.56^{ef}	5.51^{b}	5.73^{fg}
T_7	POPR+ sodium silicate	6.28^{c}	5.55^{b}	6.67^{c}
T_8	POPR+ calcium silicate	6.29^{c}	5.46^{b}	6.78^{bc}
T_9	POPR+ sodium silicate without lime	5.49^{f}	5.16^{c}	5.93^{ef}
T_{10}	POPR+ borax	7.17^{a}	5.92^{a}	7.47^{a}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	7.29^{a}	5.92^{a}	7.64^{a}
T_{12}	Absolute control	3.65^{h}	2.95^{f}	4.13^{h}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

highest dose of K (T_5), magnesium application (T_6), silica application irrespective of source (T_7 and T_8) recorded comparable B content in grain. Soil test based nutrient application (T_1) and POPR (T_2) recorded comparable B content and was better than POPR without FYM (T_3). Higher dose of K (T_4) and sodium silicate application without lime (T_9) also did not show variation in B content in grain.

The B content in straw at harvest also showed the same trend as that at 60 DAS. B content in straw ranged from 4.13 to 7.64 mg kg^{-1} with the highest by application of combination of magnesium, boron and silica (T_{11}). The control treatment recorded lowest B content of 3.65, 4.13 and 2.95 mg kg^{-1} at 60 DAS and in straw and grain at harvest respectively.

4.5.11 Silica content of plant

The effect of treatments on silicon content at 60 DAS and in grain and straw at harvest is given in Table 4.17. Application of sodium silicate (T_7) recorded significantly higher amount of silica content at 60 DAS which was on par with calcium silicate application (T_8). This was followed by combined application of magnesium, boron and silica (T_{11}). Sodium silicate application without lime (T_9) also recorded higher amount of silica than POPR (T_2). POPR was better in silica content of plant compared to soil test based nutrient application (T_1). Among the doses of K, highest dose (T_5) recorded better Si content than lower dose (T_4). Magnesium application (T_6) also recorded more Si content than POPR. There was a profound decrease in Si content in control treatment (T_{12}) and it recorded lowest Si content of 1.65 % at 60 DAS.

Si content in grain was the highest (3.19%) by combined application of magnesium, boron and silica (T_{11}) followed by calcium silicate application (T_8). Soil test based nutrient application (T_1), POPR (T_2), higher doses of K (T_4 and T_5) and magnesium application showed comparable Si content and were better than POPR without FYM (T_3). Sodium silicate (T_7) with lime recorded more Si content than sodium silicate alone (T_9). Lowest amount of Si content of grain (1.56 %) was observed in control plot (T_{12}).

In the case of straw, Si content was highest (5.23%) by sodium silicate (T_7) application followed by combined application of magnesium, boron and silica (T_{11}). Soil test

Table 4.18 Effect of nutrients and soil ameliorants on silicon content of rice (%)

Treatments		60 DAS	Harvest	
			Grain	Straw
T_1	STNP+ FYM+ lime	2.65^{fg}	2.69^{d}	3.69^{d}
T_2	POPR	2.71^{f}	2.57^{d}	3.71^{d}
T_3	POPR without FYM	2.07^{h}	2.07^{e}	3.21^{e}
T_4	110:45:85 kg NPK+FYM+lime	2.55^{g}	2.64^{de}	3.76^{d}
T_5	110:45:110 kg NPK+FYM+lime	2.89^{e}	2.66^{d}	3.80^{d}
T_6	POPR+ MgO	2.75^{f}	2.58^{d}	3.80^{d}
T_7	POPR+ sodium silicate	4.19^{a}	2.97^{abc}	5.23^{a}
T_8	POPR+ calcium silicate	4.07^{ab}	3.10^{ab}	4.99^{b}
T_9	POPR+ sodium silicate without lime	3.74^{c}	2.84^{bcd}	4.6^{8c}
T_{10}	POPR+ borax	3.07^{d}	2.74^{cd}	5.04^{b}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	3.98^{b}	3.19^{a}	5.09^{ab}
T_{12}	Absolute control	1.65^{i}	1.56^{f}	2.61^{f}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

based nutrient application (T_1), POPR (T_2), higher doses of K (T_4 and T_5) and magnesium application (T_6) recorded comparable Si content at harvest. POPR with FYM (T_2) was better than POPR alone (T_3). Calcium silicate application (T_8) and borax application (T_{10}) recorded comparable Si content and were better than sodium silicate application without lime (T_9). Lowest Si content (2.61%) was observed in control plot (T_{12}).

4.6 Nutrient uptake of plant

4.6.1 Nitrogen uptake

The data pertaining to nitrogen uptake by the crop at harvest is shown in Table 4.18. The combined application of magnesium, boron and silica (T_{11}) and sodium silicate application (T_7) recorded significantly higher N uptake by grain (109.90 kg ha^{-1}) followed by application of boron (T_{10}) and calcium silicate (T_8). Soil test based nutrient application (T_1) was better in N uptake compared to POPR (T_2). Higher dose of K (T_4), magnesium application (T_6), sodium silicate without lime (T_9) and application of POPR without FYM (T_3) resulted in lower N uptake by grain. Lowest N uptake in grain (29.15 kg ha^{-1}) was recorded in control plot (T_{12}).

N uptake in straw followed a different pattern. The higher N uptake in straw was observed with application of calcium silicate (T_8), highest dose of K (T_5), magnesium application (T_6) and combined application of magnesium, boron and silica (T_{11}). Soil test based nutrient application (T_1) and POPR (T_2) did not produce difference in N uptake but were better than POPR without FYM (T_3). Boron application (T_{10}) also recorded higher N uptake compared to POPR. Lowest N uptake of 18.86 kg ha^{-1} in straw was recorded in control treatment (T_{12}).

The total uptake of N in control (T_{12}) was 48.01 kg ha^{-1} while it was the highest (171.5 kg ha^{-1}) with combined application of magnesium, boron and silica (T_{11}). Soil test based nutrient application (T_1) was better in total N uptake than POPR (T_2). Application of higher dose of K (T_5) was better for increased uptake compared to lower dose. N uptake was lower when nutrients were applied as per POPR without FYM. Magnesium application also recorded relatively lower N uptake.

Table 4.19 Effect of nutrients and soil ameliorants on N uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	STNP+ FYM+ lime	87.30^{c}	51.49^{d}	138.80^{efg}
T_2	POPR	81.81^{d}	50.94^{d}	132.80^{g}
T_3	POPR without FYM	57.75^{f}	32.51^{e}	90.26^{i}
T_4	110:45:85 kg NPK+FYM+lime	80.16^{d}	57.96^{abc}	138.10^{fg}
T_5	110:45:110 kg NPK+FYM+lime	83.96^{cd}	62.90^{a}	146.90^{de}
T_6	POPR+ MgO	81.66^{d}	62.77^{a}	144.40^{def}
T_7	POPR+ sodium silicate	105.30^{a}	60.17^{ab}	165.50^{ab}
T_8	POPR+ calcium silicate	95.36^{b}	63.01^{a}	158.40^{bc}
T_9	POPR+ sodium silicate without lime	71.72^{e}	53.13^{cd}	124.90^{h}
T_{10}	POPR+ borax	97.01^{b}	55.55^{bcd}	152.60^{cd}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	109.90^{a}	61.59^{a}	171.50^{a}
T_{12}	Absolute control	29.15^{g}	18.86^{f}	48.01^{j}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

4.6.2 Phosphorous uptake

The effect of various treatments on P uptake by the crop is presented in Table 4.19. The combined application of magnesium, boron and silica (T_{11}), boron application (T_{10}) and calcium silicate application (T_8) recorded significantly higher P uptake in grain. There was no significant variation in P uptake in grain with respect to soil test based nutrient application (T_1), POPR (T_2), doses of K (T_4 and T_5) and sodium silicate application without lime (T_9). Magnesium application (T_6) and application of POPR without FYM (T_3) recorded lower P uptake in grain than POPR.

P uptake by straw was comparable (28.50 kg ha^{-1}) in soil test based nutrient application (T_1), combined application of magnesium, boron and silica (T_{11}), magnesium application (T_6), boron application (T_{10}), higher doses of K (T_4 and T_5) and sodium silicate application (T_7). Calcium silicate application (T_8), sodium silicate application without lime (T_9) and POPR (T_2) did not show variation in P uptake in straw and had comparable values. Application of FYM resulted in increased uptake of P (T_2).

The total uptake of P also followed the same trend as that of straw. Magnesium application (T_6), sodium silicate application without lime (T_9) and POPR (T_2) did not show variation in total uptake of P and had comparable values. The lowest uptake was recorded in control treatment (T_{12}) in grain, straw and total uptake i.e. 7.16 kg ha^{-1}, 6.30 kg ha^{-1}and13.46 kg ha^{-1} respectively.

4.6.3 Potassium uptake

The effect of treatments on K uptake by the crop is shown in Table 4.21. The K uptake by grain was significantly higher (21.50 kg ha^{-1}) by combined application of magnesium, boron and silica (T_{11}) followed by boron application (T_{10}). K uptake by sodium silicate (T_7), calcium silicate (T_8) and sodium silicate without lime (T_9) application showed comparable values. Magnesium application (T_6) also recorded lower K uptake by grain. Soil test based nutrient application (T_1) and POPR (T_2) recorded comparable K uptake by grain. Application of higher dose of K (T_5) increased K uptake by grain.

Combined application of magnesium, boron and silica (T_{11}), highest dose of K (T_5), magnesium application (T_6) and sodium silicate application without lime (T_9) recorded relatively higher K uptake by straw. Soil test based nutrient application (T_1), POPR (T_2) and

Table 4.20 Effect of nutrients and soil ameliorants on P uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	STNP+ FYM+ lime	25.33^{ab}	28.50^{a}	53.83^{ab}
T_2	POPR	24.62^{ab}	22.08^{ab}	46.69^{b}
T_3	POPR without FYM	16.25^{c}	15.98^{b}	32.24^{c}
T_4	110:45:85 kg NPK+FYM+lime	24.85^{ab}	21.68^{ab}	46.53^{b}
T_5	110:45:110 kg NPK+FYM+lime	26.25^{ab}	25.43^{a}	51.68^{ab}
T_6	POPR+ MgO	20.15^{bc}	27.58^{a}	47.74^{b}
T_7	POPR+ sodium silicate	26.50^{ab}	25.21^{a}	51.70^{ab}
T_8	POPR+ calcium silicate	27.27^{a}	22.90^{ab}	50.18^{ab}
T_9	POPR+ sodium silicate without lime	25.54^{ab}	22.35^{ab}	47.90^{b}
T_{10}	POPR+ borax	28.13^{a}	25.49^{a}	53.62^{ab}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	31.03^{a}	27.63^{a}	58.66^{a}
T_{12}	Absolute control	7.16^{d}	6.30^{c}	13.46^{d}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Table 4.21 Effect of nutrients and soil ameliorants on K uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	STNP+ FYM+ lime	15.47^{e}	182.4^{b}	197.89^{b}
T_2	POPR	15.20^{e}	179.20^{b}	194.38^{b}
T_3	POPR without FYM	12.81^{f}	128.60^{c}	141.38^{c}
T_4	110:45:85 kg NPK+FYM+lime	11.27^{f}	197.60^{ab}	208.91^{b}
T_5	110:45:110 kg NPK+FYM+lime	16.40^{de}	215.10^{a}	231.53^{a}
T_6	POPR+ MgO	17.87^{cd}	215.50^{a}	233.34^{a}
T_7	POPR+ sodium silicate	18.80^{bc}	185.50^{b}	204.33^{b}
T_8	POPR+ calcium silicate	18.66^{bc}	183.10^{b}	201.76^{b}
T_9	POPR+ sodium silicate without lime	18.34^{bc}	216.10^{a}	234.40^{a}
T_{10}	POPR+ borax	19.68^{b}	176.60^{b}	196.31^{b}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	21.50^{a}	212.70^{a}	234.24^{a}
T_{12}	Absolute control	4.63^{g}	67.41^{d}	72.04^{d}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

both the sources of silica did not show any variation in K uptake by straw and had comparable values.

Total uptake of K also followed the same trend as that of K uptake by straw. Total uptake of K varied from 72.04 kg ha^{-1} to 234.4 kg ha^{-1} by application of various treatments. POPR without FYM (T_3) showed comparatively lower K uptake by grain and straw and hence also total uptake compared to POPR application. Control plot (T_{12}) recorded the lowest K uptake of 4.63 kg ha^{-1}, 67.41 kg ha^{-1} and 72.04 kg ha^{-1} by grain, straw and total uptake respectively.

4.6.4 Calcium uptake

The data on Ca uptake by rice at harvest is shown in Table 4.22. The highest uptake of Ca by grain (1.22 kg ha^{-1}) was observed in combined application of magnesium, boron and silica (T_{11}) followed by boron application (T_{10}) and calcium silicate application (T_8). POPR (T_2) recorded comparable value for Ca uptake with soil test based nutrient application (T_1) and POPR without FYM (T_3). Higher dose of K (T_5) recorded more Ca uptake in grain than lower dose (T_4). Among sources of silica, calcium silicate was better in uptake than sodium silicate (T_7). Control plot (T_{12}) recorded the lowest uptake of Ca in grain (0.40 kg ha^{-1}).

The application of calcium silicate recorded the highest Ca uptake by straw (38.25 kg ha^{-1}) followed by highest dose of K (T_5). Combined application of magnesium, boron and silica (T_{11}) and sodium silicate application (T_7) resulted in comparable Ca uptake in straw. Soil test based nutrient application (T_1) and POPR (T_2) were better in Ca uptake compared to POPR without FYM (T_3). Control plot recorded the lowest Ca uptake by straw (16.99 kg ha^{-1}).

The Ca accumulated in grain was very less compared to total uptake and the Ca left in the straw. Total Ca uptake showed the same trend as that by straw. Calcium silicate application (T_8) recorded the highest calcium uptake of 39.39 kg ha^{-1} and lowest of 17.40 kg ha^{-1} in control treatment (T_{12}).

4.6.5 Magnesium uptake

The magnesium uptake by rice at harvest is shown in Table 4.23. Mg uptake was highest (7.72 kg ha^{-1}, 8.84 kg ha^{-1} and 16.58 kg ha^{-1} in grain, straw and total respectively) by combined application of magnesium, boron and silica (T_{11}). In all the cases, soil test based

Table 4.22 Effect of nutrients and soil ameliorants on Ca uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	STNP+ FYM+ lime	0.94^{d}	30.39^{ef}	31.33^{ef}
T_2	POPR	0.96^{cd}	31.60^{ef}	32.57^{ef}
T_3	POPR without FYM	0.54^{f}	23.72^{g}	24.27^{g}
T_4	110:45:85 kg NPK+FYM+lime	0.92^{d}	34.37^{cd}	35.30^{cd}
T_5	110:45:110 kg NPK+FYM+lime	1.01^{cd}	37.22^{ab}	38.23^{ab}
T_6	POPR+ MgO	0.71^{e}	29.71^{f}	30.42^{f}
T_7	POPR+ sodium silicate	1.06^{bc}	34.79^{bc}	35.86^{bc}
T_8	POPR+ calcium silicate	1.13^{ab}	38.25^{a}	39.39^{a}
T_9	POPR+ sodium silicate without lime	0.77^{e}	32.31^{de}	33.09^{de}
T_{10}	POPR+ borax	1.14^{ab}	32.16^{def}	33.30^{de}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	1.22^{a}	35.30^{bc}	36.52^{bc}
T_{12}	Absolute control	0.40^{g}	16.99^{h}	17.40^{h}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Table 4.23 Effect of nutrients and soil ameliorants on Mg uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	STNP+ FYM+ lime	4.72^{f}	6.89^{e}	11.63^{g}
T_2	POPR	4.64^{f}	6.90^{e}	11.55^{g}
T_3	POPR without FYM	2.76^{g}	4.64^{f}	7.40^{h}
T_4	110:45:85 kg NPK+FYM+lime	5.62^{de}	7.69^{c}	13.32^{e}
T_5	110:45:110 kg NPK+FYM+lime	5.89^{d}	8.08^{b}	13.95^{d}
T_6	POPR+ MgO	5.98^{d}	8.72^{a}	14.71^{bc}
T_7	POPR+ sodium silicate	7.20^{b}	7.69^{c}	14.90^{b}
T_8	POPR+ calcium silicate	6.72^{c}	7.64^{c}	14.37^{cd}
T_9	POPR+ sodium silicate without lime	5.39^{e}	6.88^{e}	12.27^{f}
T_{10}	POPR+ borax	6.66^{c}	7.24^{d}	13.90^{d}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	7.72^{a}	8.84^{a}	16.58^{a}
T_{12}	Absolute control	2.57^{g}	2.99^{g}	5.56^{i}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

nutrient application (T_1) and POPR (T_2) recorded comparable Mg uptake and were better compared to POPR without FYM (T_3).

Application of sodium silicate (T_7) recorded better Mg uptake in grain than T_{11}. Calcium silicate application (T_8) and boron application showed comparable Mg uptake in grain and it was higher than POPR. Lowest uptake of Mg (2.57 kg ha^{-1}) was recorded by control plot (T_{12}).

Mg uptake by straw was the highest in T_{11} followed by magnesium application (T_6). Soil test based nutrient application (T_1), POPR (T_2) and sodium silicate application without lime (T_9) were relatively less efficient in Mg uptake by straw. Application of higher dose of K (T_4) increased Mg uptake. The sources of silica did not influence the Mg uptake by straw. Control plot (T_{12}) recorded the lowest Mg uptake of 2.99 kg ha^{-1}.

The total uptake of Mg was highest in T_{11} followed by sodium silicate application (T_7) and this was on par with magnesium application (T_6). Highest dose of K (T_5) was better than T_4 in Mg uptake. Lime application with silica increased the Mg uptake (T_7 and T_8). Lowest Mg uptake (5.56 kg ha^{-1}) was recorded by control plot (T_{12}).

4.6.6 Sulphur uptake

The effect of various treatments on S uptake by rice is shown in Table 4.23. The S uptake by grain was highest (5.14 kg ha^{-1}) by combined application of magnesium, boron and silica (T_{11}) followed by application of sodium silicate (T_7) and boron application (T_{10}). Soil test based nutrient application (T_1) was better than POPR (T_2) for S uptake by grain. Highest dose of K (T_5) and magnesium application (T_6) recorded relatively higher S uptake and it was lowest (1.78 kg ha^{-1}) in control plot (T_{12}).

The S uptake by straw was highest (23.75 kg ha^{-1}) by boron application (T_{10}) followed by magnesium application (T_6). Highest dose of K (T_5) and both the sources of silica recorded comparable S uptake in straw. Combined application of magnesium, boron and silica (T_{11}), higher dose of K (T_4), POPR (T_2) and sodium silicate application without lime (T_9) had comparable values for S uptake. Soil test based nutrient application (T_1) showed lower S uptake in straw than POPR (T_2) but was better than POPR without FYM (T_3). Control plot (T_{12}) recorded lowest S uptake of 5.73 kg ha^{-1}.

Table 4.24 Effect of nutrients and soil ameliorants on S uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	STNP+ FYM+ lime	4.03^{cd}	16.68^{d}	20.72^{f}
T_2	POPR	3.97^{d}	17.87^{cd}	21.85^{def}
T_3	POPR without FYM	2.85^{f}	10.63^{e}	13.49^{g}
T_4	110:45:85 kg NPK+FYM+lime	4.01^{cd}	18.38^{cd}	22.40^{cdef}
T_5	110:45:110 kg NPK+FYM+lime	4.23^{c}	19.99^{bc}	24.23^{bcd}
T_6	POPR+ MgO	4.26^{c}	21.70^{ab}	25.96^{b}
T_7	POPR+ sodium silicate	5.12^{a}	19.92^{bc}	25.04^{b}
T_8	POPR+ calcium silicate	4.77^{b}	19.75^{bc}	24.53^{bc}
T_9	POPR+ sodium silicate without lime	3.68^{e}	17.68^{cd}	21.36^{ef}
T_{10}	POPR+ borax	5.02^{a}	23.75^{a}	28.77^{a}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	5.14^{a}	18.64^{cd}	23.78^{bcde}
T_{12}	Absolute control	1.78^{g}	5.73^{f}	7.51^{h}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

The highest total uptake of S by rice was observed due to boron application (T_7) followed by magnesium (T_6) and sodium silicate application (T_7). POPR (T_2) was better than soil test based nutrient application (T_1) for total uptake of S. Highest dose of K (T_5) and combined nutrient application of magnesium, boron and silica (T_{11}) recorded higher total uptake of S. Sodium silicate application (T_9) and POPR without FYM (T_3) recorded comparatively lower total uptake of S and it was least (7.51 kg ha^{-1}) in control plot (T_{12}).

4.6.7 Iron uptake

The effect of various treatments on Fe uptake by rice is shown in Table 4.25. The Fe uptake by grain was highest (1.52 kg ha^{-1}) in sodium silicate without lime (T_9) and sodium silicate (T_7) applied treatments. Magnesium application (T_6), higher dose of K (T_4), boron application (T_{10}) and POPR without FYM (T_3) recorded higher Fe uptake in grain and had comparable values. Calcium silicate application (T_8) and POPR (T_2) were on par for Fe uptake by grain. Soil test based nutrient application (T_1) and combined application of magnesium, boron and silica (T_{11}) showed comparable uptake of Fe by grain and lowest uptake of Fe (1.02 kg ha^{-1}) by grain was observed in control plot (T_{12}).

In case of straw there was no significant difference among the treatments for Fe uptake. Almost all the treatments were on par with each other. It was highest (3.34 kg ha^{-1}) in POPR (T_2) applied treatment and the lowest (2.30 kg ha^{-1}) by application of calcium silicate (T_8).

The total uptake of Fe by the crop was highest (4.85 kg ha^{-1}) by sodium silicate application without lime (T_9). There was no considerable variation among the treatments for total Fe uptake and all treatments were on par with each other. The combined application of magnesium, boron and silica (T_{11}) recorded the lowest total uptake of Fe (3.52 kg ha^{-1}).

4.6.8 Manganese uptake

The uptake of Mn by the application of various treatments is shown in Table 4.26. Mn uptake was highest (0.59 kg ha^{-1}, 1.55 kg ha^{-1} and 2.14 kg ha^{-1} in grain, straw and total respectively) by application of sodium silicate without lime (T_9).

Application of higher dose of K reduced the Mn uptake by grain. Combined application of magnesium, boron and silica (T_{11}) showed lower Mn uptake than POPR. There

Table 4.25 Effect of nutrients and soil ameliorants on Fe uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	STNP+ FYM+ lime	1.17^{bc}	3.01^{ab}	4.18^{abcd}
T_2	POPR	1.22^{abc}	3.34^{a}	4.57^{ab}
T_3	POPR without FYM	1.32^{ab}	3.18^{a}	4.50^{ab}
T_4	110:45:85 kg NPK+FYM+lime	1.37^{ab}	3.22^{a}	4.59^{ab}
T_5	110:45:110 kg NPK+FYM+lime	1.26^{abc}	3.10^{a}	4.36^{abc}
T_6	POPR+ MgO	1.38^{ab}	3.29^{a}	4.68^{ab}
T_7	POPR+ sodium silicate	1.49^{a}	2.84^{abc}	4.34^{abc}
T_8	POPR+ calcium silicate	1.27^{abc}	2.30^{c}	3.58^{cd}
T_9	POPR+ sodium silicate without lime	1.52^{a}	3.32^{a}	4.85^{a}
T_{10}	POPR+ borax	1.34^{ab}	2.68^{abc}	4.02^{abcd}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	1.11^{bc}	2.41^{bc}	3.52^{d}
T_{12}	Absolute control	1.02^{c}	2.86^{abc}	3.88^{bcd}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Table 4.26 Effect of nutrients and soil ameliorants on Mn uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	STNP+ FYM+ lime	0.56^{ab}	1.28^{c}	1.84^{bcd}
T_2	POPR	0.54^{bc}	1.36^{c}	1.90^{b}
T_3	POPR without FYM	0.50^{cd}	1.30^{bc}	1.80^{cd}
T_4	110:45:85 kg NPK+FYM+lime	0.46^{de}	1.36^{b}	1.83^{bcd}
T_5	110:45:110 kg NPK+FYM+lime	0.44^{e}	1.32^{bc}	1.77^{d}
T_6	POPR+ MgO	0.38^{f}	1.26^{c}	1.65^{e}
T_7	POPR+ sodium silicate	0.50^{c}	1.35^{bc}	1.86^{bc}
T_8	POPR+ calcium silicate	0.50^{c}	1.37^{b}	1.87^{bc}
T_9	POPR+ sodium silicate without lime	0.59^{a}	1.55^{a}	2.14^{a}
T_{10}	POPR+ borax	0.53^{bc}	1.32^{bc}	1.85^{bc}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	0.50^{cd}	1.31^{bc}	1.81^{cd}
T_{12}	Absolute control	0.38^{f}	0.97^{d}	1.35^{f}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

was no variation for Mn uptake with different sources of silica (T_7 and T_8). Lowest Mn uptake by grain was recorded in magnesium applied plot (T_6) and control plot (T_{12}). Soil test based nutrient application (T_1) recorded lower Mn uptake by straw than POPR and it was on par with POPR without FYM (T_3). Higher doses of K (T_4 and T_5), borax application and combined application of magnesium, boron and silica were on par with POPR application for Mn uptake. There was no variation in Mn uptake among the sources of silica (T_7 and T_8). The control treatment recorded the lowest Mn uptake by straw of 0.97 kg ha^{-1}.

The total uptake of Mn also followed the same trend as that of straw. It was highest in T_9 and lowest in control plot (T_{12}).

4.6.9 Zinc uptake

The effect of various treatments on the uptake of Zn by rice is given in Table 4.27. The Zn uptake by grain varied from 0.02 to 0.08 kg ha^{-1} and from 0.12 to 0.54 kg ha^{-1} in straw. The total Zn uptake ranged from 0.14 to 0.63 kg ha^{-1}. The highest Zn uptake by grain and straw was noticed by combined application of magnesium, boron and silica (T_{11}) with total Zn uptake of 0.63 kg ha^{-1}. FYM application increased the Zn uptake but sources of silica did not produce variation in Zn uptake by the plant. Boron application (T_{10}) and silica application resulted in better Zn uptake by grain and straw and hence total uptake. The lowest uptake was recorded in control (T_{12}).

4.6.10 Boron uptake

The data on Boron uptake by the rice due to application of nutrients and soil ameliorants are presented in Table 4.28. B uptake was highest (0.047 kg ha^{-1}, 0.062 kg ha^{-1} and 0.11 kg ha^{-1} in grain, straw and total respectively) by combined application of magnesium, boron and silica (T_{11}). Soil test based nutrient application (T_1) and POPR (T_2) recorded comparable B uptake by grain. Highest dose of K (T_5) recorded more uptake of B than lower dose. Among the source of silica, sodium silicate (T_7) recorded better B uptake by grain than calcium silicate (T_6). The uptake of boron by grain was lowest (0.011 kg ha^{-1}) in control plot (T_{12})

In case of B uptake by straw, T_{11} recorded the highest. POPR was better in B uptake by straw compared to soil test based nutrient application (T_1) and POPR without FYM (T_3). Higher doses of K recorded higher B uptake. The sources of silica, sodium silicate (T_7) and

Table 4.27 Effect of nutrients and soil ameliorants on Zn uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	STNP+ FYM+ lime	0.06^{c}	0.36^{cd}	0.43^{de}
T_2	POPR	0.06^{c}	0.31^{d}	0.38^{e}
T_3	POPR without FYM	0.04^{d}	0.20^{e}	0.24^{f}
T_4	110:45:85 kg NPK+FYM+lime	0.06^{c}	0.33^{d}	0.40^{e}
T_5	110:45:110 kg NPK+FYM+lime	0.06^{c}	0.40^{bc}	0.47^{bcd}
T_6	POPR+ MgO	0.06^{c}	0.39^{bc}	0.46^{cd}
T_7	POPR+ sodium silicate	0.08^{b}	0.41^{bc}	0.49^{bc}
T_8	POPR+ calcium silicate	0.07^{b}	0.41^{bc}	0.49^{bc}
T_9	POPR+ sodium silicate without lime	0.07^{c}	0.40^{bc}	0.48^{bcd}
T_{10}	POPR+ borax	0.08^{b}	0.44^{b}	0.53^{b}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	0.08^{a}	0.54^{a}	0.63^{a}
T_{12}	Absolute control	0.02^{e}	0.12^{f}	0.14^{g}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Table 4.28 Effect of nutrients and soil ameliorants on B uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	STNP+ FYM+ lime	0.029^{f}	0.047^{g}	0.076^{f}
T_2	POPR	0.029^{f}	0.051^{d}	0.081^{e}
T_3	POPR without FYM	0.022^{g}	0.033^{h}	0.056^{g}
T_4	110:45:85 kg NPK+FYM+lime	0.033^{e}	0.049^{e}	0.083^{e}
T_5	110:45:110 kg NPK+FYM+lime	0.036^{d}	0.052^{d}	0.088^{d}
T_6	POPR+ MgO	0.034^{de}	0.047^{fg}	0.082^{e}
T_7	POPR+ sodium silicate	0.042^{b}	0.054^{c}	0.097^{c}
T_8	POPR+ calcium silicate	0.039^{c}	0.055^{c}	0.095^{c}
T_9	POPR+ sodium silicate without lime	0.034^{de}	0.049^{ef}	0.083^{e}
T_{10}	POPR+ borax	0.045^{a}	0.058^{b}	0.104^{b}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	0.047^{a}	0.062^{a}	0.110^{a}
T_{12}	Absolute control	0.011^{h}	0.018^{i}	0.030^{h}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

calcium silicate (T_8) had comparable B uptake values by straw. Lowest B uptake of 0.018 kg ha^{-1} by straw was recorded in control plot (T_{12}).

The total uptake of B followed the same trend as that of straw with highest in T_{11} and lowest in control plot (T_{12}).

4.6.11 Silica uptake

The uptake of silica by rice crop due to the application of nutrients and soil ameliorants is given in Table 4.29. The silica uptake by grain was highest (253.9 kg ha^{-1}) by combined application of magnesium, boron and silica (T_{11}) followed by application of silica i.e. sodium silicate and calcium silicate (T_8). There was no significant difference between the rest of treatments for silica uptake except POPR without FYM (T_3) and control treatment which recorded lower silica uptake by grain. Lowest silica uptake of 58.89 kg ha^{-1} in grain was observed in control plot (T_{12}).

Sodium silicate application (T_7) recorded the highest silica uptake by straw followed by combined application of magnesium, boron and silica (T_{11}) and calcium silicate (T_8). Soil test based nutrient application (T_1) and POPR (T_2) recorded comparable silica content and were better than POPR without FYM (T_3). Higher doses of K (T_4 and T_5) and magnesium application (T_6) recorded lower silica uptake but higher than POPR. Control plot (T_{12}) recorded lowest silica uptake of 117.70 kg ha^{-1} by straw.

Total uptake of silica followed the same trend as that by straw. It was highest by combined application of magnesium, boron and silica (T_{11}) and lowest (176.6 kg ha^{-1}) in control plot (T_{12}).

4.7 Nutrient status of soil

4.7.1 pH of soil

The effect of various treatments and soil ameliorants on soil pH at every two weeks interval from ploughing to harvest of the crop is presented in Table 4.30. The trend of pH from ploughing to harvest was linear with declining at harvest. Initially the pH of the soil was very low (4.13 to 4.43) and further there was a gradual increase in pH of soil (4.40 to 4.70) due to the addition of nutrients and soil ameliorants. The pH values showed an increasing trend compared to without lime treatments (T_9). There was an increase from 5.13

Table 4.29 Effect of nutrients and soil ameliorants on Silica uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	STNP+ FYM+ lime	173.50^{c}	263.10^{f}	436.30^{f}
T_2	POPR	163.00^{c}	273.00^{f}	436.00^{f}
T_3	POPR without FYM	111.00^{d}	195.20^{g}	306.20^{g}
T_4	110:45:85 kg NPK+FYM+lime	169.80^{c}	300.90^{e}	470.70^{e}
T_5	110:45:110 kg NPK+FYM+lime	174.90^{c}	315.20^{e}	490.10^{e}
T_6	POPR+ MgO	161.20^{c}	314.50^{e}	475.70^{e}
T_7	POPR+ sodium silicate	227.40^{b}	425.60^{a}	653.00^{ab}
T_8	POPR+ calcium silicate	222.50^{b}	409.00^{bc}	631.50^{bc}
T_9	POPR+ sodium silicate without lime	186.00^{c}	388.10^{d}	574.10^{d}
T_{10}	POPR+ borax	210.40^{b}	398.00^{cd}	608.40^{c}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	253.90^{a}	417.20^{ab}	671.10^{a}
T_{12}	Absolute control	58.89^{e}	117.70^{h}	176.60^{h}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Table 4.30 Effect of treatments and soil ameliorants on soil pH during experimentation

Treatments		Initial	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	12 weeks	14 weeks	16 weeks	Harvest
T_1	STNP+ FYM+ lime	4.33^{abcd}	4.56^{ab}	5.85^{ab}	5.91^{de}	5.92^{c}	6.11^{bc}	6.18^{d}	6.22^{d}	6.17^{ef}	5.36^{b}
T_2	POP	4.43^{a}	4.63^{a}	5.81^{ab}	5.92^{bc}	5.91^{d}	6.11^{bc}	6.18^{c}	6.24^{ab}	6.17^{cd}	5.40^{b}
T_3	POP without FYM	4.36^{abc}	4.63^{a}	5.64^{c}	5.91^{ef}	5.90^{e}	6.11^{bc}	6.18^{d}	6.23^{c}	6.17^{de}	5.43^{b}
T_4	110:45:85 kg NPK+FYM+lime	4.16^{cd}	4.63^{a}	5.77^{b}	5.91^{cd}	5.92^{c}	6.08^{c}	6.18^{d}	6.25^{a}	6.17^{cd}	5.46^{b}
T_5	110:45:110 kg NPK+FYM+lime	4.40^{ab}	4.66^{a}	5.83^{ab}	5.90^{g}	5.92^{c}	6.09^{c}	6.17^{de}	6.19^{e}	6.17^{ef}	5.50^{b}
T_6	POP+ MgO	4.30^{abcd}	4.60^{a}	5.81^{ab}	5.90^{f}	5.90^{e}	6.09^{bc}	6.17^{ef}	6.19^{e}	6.16^{g}	5.43^{b}
T_7	POP+ sodium silicate	4.36^{abc}	4.70^{a}	5.90^{a}	5.92^{b}	5.94^{b}	6.13^{abc}	6.20^{b}	6.24^{b}	6.21^{a}	5.63^{a}
T_8	POP+ calcium silicate	4.13^{d}	4.70^{a}	5.92^{a}	5.93^{a}	5.96^{a}	6.15^{ab}	6.22^{a}	6.25^{a}	6.20^{b}	5.66^{a}
T_9	POP+ sodium silicate without lime	4.20^{bcd}	4.43^{bc}	5.43^{d}	5.63^{h}	5.75^{f}	5.82^{d}	5.85^{g}	5.91^{f}	5.62^{h}	5.06^{c}
T_{10}	POP+ borax	4.33^{abcd}	4.63^{a}	5.82^{ab}	5.91^{cd}	5.90^{e}	6.17^{a}	6.17^{f}	6.22^{d}	6.18^{c}	5.43^{b}
T_{11}	POP+ MgO+ silica(sodium silicate)+borax	4.33^{abcd}	4.63^{a}	5.84^{ab}	5.91^{ef}	5.92^{c}	6.18^{a}	6.17^{ef}	6.23^{c}	6.16^{f}	5.64^{a}
T_{12}	Absolute control	4.40^{ab}	4.40^{c}	5.13^{e}	5.21^{i}	5.41^{g}	5.56^{e}	5.59^{h}	5.64^{g}	5.41^{i}	4.94^{d}

*The common alphabets do not differ significantly at 5% in DMRT to 5.92 within two weeks after application of treatments. pH was almost stable by six and eight weeks after sowing and continued as such up to harvest. At harvest there was decrease in pH from 5.66 to 4.94.

At initial stages there was no significant difference between the treatments for soil pH and were on par with each other. At four weeks after sowing there was increase in pH in all treatments except sodium silicate without lime applied treatment (T_9) and control (T_{12}). Highest pH was recorded in silica applied plots (T_7 and T_8).

In the case of six and eight weeks after sowing also gradual increasing trend was noticed in pH in all the treatments and silica application with lime (T_7 and T_8) recoded higher pH compared to other treatments. Lowest pH was noticed in control treatment (T_{12}).

At twelve, fourteen and sixteen weeks after sowing it was noticed that the pH was almost stabilised and it was in slightly acidic range. The highest pH was recorded in silicate applied treatments (T_7 and T_8) and lowest in control treatment (T_{12}).

There was a slight reduction in pH at harvest with the same trend of highest being in silica applied treatments. The control plot recorded the lowest pH of 4.94

4.7.2 EC of soil

The effect of application of nutrients and soil ameliorants on EC of soil at every two weeks interval from ploughing to harvest of the crop is presented in Table 4.31. The EC of the soil ranged from 0.84 ds m^{-1} to 0.12 ds m^{-1} from ploughing of field to harvesting. There was a gradual decrease in EC values due to the application of nutrients and soil ameliorants compared to control (T_{12}). There was a decrease in EC by four weeks after sowing and it was almost stable at six and eight weeks and EC ranged from 0.13 ds m^{-1} to 0.24 ds m^{-1}. EC values were not changed considerably up to 10 weeks after sowing after which a slight increase was noticed during the next 4 weeks. By harvest the EC was decreased to the range of 0.12 ds m^{-1} to 0.24 ds m^{-1}.

At initial stages there was no significant difference between the treatments for soil EC and the lowest EC was recorded in boron applied treatment (T_{10}). This trend was continued up to 16 weeks after sowing with lowest EC recorded in control plot. At harvest the EC was highest in combined application of magnesium, boron and silica (T_{11}) and lowest in control treatment (T_{12}).

Table 4.30 Effect of treatments and soil ameliorants on EC of soil during experimentation

Treatments		Initial	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	12 weeks	14 weeks	16 weeks	Harvest
T_1	STNP+ FYM+ lime	0.84^{ab}	0.42^{a}	0.20^{ab}	0.23^{b}	0.27^{b}	0.30^{ab}	0.42^{a}	0.38^{a}	0.31^{ab}	0.23^{b}
T_2	POP	0.83^{ab}	0.40^{a}	0.24^{a}	0.25^{ab}	0.34^{a}	0.31^{a}	0.41^{ab}	0.40^{a}	0.28^{ab}	0.19^{f}
T_3	POP without FYM	0.82^{ab}	0.38^{a}	0.20^{ab}	0.26^{ab}	0.32^{ab}	0.29^{ab}	0.38^{ab}	0.41^{a}	0.26^{bc}	0.18^{h}
T_4	110:45:85 kg NPK+FYM+lime	0.82^{ab}	0.37^{a}	0.17^{bc}	0.28^{ab}	0.28^{ab}	0.33^{a}	0.40^{ab}	0.38^{a}	0.27^{b}	0.17^{j}
T_5	110:45:110 kg NPK+FYM+lime	0.83^{a}	0.40^{a}	0.20^{ab}	0.27^{ab}	0.31^{ab}	0.33^{a}	0.40^{ab}	0.42^{a}	0.34^{a}	0.18^{g}
T_6	POP+ MgO	0.83^{ab}	0.36^{a}	0.18^{abc}	0.29^{ab}	0.31^{ab}	0.32^{a}	0.40^{ab}	0.43^{a}	0.29^{ab}	0.19^{e}
T_7	POP+ sodium silicate	0.82^{ab}	0.36^{a}	0.19^{abc}	0.27^{ab}	0.26^{b}	0.34^{a}	0.41^{ab}	0.43^{a}	0.31^{ab}	0.17^{i}
T_8	POP+ calcium silicate	0.79^{ab}	0.33^{a}	0.17^{bc}	0.29^{ab}	0.31^{ab}	0.30^{ab}	0.43^{a}	0.41^{a}	0.30^{ab}	0.21^{d}
T_9	POP+ sodium silicate without lime	0.73^{b}	0.34^{a}	0.18^{abc}	0.30^{a}	0.30^{ab}	0.30^{ab}	0.41^{ab}	0.40^{a}	0.28^{ab}	0.17^{k}
T_{10}	POP+ borax	0.76^{b}	0.36^{a}	0.18^{abc}	0.26^{ab}	0.32^{ab}	0.32^{a}	0.41^{ab}	0.41^{a}	0.29^{ab}	0.23^{c}
T_{11}	POP+ MgO+ silica(sodium silicate)+borax	0.79^{ab}	0.36^{a}	0.22^{ab}	0.28^{ab}	0.31^{ab}	0.34^{a}	0.41^{ab}	0.42^{a}	0.29^{ab}	0.24^{a}
T_{12}	Absolute control	0.78^{ab}	0.33^{a}	0.13^{c}	0.18^{c}	0.19^{c}	0.25^{b}	0.33^{b}	0.25^{b}	0.21^{c}	0.12^{l}

*The common alphabets do not differ significantly at 5% in DMRT

Table 4.32 Effect of nutrients and soil ameliorants on organic carbon content of soil after the experiment

Treatments		Organic carbon (%)
T_1	STNP+ FYM+ lime	2.07[bc]
T_2	POPR	2.03[cd]
T_3	POPR without FYM	1.86[f]
T_4	110:45:85 kg NPK+FYM+lime	2.09[abc]
T_5	110:45:110 kg NPK+FYM+lime	2.13[a]
T_6	POPR+ MgO	2.06[bc]
T_7	POPR+ sodium silicate	2.04[cd]
T_8	POPR+ calcium silicate	1.99[de]
T_9	POPR+ sodium silicate without lime	1.96[e]
T_{10}	POPR+ borax	1.98[de]
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	2.11[ab]
T_{12}	Absolute control	1.76[g]

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

4.7.3 Organic carbon

The organic carbon content of soil at harvest of crop is given in Table 4.32. The organic carbon of soil at harvest varied from 1.76% to 2.13% due to various treatments. The organic carbon content was increased compared to initial value (1.2%). The application of highest dose of K (T_5) recorded the highest organic carbon content (2.13%) followed by combined application of magnesium, boron and silica (T_{11}). Soil test based nutrient application (T_1) and magnesium application (T_6) recorded comparable organic carbon content which were higher than POPR (T_2). Among the sources of silica, sodium silicate application (T_7) was better than calcium silicate application (T_8) in organic carbon content of soil. Boron application recorded significantly lower values for organic carbon content of soil. Lower organic carbon content was also recorded by application of POPR without FYM (T_3) and sodium silicate application without lime (T_9). Control plot (T_2) recorded the lowest organic carbon content of 1.76%.

4.7.4 Available N content of soil

The data on available N content of soil is shown in Table 4.33. The available N status in soil after harvest did not show variation compared to pre experiment data (342 kg ha^{-1}). Soil test based nutrient application recorded significantly higher available N in soil (330.3 kg ha^{-1}) which was on par with sodium silicate application (T_7) and combined application of magnesium, boron and silica (T_{11}). POPR (T_2), higher doses of K (T_4 and T_5) and magnesium application (T_6) did not produce much variation in N content of soil. FYM application increased the available N status of soil and it was higher than that of POPR without FYM (T_3).

4.7.5 Available P_2O_5 content of soil

The data on available P_2O_5 content of soil is shown in Table 4.32. An increase in available P_2O_5 content of soil was noticed at harvest compared to pre experiment data (6.75 kg ha^{-1}). Application of boron (T_{10}) recorded highest available P_2O_5 content of soil at harvest (14.38 kg ha^{-1}). Soil test based nutrient application (T_1), POPR (T_2), highest dose of K (T_5), calcium silicate application (T_8) and combined application of magnesium, boron and silica (T_{11}) recorded comparable values for available P_2O_5 content. Higher dose of K (T_4) and magnesium applied treatment (T_6) recorded lower P_2O_5 content of soil compared to POPR. Sodium silicate application with lime (T_7) and without lime (T_9) had no significant difference

Table 4.33 Effect of nutrients and soil ameliorants on available N, P_2O_5 and K_2O content (kg ha^{-1}) of soil after the experiment

Treatments		Available N	Available P_2O_5	Available K_2O
T_1	STNP+ FYM+ lime	330.30[a]	12.02[ab]	110.00[ab]
T_2	POPR	271.80[c]	11.47[ab]	109.70[ab]
T_3	POPR without FYM	179.80[f]	7.18[d]	85.49[d]
T_4	110:45:85 kg NPK+FYM+lime	271.80[c]	9.54[bcd]	111.50[ab]
T_5	110:45:110 kg NPK+FYM+lime	288.50[c]	11.80[ab]	112.20[ab]
T_6	POPR+ MgO	288.50[c]	9.54[bcd]	98.71[c]
T_7	POPR+ sodium silicate	317.80[ab]	10.65[bc]	115.80[a]
T_8	POPR+ calcium silicate	309.40[b]	12.57[ab]	111.10[ab]
T_9	POPR+ sodium silicate without lime	213.20[e]	10.26[bc]	104.90[bc]
T_{10}	POPR+ borax	250.90[d]	14.38[a]	118.60[a]
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	313.60[ab]	12.24[ab]	116.30[a]
T_{12}	Absolute control	96.17[g]	8.05[cd]	72.78[e]

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

in P_2O_5 content of soil. Control plot (T_{12}) recorded lowest P_2O_5 content of 8.05 kg ha^{-1} at harvest.

4.7.6 Available K_2O content of soil

The effect of various treatments on available K_2O of soil at harvest is shown in Table 4.33. The available K_2O content of soil varied from 72.78 kg ha^{-1} to 118.6 kg ha^{-1} due to various treatments. The highest K content was noticed due to application of boron (T_{10}). Soil test based nutrient application (T_1), POPR (T_2) and highest dose of K (T_5) did not produce significant effect on available K content of soil. Sodium silicate application without lime and magnesium application (T_6) recorded lower K_2O content of soil. The control treatment recorded the lowest K_2O content of 72.78 kg ha^{-1} in soil at harvest.

4.7.7 Available Ca content of soil

The available Ca content of soil at harvest of crop is presented in Table 4.34. The available Ca content of soil at harvest was lower compared to that before the experiment (1152 mg kg^{-1}). The application of calcium silicate recorded significantly highest available Ca content of soil (443.0 mg kg^{-1}). POPR application (T_2), higher doses of K (T_4 and T_5) and combined application of magnesium, boron and silica (T_{11}) did not produce much variation in Ca content of soil and had comparable values. Magnesium application (T_6) and sodium silicate application (T_7) recorded comparable available Ca content at harvest. Sodium silicate application without lime (T_9) recorded lower available Ca content than POPR. Lowest available Ca content of soil (351.3 mg kg^{-1}) was recorded by control treatment (T_{12}).

4.7.8 Available Mg content of soil

The available Mg content in soil at harvest of rice is given in Table 4.34. Available Mg content of soil at harvest did not show variation compared to the pre experiment value (23 mg kg^{-1}). There was no significant difference between the treatments on available Mg content of soil at harvest. However, magnesium application (T_6) resulted in highest Mg content of 26.03 mg kg^{-1} available Mg where as it was only 19.86 in absolute control (T_{12}).

4.7.9 Available S content of soil

The effect of treatments on available S content of soil is shown in Table 4.34. The available S content of soil at harvest was increased compared to initial value (6.12 mg kg^{-1}). The available S content was significantly higher (21.29 mg kg^{-1}) in magnesium applied plot

Table 4.34 Effect of nutrients and soil ameliorants on available Ca, Mg and S contents (mg kg^{-1}) of soil after the experiment

Treatments		Available Ca	Available Mg	Available S
T_1	STNP+ FYM+ lime	413.60^{bc}	22.70^{abcd}	16.89^{d}
T_2	POPR	433.60^{ab}	23.24^{abcd}	17.13^{d}
T_3	POPR without FYM	378.90^{d}	20.24^{d}	13.42^{e}
T_4	110:45:85 kg NPK+FYM+lime	435.90^{ab}	24.10^{abc}	17.82^{cd}
T_5	110:45:110 kg NPK+FYM+lime	437.30^{ab}	24.38^{abc}	18.28^{bcd}
T_6	POPR+ MgO	420.10^{abc}	26.03^{a}	21.29^{a}
T_7	POPR+ sodium silicate	425.90^{abc}	23.31^{abcd}	18.75^{bc}
T_8	POPR+ calcium silicate	443.00^{a}	22.18^{bcd}	19.44^{b}
T_9	POPR+ sodium silicate without lime	405.40^{c}	20.18^{d}	14.35^{e}
T_{10}	POPR+ borax	422.80^{abc}	21.67^{cd}	18.05^{cd}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	433.50^{ab}	25.65^{ab}	21.28^{a}
T_{12}	Absolute control	351.30^{e}	19.86^{d}	10.96^{f}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

and was better than T_6 and combined application of magnesium, boron and silica (T_{11}). Soil test based nutrient application (T_1) and POPR (T_2) had comparable POPR without FYM (T_3). Higher doses of K (T_5 and T_4) did not produce variation in S content of soil. Among the sources of silica, calcium silicate (T_8) was better source for increased available S content of soil compared to sodium silicate (T_7). Lowest available sulphur (10.96 mg kg^{-1}) was recorded in control plot (T_{12}).

4.7.10 Available Fe content of soil

The available Fe content of soil at harvest of crop is presented in Table 4.35. The control treatment (T_{12}) showed the highest available Fe content of soil (1498 mg kg^{-1}), followed by POPR without FYM (T_3). The available Fe content of soil did not vary between soil test based nutrient application (T_1) and POPR (T_2). Among the sources of silica, sodium silicate (T_7) recorded lower available Fe content than calcium silicate (T_8). Lowest available Fe content (1058 mg kg^{-1}) was recorded by combined application of magnesium, boron and silica (T_{11}).

Available Mn content of soil

The available Mn content in soil at harvest of rice crop is given in Table 4.35. The application of manganese (T_6) recorded the highest available Mn content of soil (100.6 mg kg^{-1}) which was on par with boron application (T_{10}). Soil test based application recorded lower available Mn content than POPR (T_2). Higher doses of K (T_4 and T_5) recorded lower available Mn content compared to POPR. Among the sources of silica, sodium silicate application (T_7) recorded more available Fe content than calcium silicate (T_8). Combined application of magnesium, boron and silica (T_{11}) recorded lower available Mn content than POPR. The Lowest Mn content (85.33mg kg^{-1}) was observed in control treatment (T_{12}) and it was on par with POPR without FYM (T_3).

Available Zn content of soil

The effect of treatments on available Zn content of soil at harvest is presented in Table 4.35. The available Zn content of soil was noticed to be increased compared to that before cropping (1.75 mg kg^{-1}). The highest Zn content (4.63 mg kg^{-1}) of soil was observed due to combined application of magnesium, boron and silica (T_{11}). POPR (T_2) recorded higher Zn content of soil compared to soil test based application (T_1). Higher doses of K (T_4

Table 4.35 Effect of nutrients and soil ameliorants on available Fe, Mn and Zn (mg kg^{-1}) of soil after the experiment

Treatments		Available Fe	Available Mn	Available Zn
T_1	STNP+ FYM+ lime	1216.00^{bc}	93.09^{d}	3.47^{cd}
T_2	POPR	1223.00^{bc}	94.22^{cd}	3.73^{bcd}
T_3	POPR without FYM	1304.00^{b}	85.97^{fg}	2.86^{e}
T_4	110:45:85 kg NPK+FYM+lime	1113.00^{de}	88.85^{ef}	3.67^{bcd}
T_5	110:45:110 kg NPK+FYM+lime	1188.00^{cd}	89.23^{e}	3.87^{bc}
T_6	POPR+ MgO	1154.00^{cde}	100.6^{a}	3.86^{bc}
T_7	POPR+ sodium silicate	1079.00^{e}	97.34^{abc}	4.02^{b}
T_8	POPR+ calcium silicate	1142.00^{cde}	95.92^{bcd}	3.43^{d}
T_9	POPR+ sodium silicate without lime	1198.00^{cd}	93.79^{d}	3.74^{bcd}
T_{10}	POPR+ borax	1146.00^{cde}	98.19^{ab}	3.96^{b}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	1058.00^{e}	95.83^{bcd}	4.63^{a}
T_{12}	Absolute control	1498.00^{a}	85.33^{g}	2.55^{e}

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

and T_5) and magnesium application (T_6) recorded comparable Zn content of soil. Sodium silicate application (T_7) recorded more Zn content of soil when compared to calcium silicate application (T_8). The available Zn content did not show variation due to application of boron (T_{10}) or sodium silicate (T_7). The lowest available Zn content in soil was recorded in control treatment (T_{12}).

4.7.13 Available B content of soil

The effect of various treatments on available B content of soil is shown in Table 4.36. Combined application of magnesium, boron and silica (T_{11}) and boron application (T_{10}) recorded significantly higher available B content which was on par with application of highest dose K (T_5). Soil test based nutrient application (T_1) was better in available B content of soil than POPR (T_2) and POPR without FYM (T_3). Control treatment recorded lowest (0.33 mg kg^{-1}) available B content of soil.

4.7.14 Available Silica content of soil

The effect of treatments on available Si content of soil is presented in Table 4.36. The highest available Si content (43.37 kg ha^{-1}) in soil was observed due to sodium silicate application (T_7) which was on par with combined application of magnesium, boron and silica (T_{11}) and calcium silicate application (T_8). Application of nutrients as per POPR (T_2) recorded higher available Si content than soil test based nutrient application (T_1) and POPR without FYM (T_3). The doses of K did not influence the available Si content of soil. Application of magnesium (T_6) and boron (T_{10}) produced comparable Si content which were on par with that of POPR. Control treatment (T_{12}) recorded the lowest (14.75 kg ha^{-1}) available Si content of soil.

4.8. Economics of cultivation

The effect of treatments on the economics of cultivation is presented in Table 4.37. The cost of cultivation was highest by combined application of magnesium, boron and silica (T_{11}) followed by boron (T_{10}) and silica application (T_8 and T_7). The lowest cost for cultivation was calculated in the control plot and when the nutrients were applied as per POPR without FYM. The gross return showed a different trend. The highest return of Rs 1,59,850 was manifested by combined application of magnesium, boron and silica followed by boron applied plot (Rs 1,53,840). Sodium silicate application also registered considerably

Table 4.36 Effect of nutrients and soil ameliorants on available B (mg kg^{-1}) and Si (kg ha^{-1}) of soil after the experiment

Treatments		Boron (mg kg^{-1})	Silica (kg ha^{-1})
T_1	STNP+ FYM+ lime	1.13^d	30.92^d
T_2	POPR	0.94^e	31.58^{cd}
T_3	POPR without FYM	0.79^f	20.75^e
T_4	110:45:85 kg NPK+FYM+lime	1.29^c	30.85^d
T_5	110:45:110 kg NPK+FYM+lime	1.51^b	34.17^{cd}
T_6	POPR+ MgO	1.34^c	31.75^{cd}
T_7	POPR+ sodium silicate	1.35^c	43.37^a
T_8	POPR+ calcium silicate	1.21^{cd}	42.25^a
T_9	POPR+ sodium silicate without lime	0.97^e	34.67^b
T_{10}	POPR+ borax	1.81^a	32.00^{cd}
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	1.90^a	41.83^a
T_{12}	Absolute control	0.33^g	14.75^f

* The means followed by common alphabets do not differ significantly at 5% level in DMRT

Table 4.37 Effect of nutrients and soil ameliorants on economics of cultivation (Rs/ha)

Treatments		Cost of cultivation	Gross return	BC Ratio
T_1	STNP+ FYM+ lime	70,322/-	1,30,320/-	1.85
T_2	POPR	69,897/-	1,28,460/-	1.83
T_3	POPR without FYM	63,897/-	1,08,620/-	1.69
T_4	110:45:85 kg NPK+FYM+lime	70,797/-	1,31,560/-	1.85
T_5	110:45:110 kg NPK+FYM+lime	71,547/-	1,34,640/-	1.88
T_6	POPR+ MgO	70,897/-	1,28,680/-	1.81
T_7	POPR+ sodium silicate	71,875/-	1,53,420/-	2.13
T_8	POPR+ calcium silicate	72,397/-	1,45,600/-	2.01
T_9	POPR+ sodium silicate without lime	65,875/-	1,34,460/-	2.04
T_{10}	POPR+ borax	72,897/-	1,53,840/-	2.11
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	75,675/-	1,59,480/-	2.10
T_{12}	Absolute control	49,920/-	76,860/-	1.53

higher return of Rs. 1,53,420 ha^{-1}. The highest BC ratio of 2.13 was noticed due to sodium silicate (T_7) followed by boron applied plot (T_{10}) and combined application of magnesium, boron and silica (T_{11}) plot due to higher yield obtained from these plots. Calcium silicate application also recorded a higher B:C ratio of 2.01. The lowest ratio of 1.53 was recorded by control treatment.

4.8. Scoring of pests

The data on scoring of pests is presented in Table 4.38. During the crop growth period there was no severe pest attack but incidence of leaf folder was observed. The scoring of leaf folder was recorded and it was highest in POPR (T_2), Soil test based nutrient application (T_1) and POPRR without FYM (T_3) followed by control treatment (T_{12}). Scoring recorded was lowest in both sodium silicate and calcium silicate applied treatments (T_7 and T_8) and by combined application of magnesium, silica and boron (T_{11}) showing resistance to pest attack.

4.9. Scoring of diseases

The data on scoring of diseases is presented in Table 4.39. There was no severe incidence of diseases during the crop growth period but to minute extent incidence of brown spot was noticed. Scoring of the diseases was done based on PDI. Control plot recorded highest PDI of 38.38% followed by POPR application without FYM treatment (T_3). Both the silica applied treatments (T_7 and T_8) recorded lowest amount of 6.14% and 6.40% of PDI.

5.0. Correlation between biometric characters and grain yield in rice

The data on correlation between biometric characters and grain yield in rice is presented in Table 4.40. All the biometric characters at harvest were significantly correlated with yield and the highest correlation was noticed with number of spiklets/m^2 (0.93^{**}).

5.1. Correlation of nutrient content of plant, grain and straw with grain yield in rice

The data on correlation of nutrient content of plant, grain and straw with grain yield in rice is presented in Table 4.41. The content of all nutrients except Fe and Mn established a significant positive correlation with grain yield. N content followed by B content of plant recorded significantly higher correlation with yield at 60 DAS while Si content (0.91^{**} and 0.90^{**}) followed by B content (0.90^{**} and 0.89^{**}) recorded higher significant correlation with grain and straw yield at harvest respectively.

Table 4.38 Scoring for pests in rice due to nutrients and soil ameliorants

Treatments		Scores
T_1	STNP+ FYM+ lime	5
T_2	POPR	5
T_3	POPR without FYM	5
T_4	110:45:85 kg NPK+FYM+lime	3
T_5	110:45:110 kg NPK+FYM+lime	1
T_6	POPR+ MgO	3
T_7	POPR+ sodium silicate	1
T_8	POPR+ calcium silicate	1
T_9	POPR+ sodium silicate without lime	3
T_{10}	POPR+ borax	3
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	1
T_{12}	Absolute control	5

Table 4.39 Scoring for diseases in rice due to nutrients and soil ameliorants

Treatments		PDI (%)
T_1	STNP+ FYM+ lime	15.52[c]
T_2	POPR	15.21[c]
T_3	POPR without FYM	16.53[b]
T_4	110:45:85 kg NPK+FYM+lime	8.64[e]
T_5	110:45:110 kg NPK+FYM+lime	8.19[e]
T_6	POPR+ MgO	13.42[d]
T_7	POPR+ sodium silicate	6.14[g]
T_8	POPR+ calcium silicate	6.40[g]
T_9	POPR+ sodium silicate without lime	7.13[f]
T_{10}	POPR+ borax	13.21[d]
T_{11}	POPR+ MgO+ silica(sodium silicate)+borax	6.60[g]
T_{12}	Absolute control	38.38[a]

* The means followed by common alphabets do not differ significantly at 5% level by DMRT

Table 4.40 Correlation between biometric characters and grain yield in rice

Characters (harvest)	**Grain yield**
Plant height(cm)	0.91**
Tillers count per m^2	0.86**
Number of Spikelets per panicle	0.93**
Filled grains (%)	0.89**
1000 grain weight	0.84**
HI	0.48**
Straw yield(t/ha)	0.84**

Table 4.41 Correlation of nutrient content of plant, grain and straw yield in rice

Nutrient content	**Grain Yield**		
	At 60DAS	**In Grain**	**In Straw**
N content (%)	0.91**	0.83**	0.75**
P content(%)	0.72**	0.64**	0.48**
K content (%)	0.71**	0.67**	0.60**
Ca content (mg/kg)	0.71**	0.65**	0.48**
Mg content (mg/kg)	0.78**	0.69**	0.73**
S content (mg/kg)	0.61**	0.79**	0.75**
Fe content (mg/kg)	-0.73**	-0.67**	-0.86**
Mn content (mg/kg)	-0.76**	-0.74**	-0.76**
Zncontent (mg/kg)	0.85**	0.73**	0.83**
B content (mg/kg)	0.88**	0.90**	0.89**
Si content (%)	0.82**	0.91**	0.90**

5.2. Correlation between uptake of nutrients and yield

The data on correlation between uptake of nutrients and yield is presented in Table 4.42. Significant positive correlation was recorded between uptake of all nutrients except Fe and grain yield. Uptake of silicon and N was found to be highly correlated with yield. A negative relationship was noticed between Fe uptake and yield though not significant.

Table 4.42 Correlation between uptake of nutrients and yield

Nutrient	**Grain Yield**
	Total uptake
Nitrogen	0.94**
Phosphorous	0.85**
Potassium	0.73**
Calcium	0.84**
Magnesium	0.90**
Sulphur	0.85**
Iron	-0.15
Manganese	0.60**
Zinc	0.89**
Boron	0.94**
Silicon	0.95**

Discussion

V. DISCUSSION

The experiment on Soil amelioration and nutrient management of rice was conducted in Kole lands. Kole lands are low lying wetland tracts located at 0.5-1.0m below mean sea level and spread over Thrissur and Malappuram districts of Kerala. The cyclical nutrient recycling of the wetland during the flood season rendered the areas as one of the most fertile soils of Kerala. It was reported that soil acidity, toxicity of Fe and Mn and potassium deficiency are the major soil factors limiting productivity of rice in Kole lands. Use of chemical fertilizers per hectare of rice in Kole lands is two times more than that of all Kerala average. Ponnusamy (2006) reported that large scale use of fertilizers containing only major nutrients can result in the deficiencies of secondary and micronutrients.

Based on these facts, the nutrients and soil ameliorants of different sources at different doses were applied and the growth parameters, yield attributes and nutrient status of plant and soil were studied.

5.1 Effect of nutrients and soil ameliorants on growth and yield of rice

The data on growth and yield parameters revealed that there was significant improvement in growth and yield due to application of nutrients and soil ameliorants. This is clearly manifested due to the fact that the combined application of magnesium, boron and silica produced taller plants (Fig. 5.1), highest number of tillers (Fig. 5.2), chlorophyll content(Fig. 5.3), dry matter production (Fig. 5.4), number of panicles/m^2 and number of spikelets/m^2 and ultimately the yield(Fig. 5.5). Magnesium has important role in photosynthesis because it is the central atom of chlorophyll. It is also necessary as it is the activator for many critical enzymes in carbon fixation. So the application of magnesium improves the photosynthetic capacity and there by carbohydrate production and the resultant yield. Lakshmikanthan (2000) reported that application of silica was found to ameliorate the limiting influences of Fe and Mn enabling increased rice production. Application of silica may improve the soil status and provide a favourable environment for maximum absorption of nutrients which may result in increased yield. Boron is responsible for better pollination, seed setting, low spikelet sterility and more grain formation in different varieties of rice (Aslam *et al.*, 2002). This is also evident in the experiment by increased percent of filled

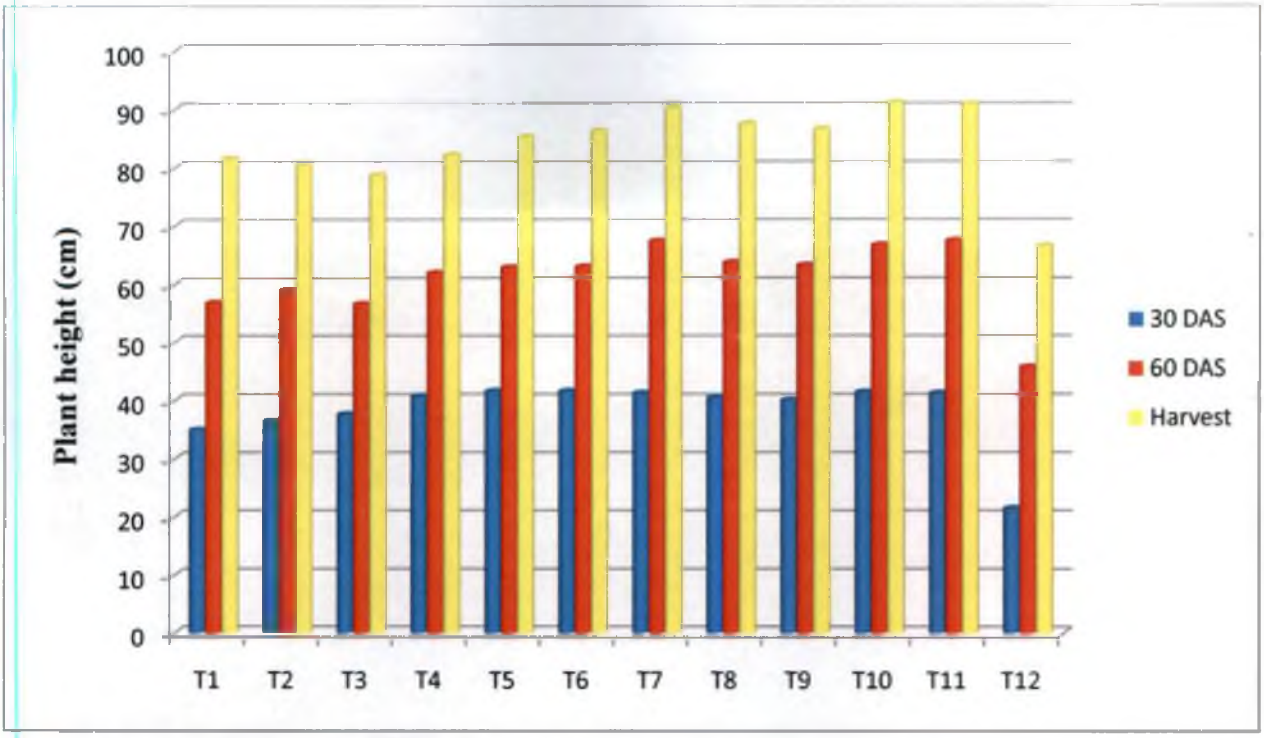

Fig. 5.1 Effect of nutrients and soil ameliorants on plant height of rice

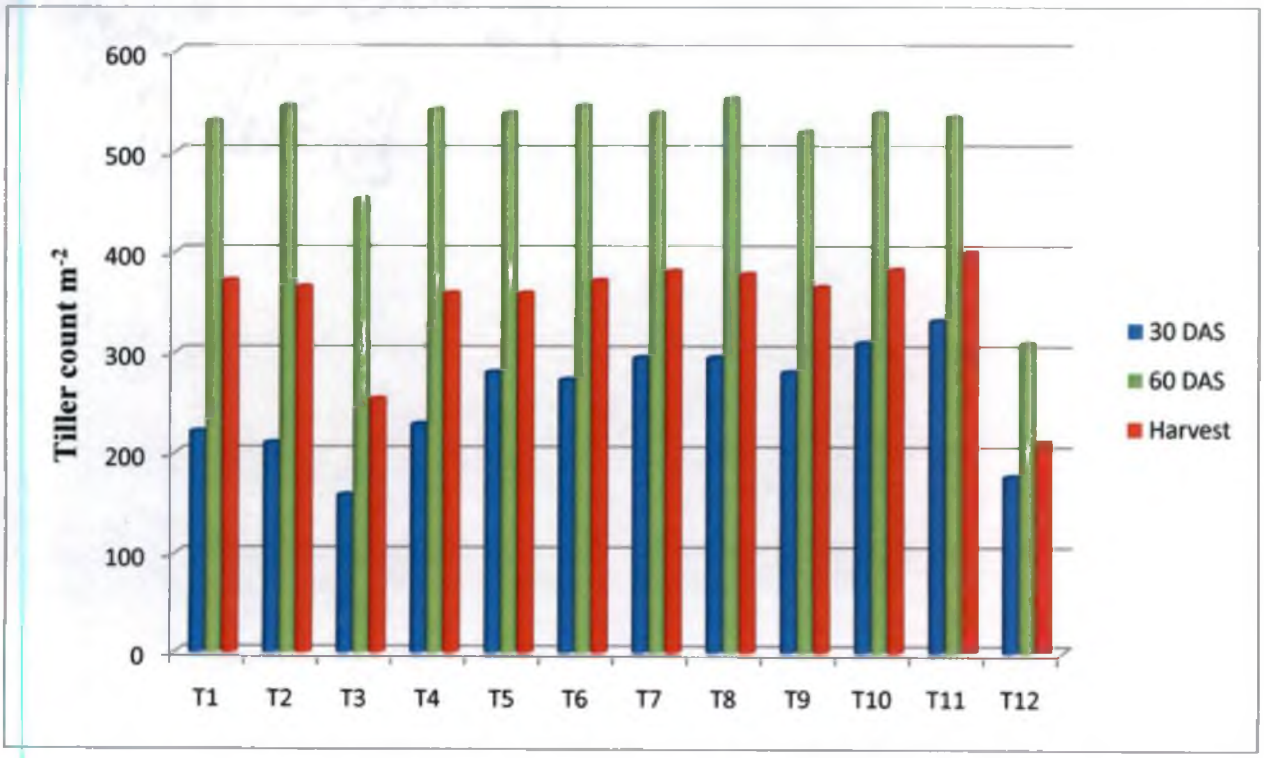

Fig. 5.2 Effect of nutrients and soil ameliorants on tiller count of rice

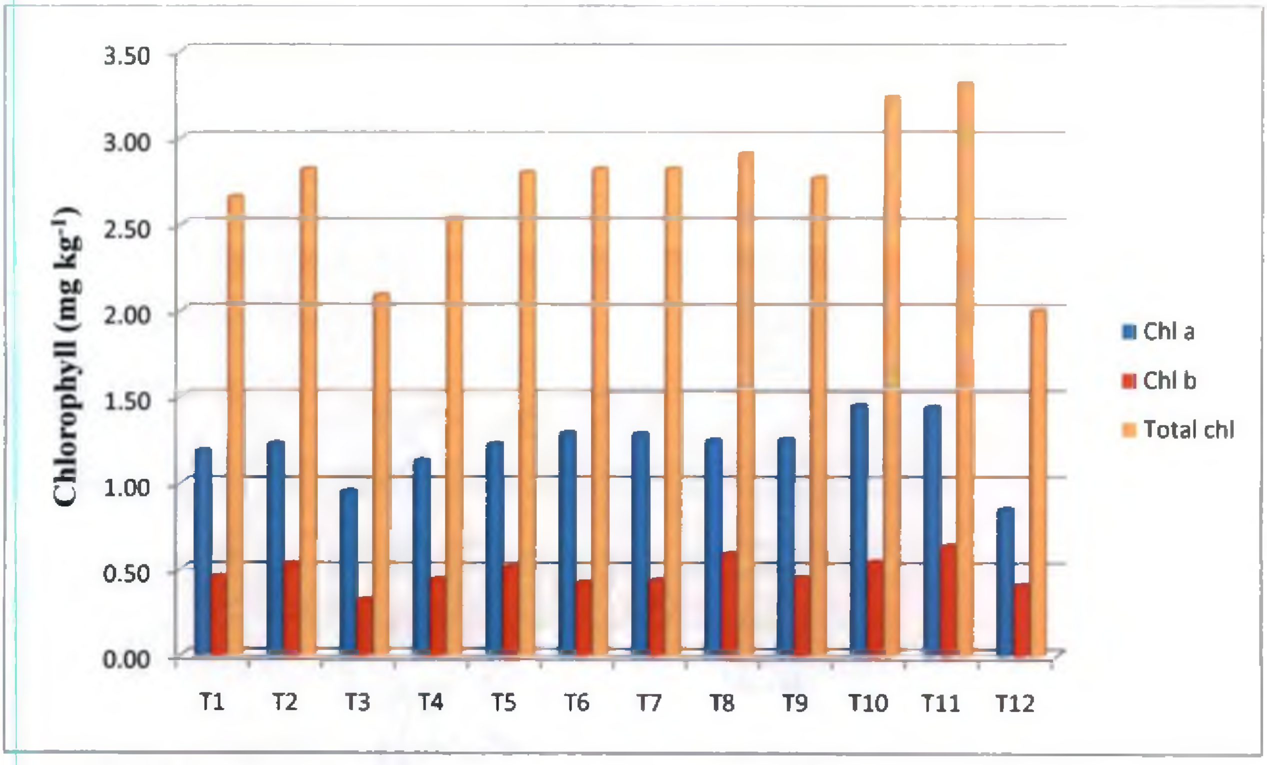

Fig. 5.3 Effect of nutrients and soil ameliorants on chlorophyll content of rice

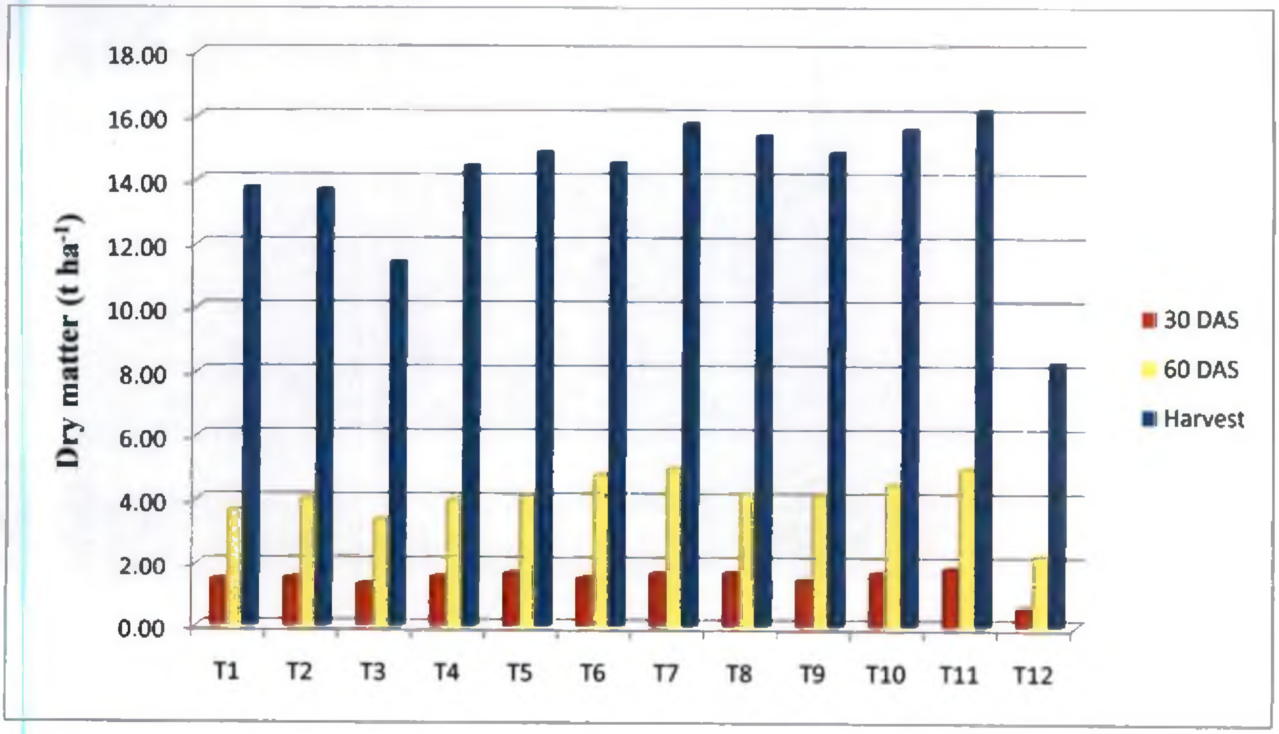

Fig. 5.4 effect of treatments and soil ameliorants on dry matter production of rice

grains in boron applied treatments. So the combined application of the nutrients and soil ameliorants collectively contributed to increased photosynthesis by magnesium, reduced pollen sterility and increased grain filling by boron, increased resistance to biotic and abiotic stresses and ameliorating the influence of Fe and Mn by silica which ultimately resulted in increased yield. The lowest content of Fe and Mn in soil by combined application of nutrients and ameliorants provided conducive situation for maximum absorption of nutrients from soil. This also indicated that balanced nutrition and creation of favourable soil environment for absorption of nutrients and their translocation and utilization are important for the increased plant metabolism and enhanced yield.

The individual application of nutrients and ameliorants also resulted in enhanced yield in rice. Application of boron produced higher yield. Addition of boron alone resulted in 1.37 t ha^{-1} of yield increase over control. This is mainly attributed to higher number of filled grains per panicles (Fig. 5.6) which was 45 per cent more compared to control and the highest among the treatments. The effect of boron towards translocation of photosynthates for grain formation is also evident from the data. The plant metabolic process like diffusion may be acting for the increased nutrient absorption and increased yield in this treatment. Ahamad *et al.* (2009) reported the function of boron in plant relate to sugar transport, flower production, retention, pollen tube elongation and germination and translocation of carbohydrate and sugars to reproductive organs, which in turn improved the spikelet number and fertility that influenced the yield and productivity.

Boron was applied in two splits at basal and at flowering stage. Higher tiller count was noticed at 30 and 60 DAS and at harvest due to boron application. The positive effect on plant tillers may be due to proper development and differentiation of tissue as boron affects the deposition of cell wall by altering membrane properties (Marschner, 1995). It was also observed that boron application at reproductive stage resulted in higher grain yield due to reduced panicle sterility and more number of grains. Increased boron content (Fig. 5.7) and uptake in the plant and grain indicated that the applied boron was efficiently translocated to the plant tissues for utilisation. Increased yield due to boron application was also reported by Sakal *et al.* (2002) and Dunn *et al.* (2005)

Harvest index was also found to be higher with boron application. Increased harvest index by boron application might be due to better carbohydrate utilisation that resulted in better seed setting and translocation of assimilates to developing grains which increase the

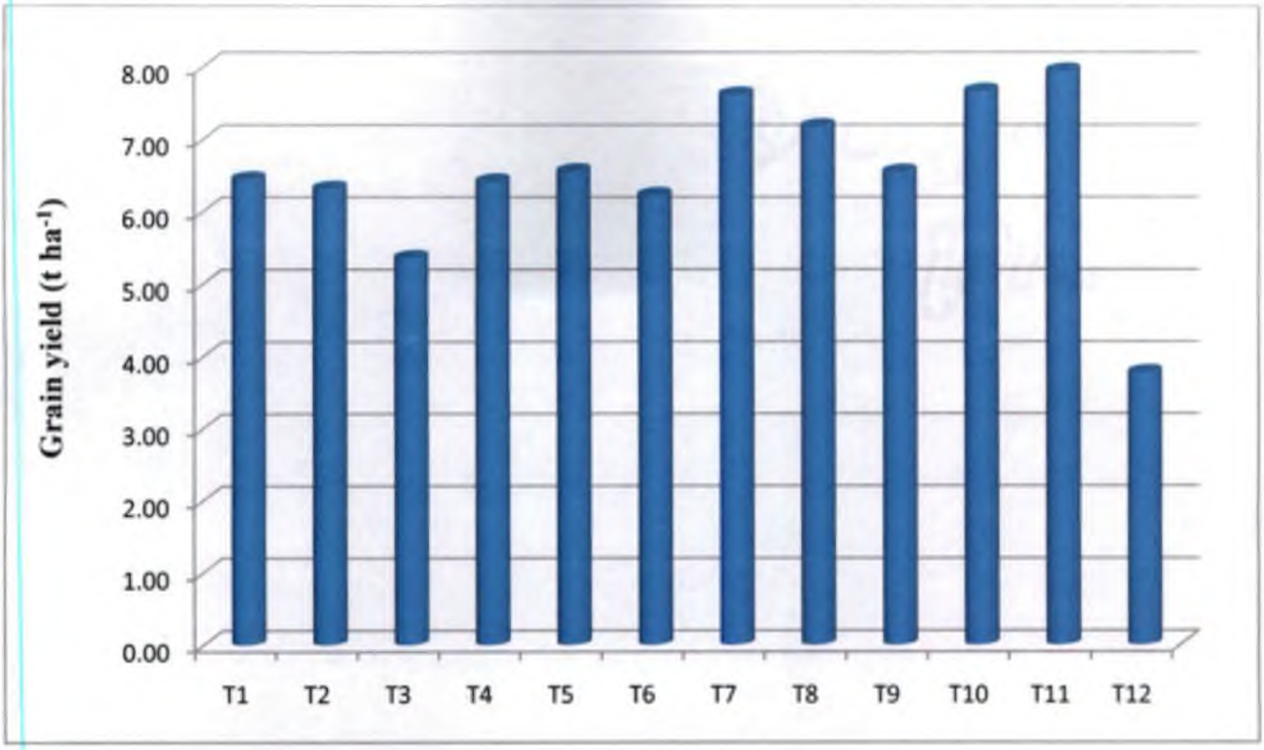

Fig. 5.5 Effect of treatments and soil ameliorants on grain yield of rice

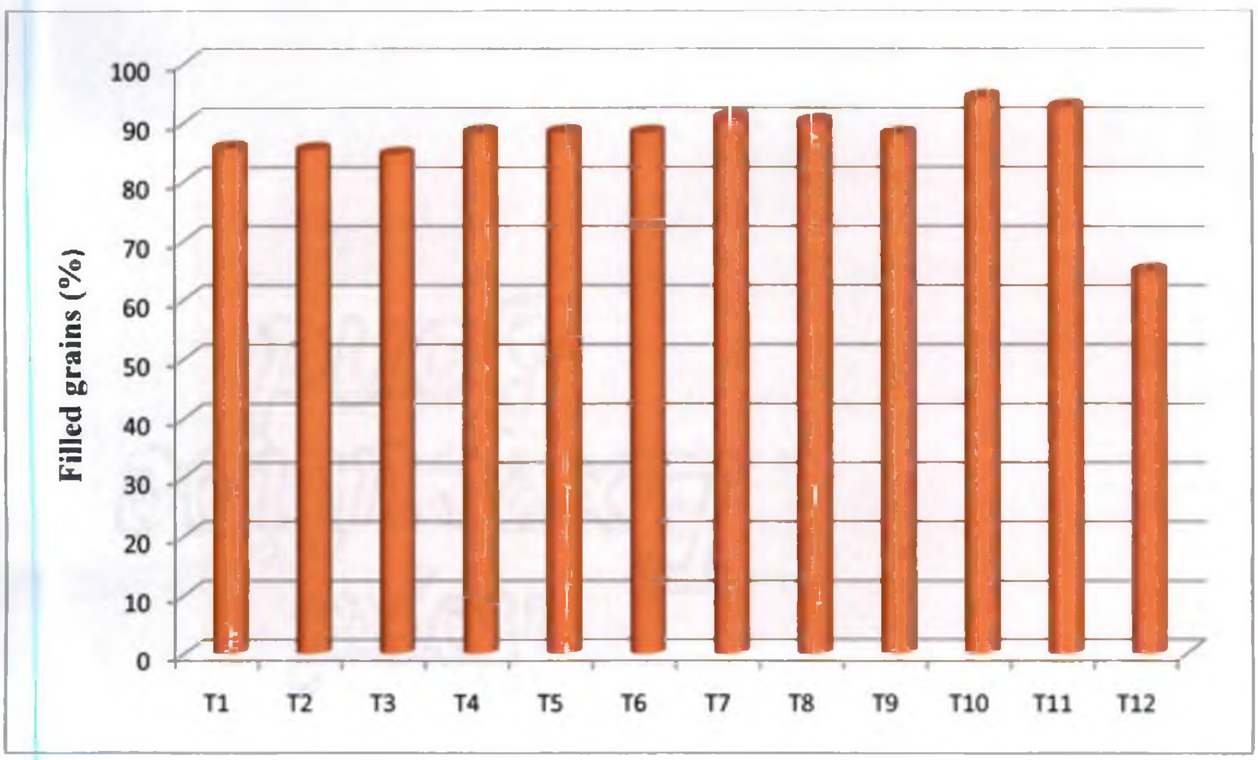

Fig. 5.6 Effect of treatments and soil ameliorants on per cent of filled grains

grain size and number of filled grains per panicle and increased economic yield because of the role of boron in pollination and seed setting and decreased sterility.

The application of silica as sodium silicate along with nutrients and lime as per package of practices (KAU, 2011) also resulted in increased grain yield due to the production of higher number of panicles, spikelets and also filled grains per panicle.

Silicon is a beneficial element for crop growth and it plays an important role in the growth and development of gramineae crops (Hodson *et al*, 2005). According Mobasser *et al.* (2008) plant height, number of tillers per plant and number of productive tillers performed better when silicon was applied as foliar, while straw yield, spikelets per panicle, 1000 grain weight and grain yield were better when silicon was soil applied. Moreover the data on correlation of yield with biometric characters denoted high, positive and significant correlation between plant height, number of spikelets per panicles and percent of filled grains per panicle with grain yield. So the increase in these yield attributes resulted in increased yield due to silica application.

The variation in source of silica was manifested in almost all the attributes studied. Sodium silicate which recorded a yield of 7.62 t ha^{-1} was superior in all the growth characteristics and yield attributes and finally the yield. Variability in source of silica effect seems to be due to the variation in the reactivity of source consequent of their translocating and ameliorating efficiency to have specific effects. Effect of sodium silicate on growth was slow in the beginning which was evident from the lower tiller count compared to calcium silicate. But application of sodium silicate increased the yield attributes as well as yield over other source which implied that the positive effect had started before panicle initiation.

Mureta (1969) reported that the floret number is decided by the nutritional status of the plant one month before. Though increased tiller count was noticed at 30 DAS in calcium silicate applied plot, it could not register higher yield for want of favourable yield attributes contributing to yield. The increased tiller number due to calcium silicate application advantageously reflected in increased straw yield which was higher than sodium silicate application. It was also noticed that though the grain yield was relatively low when calcium silicate was applied without lime the straw yield was higher (Fig. 5.8). This may be due to the

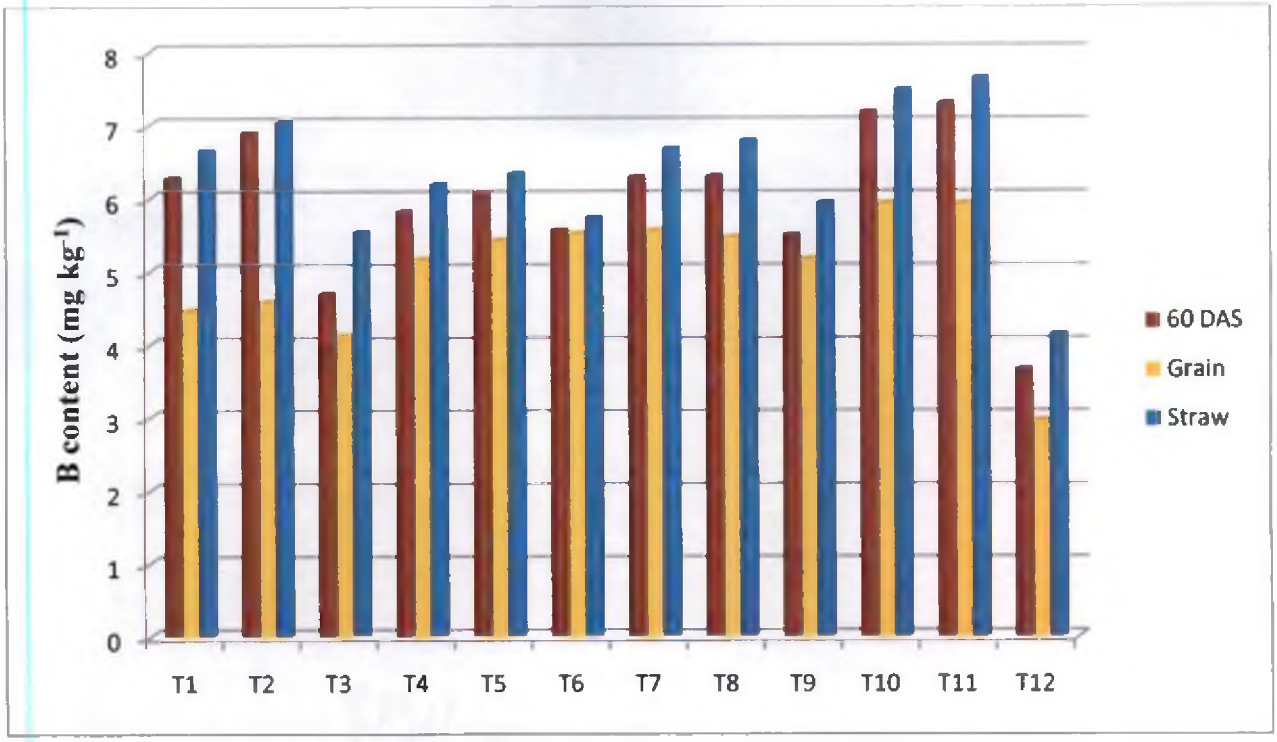

Fig. 5.7 Effect of treatments and soil ameliorants on boron content of rice

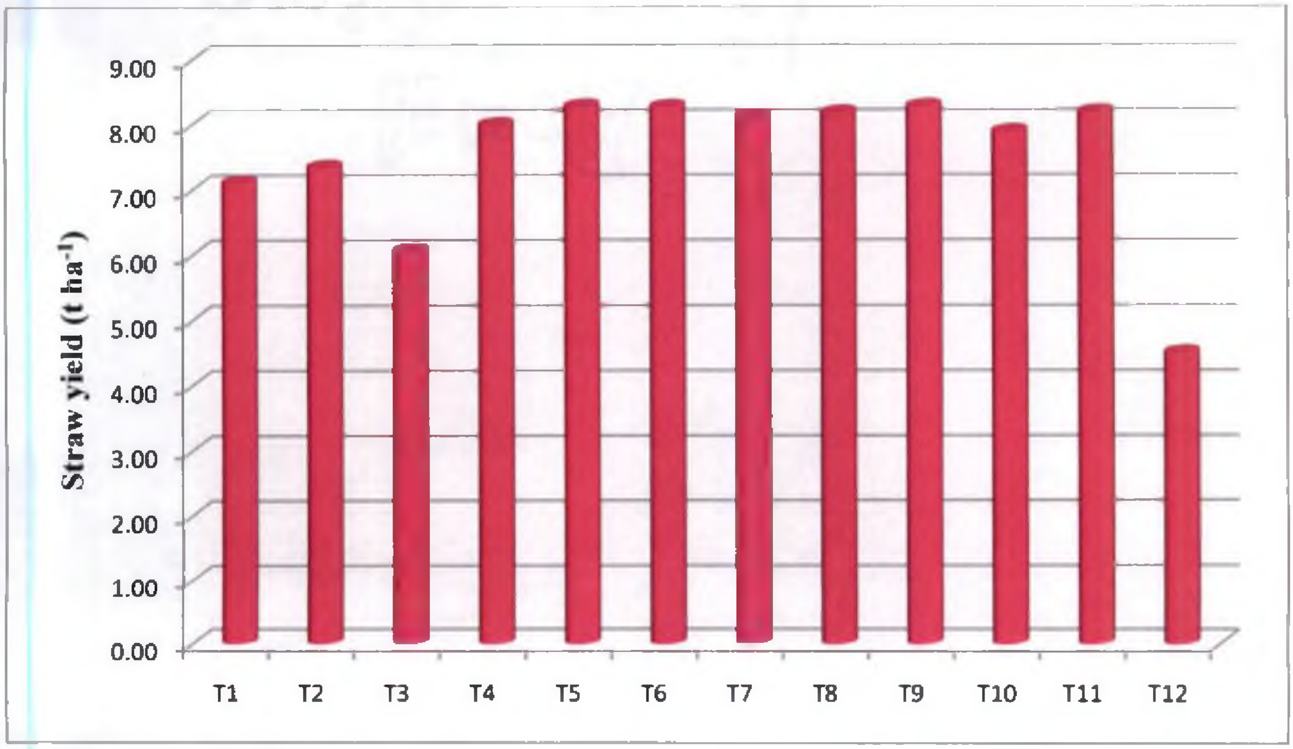

Fig.5.8 Effect of treatments and soil ameliorants on straw yield of rice

specific role of silica in disease resistance and reduced lodging due to the formation of a physical barrier in epidermal cells which contribute to stem strength and pest and disease resistance. Most of the beneficial effects of Si are realized through Si deposition in cell walls of the epidermal surfaces of leaves, stems and hulls (Melo *et al.*, 2010) and deposition of Si enhanced the strength and rigidity of cell walls and thus increased the resistance of plants to various stresses (Ma *et al.*, 2004).

It was noticed that the sodium silicate application along with lime registered lower available Fe content in the soil compared to calcium silicate (Fig. 5.9). Application of lime along with sodium silicate was found to be better for favourable soil condition for absorption and utilisation of nutrients as noticed from lower Fe content, increased pH and higher nutrient content in plants due to sodium silicate application along with lime which ultimately resulted in increased grain production. On contrary pH was significantly lower when sodium silicate was applied without lime.

The number of panicles and spikelets and thousand grain weight increased with increasing levels of K from 55 kg ha^{-1} to 110 kg ha^{-1} which resulted in increased yield. Potassium deficiency is one of the limiting factors for productivity of rice in Kole lands and application of higher levels of K responded well as evident from the data. The increment in grain yield was higher from the level of K from 85 kg ha^{-1} to 110 kg ha^{-1} compared to that from 55 kg ha^{-1} to 85 kg ha^{-1}. There was yield increase of 320 kg ha^{-1} due to additional application of 55 kg ha^{-1} of potassium. Increased number of panicles, spikelets per panicle, grain weight and yield was reported due to K application by Su (1976) and Mandal and Dasmahapatra (1983). Increased grain yield by 951and 1125 kg ha^{-1} respectively by increasing the level of K application from 52.5 to 70 kg ha^{-1} as against Package of Practice recommendation was reported by Lakshmikanthan (2000). The straw yield was also found to be increasing with increasing levels of K (Fig. 5.10).

The higher levels of K were observed to decrease the available Fe content of soil and improved the uptake of N and P. This indicated the favourable soil environmental condition created due to higher K application which might have helped the plants to absorb and utilise the nutrients efficiently and resulted in increased yield. Fe toxicity symptoms were found to be decreased on rice in an iron toxic laterite soil with increasing K application (Mithra *et al.*, 1990). John *et al.* (2004) revealed that the ill effects of Fe can be reduced by K fertilization.

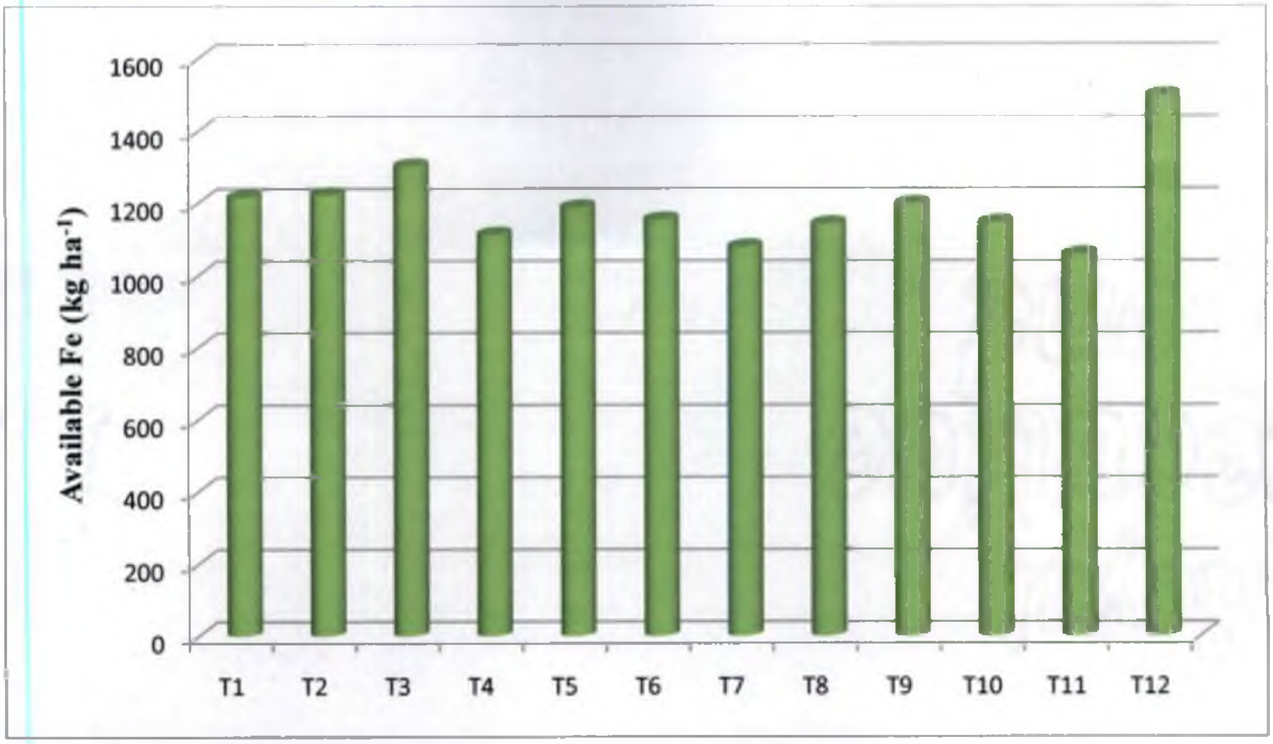

Fig. 5.9 Effect of treatments and soil ameliorants on available iron in soil after the experiment

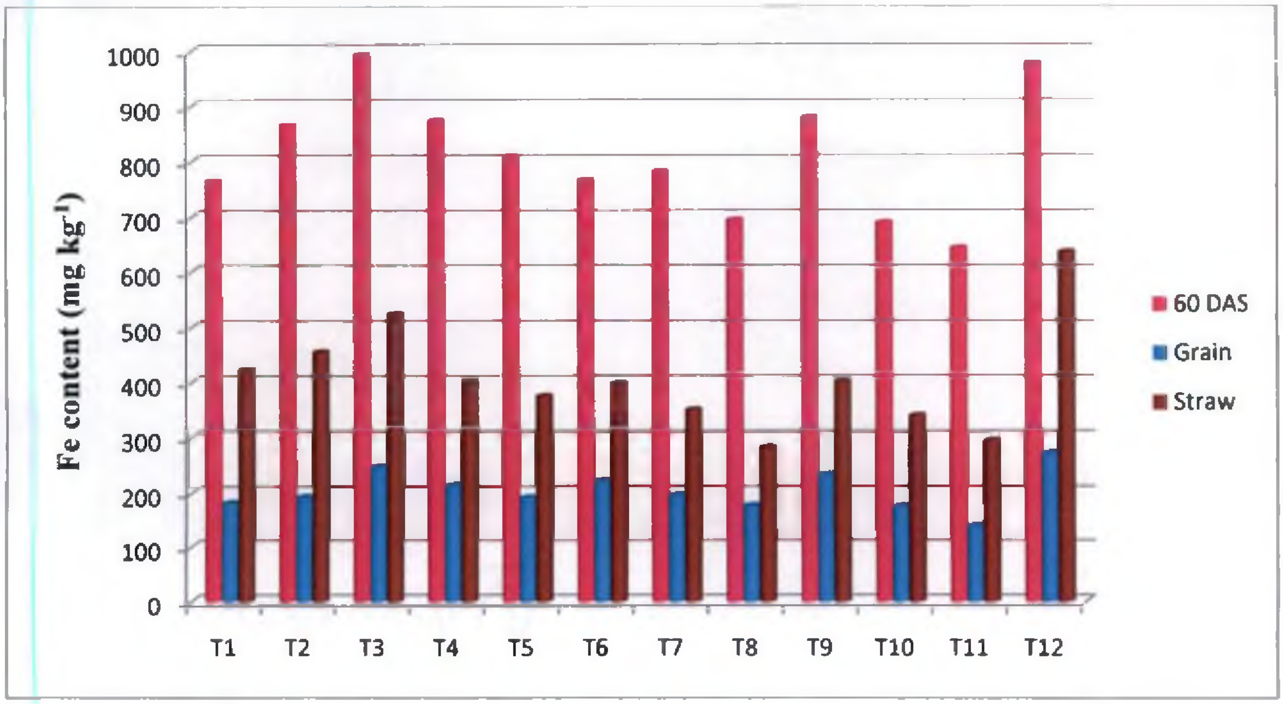

Fig. 5.10 Effect of treatments and soil ameliorants on iron content of rice

The higher K levels facilitated reduction in Fe content at panicle initiation stage up to harvest which was evident by low Fe content of straw and grain at harvest with higher levels of K. Potassium is known to be involved in production and movement of photosynthates to sink and proper uptake of other nutrients. These might have contributed to increased absorption of the nutrients with higher efficiency, utilization of absorbed nutrients for carbohydrate production and efficient translocation to produce higher straw yield. Since K is also involved to resist lodging, maximum straw yield may be possible without any loss due to K application. The results are in conformity with findings of Muthukumararaja *et al.* (2009).

The application of nutrients as per Package of Practices recommendation and soil test based nutrient package did not register significant yield variation. But the straw yield was significantly higher when nutrients were applied as per Package of Practices recommendation. The soil test data before cropping revealed that the nutrient status of soil was in the sufficiency level for N, P and K. Calcium and Magnesium were in the deficiency range. In the case of micronutrients, content of all micronutrients except B were in the sufficiency range. Fe and Mn contents after cropping were considerably above the sufficiency i.e. in the toxic levels even in silicate and borax applied plots. Application of lime along with POP and soil test based nutrient package might have taken care of calcium nutrition to the plant during cropping. Since all the other nutrients are almost in sufficiency range even before cropping, the yield variation was not noticed. However HI was noticed to be higher in plots where nutrients were applied as per soil test based package. The low HI in plots with nutrients supplied as per POP may be due to higher straw yield and thus narrow down the ratio of economic yield to biological yield. The Fe and Mn content of the plant at the panicle initiation stage was significantly lower when nutrients were applied as per need basis which resulted in balanced fertilization and increased absorption of other nutrients. Even though there was no considerable variation in Fe and Mn content of soil between application of nutrients as per POP and soil test basis.

Application of lime had pronounced influence in regulating pH of soil and ameliorating the harmful effects of Fe and Mn as evident from the pH values at weekly intervals and also from the nutrient status of plant and soil. This has led to the improvement in uptake of nutrients, increased dry matter production and grain and straw yield. Lime amendment in acid soil improved P availability and promoted absorption of P, Ca, Mg leading increase in yield (Guanghui *et al.*, 2003).The yield was significantly lower in treatments with no lime application. Increased yield components and yield of rice due to lime application was reported by Chang and Sung (2004), Suswanto *et al.* (2007) and Bridgit (1999). The Ca content of plant at 60 DAS (Fig. 5.11) and in grain and straw at harvest was higher and hence uptake of Ca was higher, in lime applied plots. It was reported that liming of acidic lateritic soil not only ameliorate soil acidity related problem but also supply Ca and increased the uptake of Ca (Fox *et al.*, 1991; Samui and Mandal, 2003).

FYM application also had profound influence on growth and yield of rice. The grain as well as straw yield were significantly decreased due to application of nutrients through inorganic sources alone without organic matter. The soils of kole lands are relatively rich in organic matter with organic carbon content of 1.76 per cent before application of treatments. But addition of FYM improved the condition of soil resulting in higher uptake of nutrients and ultimately the yield. Moreover, the effect of FYM on improvement of soil condition, water holding capacity, activity of microbes etc. is well known. This created suitable environment for maximum absorption of nutrients. There was improvement of 960 kg ha^{-1} of grain and 1280 kg ha^{-1} of straw due to application of FYM alone.

The effect of application of $MgSO_4$ was conspicuous compared to control but not to the extent of application of silica and borax. However, yield increase of 2460 kg ha^{-1} was manifested due to magnesium application compared to control. There was enhanced tiller count, LAI and dry matter production due to magnesium application over POP but no considerable variation in grain yield was noticed. The straw yield was increased by 720 kg ha^{-1} due to application of magnesium. This was also supported by the fact that the uptake of N, P and K by straw was significantly higher in magnesium applied plots, while the uptake of nutrients by grain was comparatively low.

Disease resistance:

Data on incidence of pests and diseases showed that generally the pest and disease infestation was low irrespective of treatments. However, variation in incidence among treatments would mean that the treatment effects conferred resistance. Significant reduction in percent disease incidence and infestation index was noticed with silica applied plots. Application of silica is more beneficial for disease resistance compared to combined application and boron application. Silica is known to give physical resistance (Takahashi, 1997). Santos and Oliveira, 2007 reported that higher accumulation of silica positively influenced the control of brown spot, leaf blast as well as the rice productivity. This is true with the case of silica application in the experiment conducted.

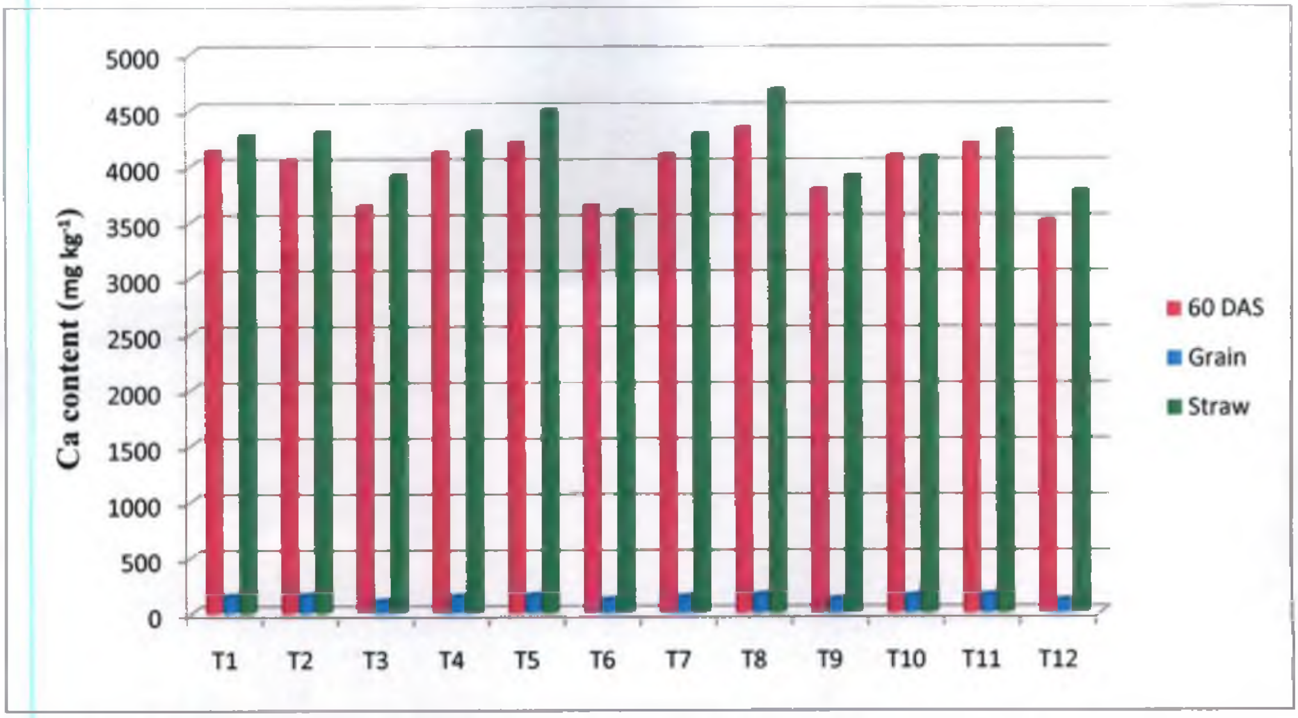

Fig. 5.11 Effect of treatments and soil ameliorants on calcium content of rice

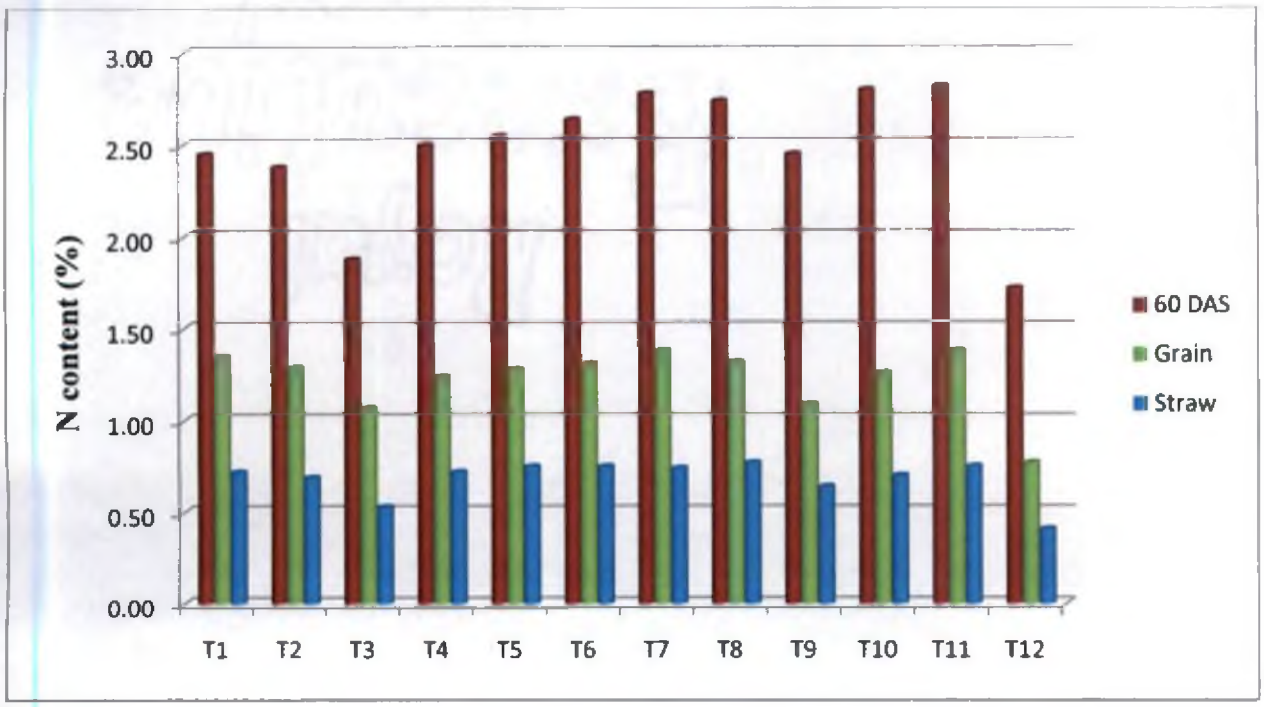

Fig. 5.12 Effect of treatments and soil ameliorants on nitrogen content of rice

5.2 Effect of nutrients and ameliorants on elemental composition and nutrient uptake of rice

The highest yield was recorded with combined application of magnesium, boron and silica followed by individual application of boron and sodium silicate. Higher nutrient content of plant especially N (Fig. 5.12), P (Fig. 5.13), K (Fig. 5.14) and Mg (Fig. 5.15) were also noticed in these treatments. Significant reduction in Fe content of plant at panicle initiation stage and in straw at harvest due to combined application of magnesium, boron and silica and also due to boron and silica application along with POP recommendation indicated that the low Fe absorption favoured the absorption of other nutrients resulting in higher yield.

The reduction in toxicity of Fe and Mn due to application of silica and boron was also evident from the data. This may create a favourable environment for increased nutrient uptake by the plant. Application of boron and silica also increased the mobility of zinc towards grain and resulted in increased yield.

In silica applied plots the Mn content of the plants was relatively low compared to other treatments. Higher plant content of silica (Fig. 5.16) in sodium silicate applied plots at panicle initiation and highest grain weight were found to be related and this may be due to increased translocation efficiency of silica in plants. Sodium silicate applied plots also registered lower contents of Fe and Mn in plant at panicle initiation stage and in grain and straw at harvest. The perusal of the data on the dry matter accumulation at panicle initiation and harvest revealed that the higher dry matter production at these stages can be linked with low Fe and Mn content (Fig. 5.17) of the plant at these stages. The low Fe and Mn content in plant had effected positively for absorption of other nutrients resulting in higher dry matter production. The Fe uptake was also considerably low with calcium silicate application. It may be due to the double benefit of regulation of pH and reduction of Fe and Mn content of soil due to silica.

Borax application also resulted in increased yield of rice. This treatment registered higher percent of filled grains and grain weight compared to other treatments which led to increased yield. However, it failed to register higher status of major nutrients in plants but it reduced the absorption of Fe and Mn by plant and increased absorption of Zn (Fig. 5.18), B and Si as evident from the data. This might have favoured the enhanced grain yield due to their functional role in rice. The correlation studies showed that Zn, B and Si content had positive and significant correlation with yield. The increased content of boron in grain and

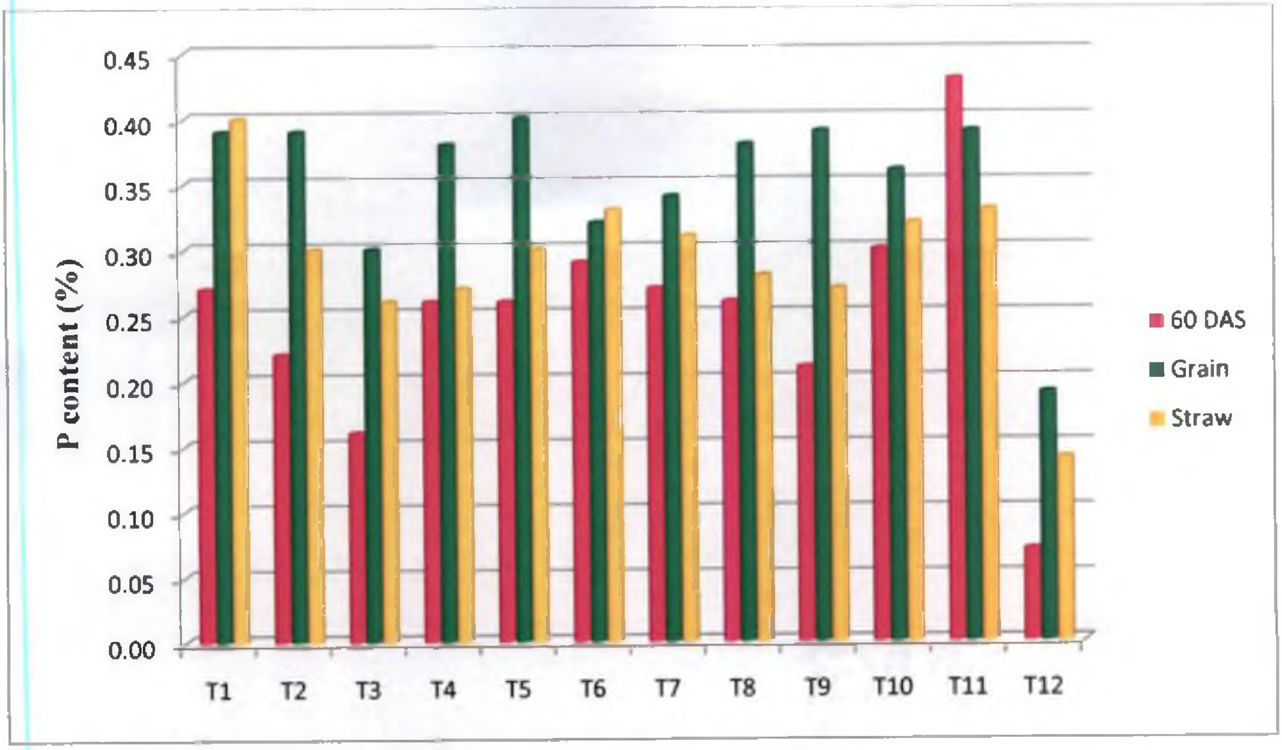

Fig. 5.13 Effect of treatments and soil ameliorants on phosphorous content of rice

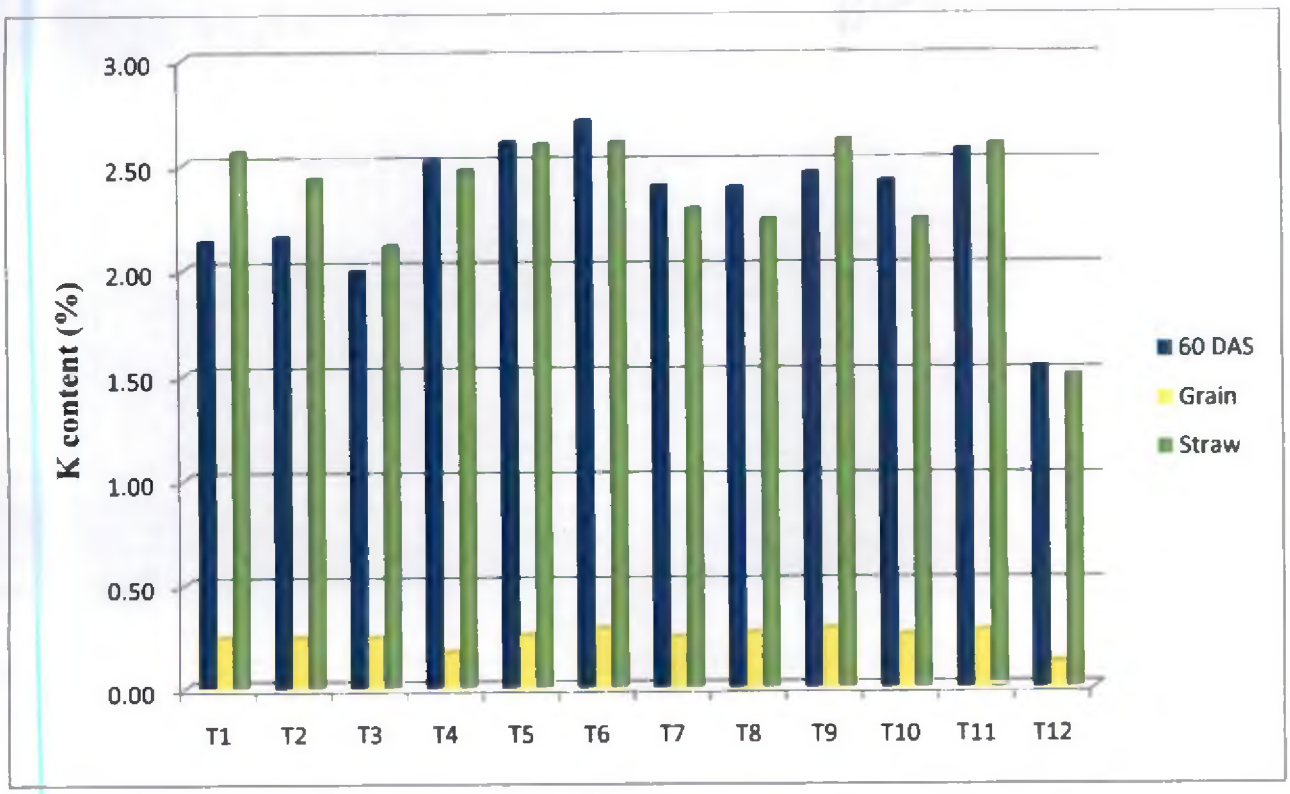

Fig. 5.14 Effect of treatments and soil ameliorants on potassium content of rice

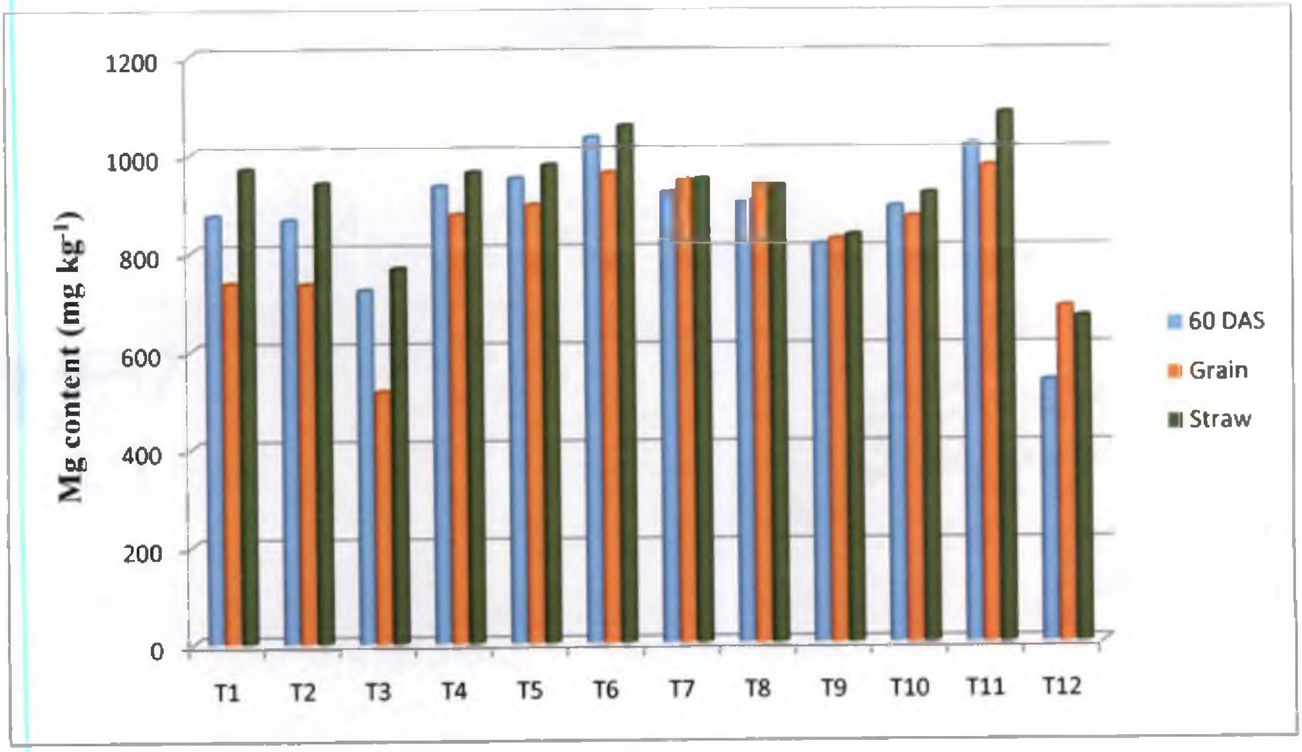

Fig. 5.15 Effect of treatments and soil ameliorants on magnesium content of rice

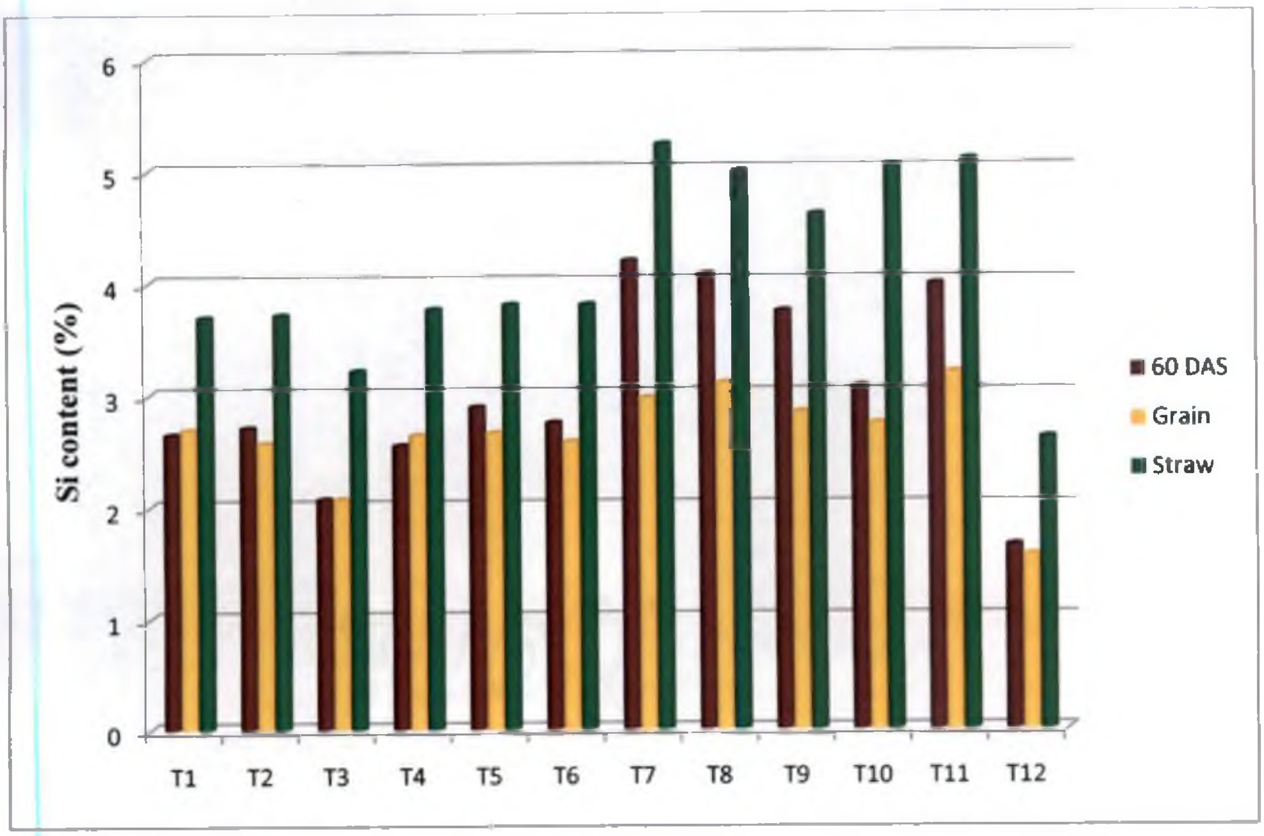

Fig. 5.16 Effect of treatments and soil ameliorants on silicon content of rice

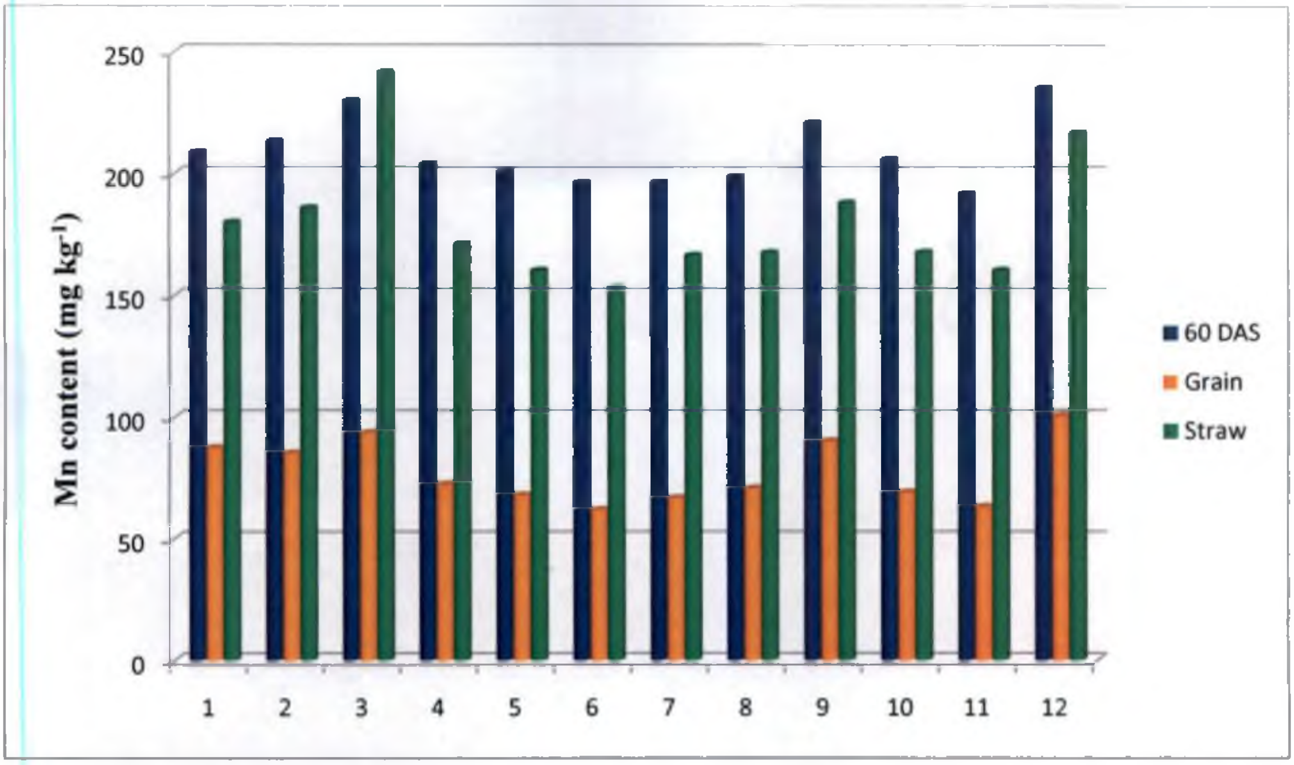

Fig. 5.17 Effect of treatments and soil ameliorants on manganese content of rice

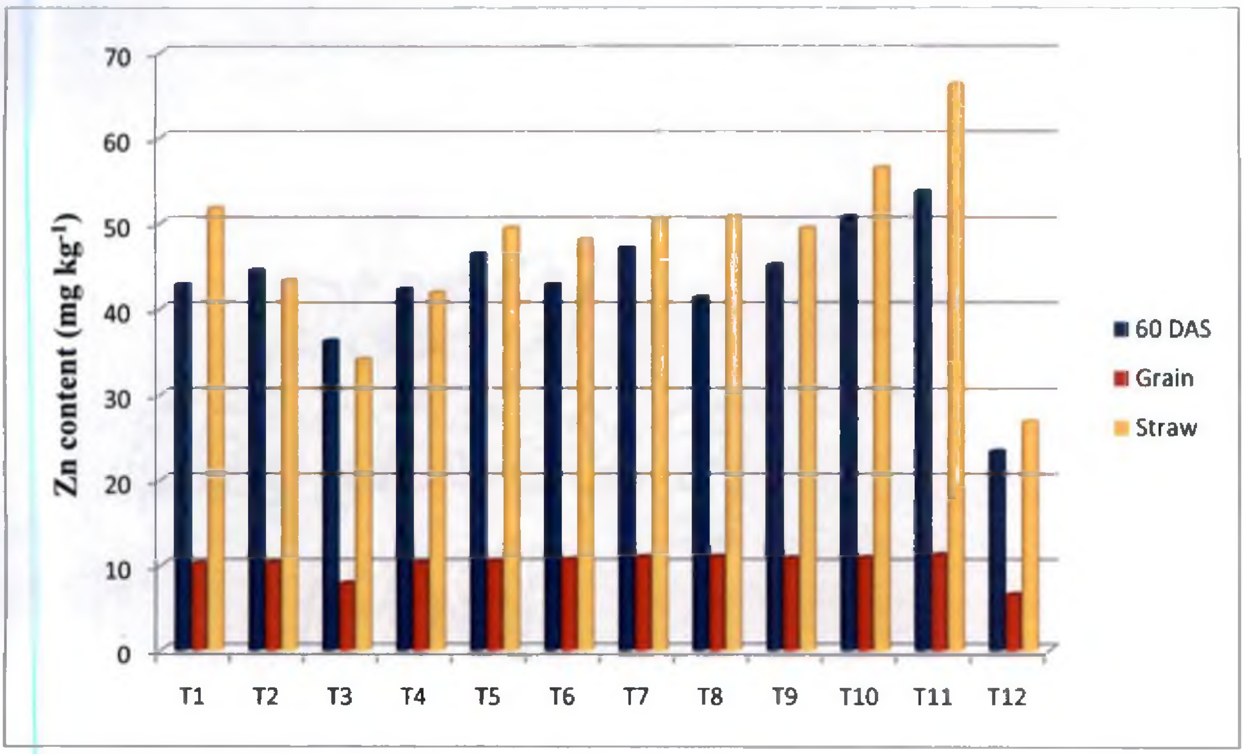

Fig. 5.18 Effect of treatments and soil ameliorants on zinc content of rice

straw due to boron application @10 kg borax ha^{-1} was noticed by Hosseini *et al.*, 2005. Gaur and Singh (2010) noticed a positive correlation between phosphorous and boron when boron was applied at higher dose. The uptake pattern showed that borax application was associated with high N and boron uptake and low Fe and Mn uptake.

Among the K levels, higher levels of K were better for registering higher yield. The higher level of K manifested high N, P, K, Zn, B and Si content of plant while Fe and Mn contents were found to be low. The effect of luxury consumption by K and antagonistic effect may result in reduced availability of Mg and led to low magnesium content even after magnesium application in soil. K application was reported to be positively correlated with uptake of N, P and K in rice by Muthuswamy *et al* (1974). High Fe toxicity is associated with high amounts of reducible Fe, low pH and low exchangeable K content which may be associated with P and Zn deficiency (Ottow *et al.*, 1982). High level of K applied in the experiment reduced the Fe and Mn uptake there by promoting the uptake of other nutrients leading to higher yield.

A strong correlation between K content of plant and grain yield was also established. It was also noticed that Fe and Mn content of plant established a strong negative correlation with grain yield. So the reduced Fe and Mn content of plant favoured the grain formation.

Higher straw yield was also achieved through higher level of K application. Bhiah *et al.* (2010) reported that K application prevented lodging incidence even under high nitrogen nutrition. It was also reported that application of K significantly improved root growth. All these might have contributed to better growth of straw and there by increased straw yield.

The N and P contents of grain were comparatively higher compared to that of straw. This may be due to the fact that N and P are structural components of plant and involved in grain formation while K exist as K^+ ions in xylem and phloem and its function is limited to leaves only

5.3 Effect of nutrients and soil ameliorants on soil nutritional characteristics

The soil properties i.e. pH (Fig. 5.19) and EC (Fig. 5.20) of soil decreased with application of nutrients and soil ameliorants in the experiment. The pH value before ploughing was 4.5 and it increased to 4.9 in absolute control without any treatment. This is because of the tendency of soil to enhance pH by itself during submergence due to self liming

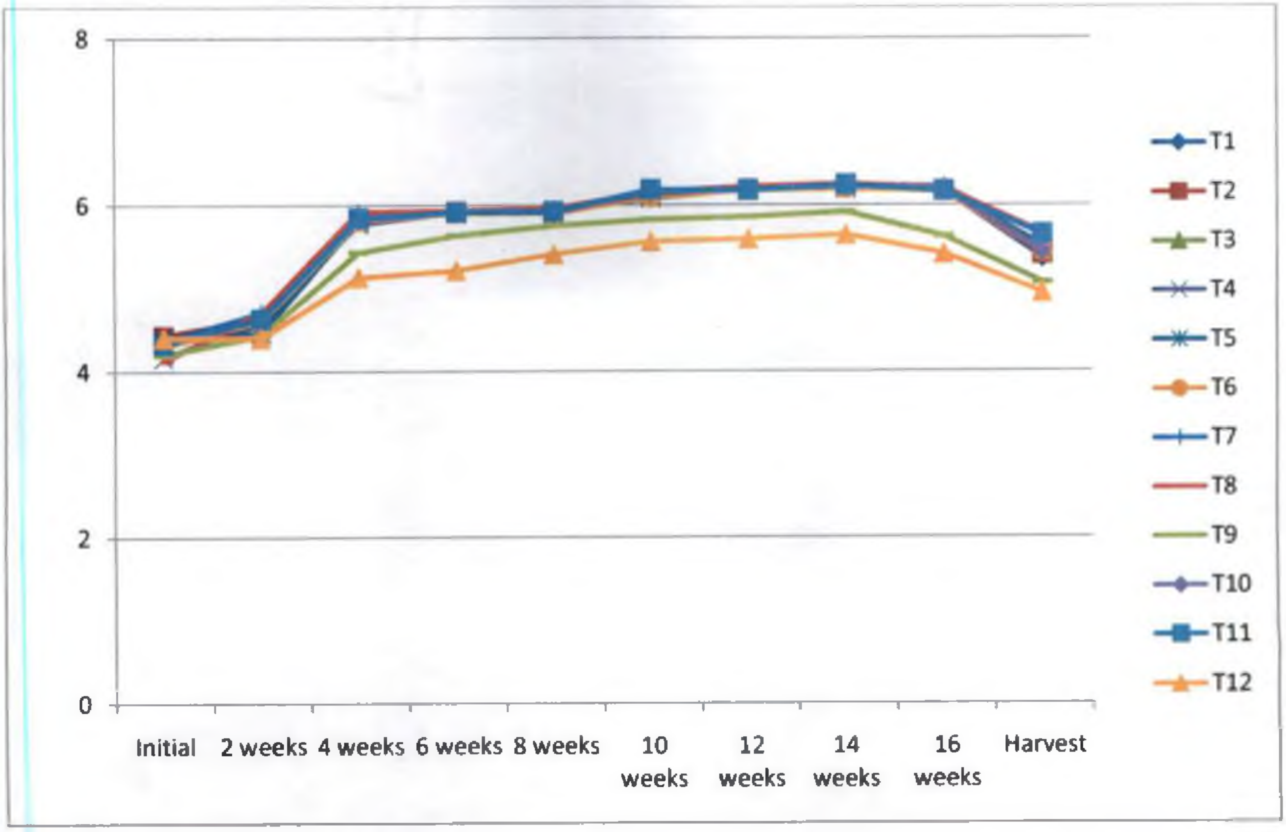

Fig. 5.19 Effect of treatments and soil ameliorants on soil pH during the experiment

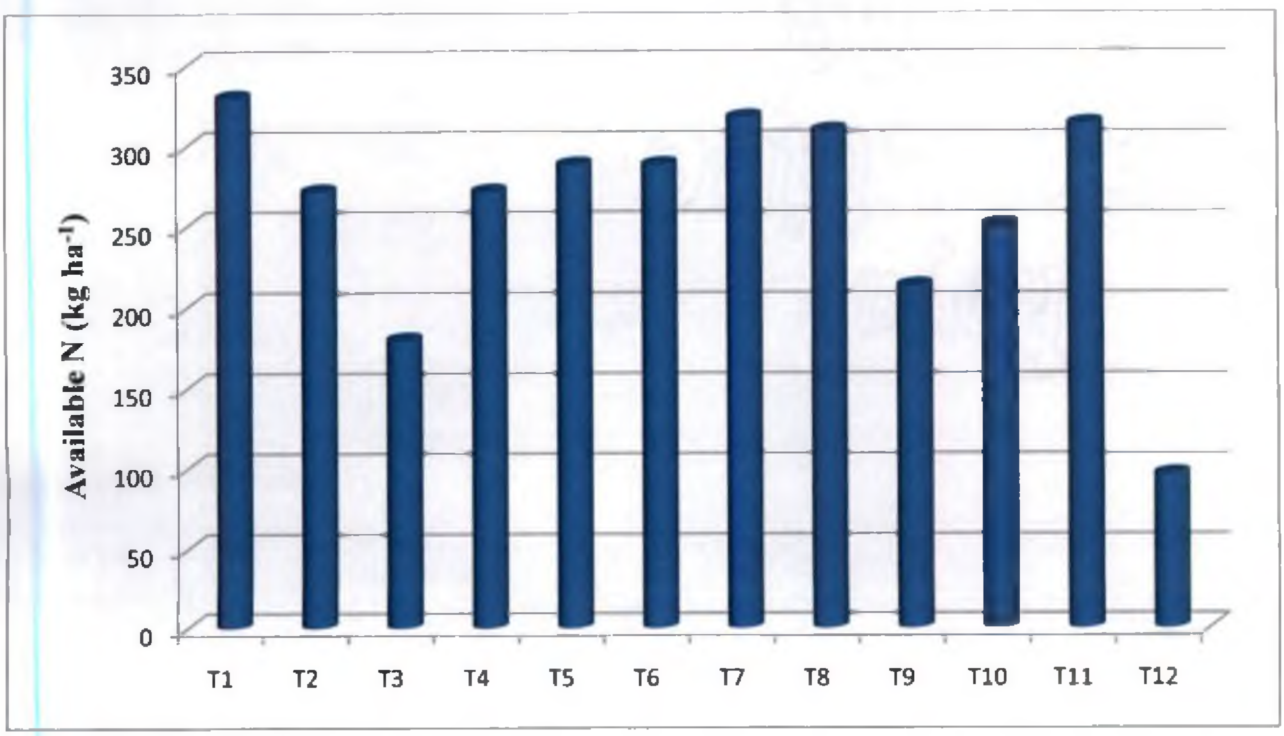

Fig. 5.20 Effect of treatments and soil ameliorants on available N in soil after the experiment

effect. Slow decline was noticed in pH of soil from ploughing to harvesting due to treatments. pH of the soil decreased at harvest stage because of drainage, were the soil was almost under saturation. However, the treatment influence was more pronounced due to application of silica along with lime irrespective of the source. These treatments could able to maintain pH within a range of 5.92-6.24 during the critical stages of rice. This might have created a favourable soil environment for maximum absorption of nutrients. EC was found to be decreased due to dilution effect during submergence. EC was found to be above critical level at all stages of crop growth. This treatment also maintains fairly higher organic carbon content in soil.

High N (Fig. 5.21), P (Fig. 5.22) and K (Fig. 5.23) status of soil was maintained due to combined application of magnesium, boron and silica and application of borax and sodium silicate individually. Even though there was carbon erosion, organic matter build up was sustained due to combined application of nutrients and soil ameliorants in T_{11} treatment. Higher Zn (Fig. 5.24) and S (Fig. 5.25) contents were also noticed with these treatments. Higher levels of K were also found to be superior in maintaining the fertility of soil with respect to N, P, K and Ca (Fig. 5.26).

Available Fe and Mn content of the soil were reduced to the maximum extent by combined application of magnesium, boron and silica and application of sodium silicate alone. The role of silica in alleviating the harmful effect of Fe and Mn and regulating pH of soil is very clear. The maximum efficiency of silica (Fig. 5.27) was noticed due to application of silica as sodium silicate rather than as calcium silicate. This was also evident from the uptake pattern of nutrients. However higher levels of K did not influence the Fe and Mn content (Fig. 5.28) of soil. The reported yield losses in farmers field due to Fe toxicity was in the range of 15 to 30 per cent (Ottow *et al.*, 1982). The factors affecting increased Fe and Mn content in soil and their uptake are to be alleviated for higher yield of rice in laterite soils. Soil acidity, toxicity of Fe and Mn and deficiency of K were reported to be the major soil factors limiting productivity in Kole lands (Johnkutty and Venugopal, 1993). Sodium silicate application and combined application of magnesium, boron and silica were found to be effective in reducing the above mentioned problems of Kole land soils.

Application of borax along with NPK and lime as per package of practice recommendations was also able to maintain relatively high level of major nutrients with

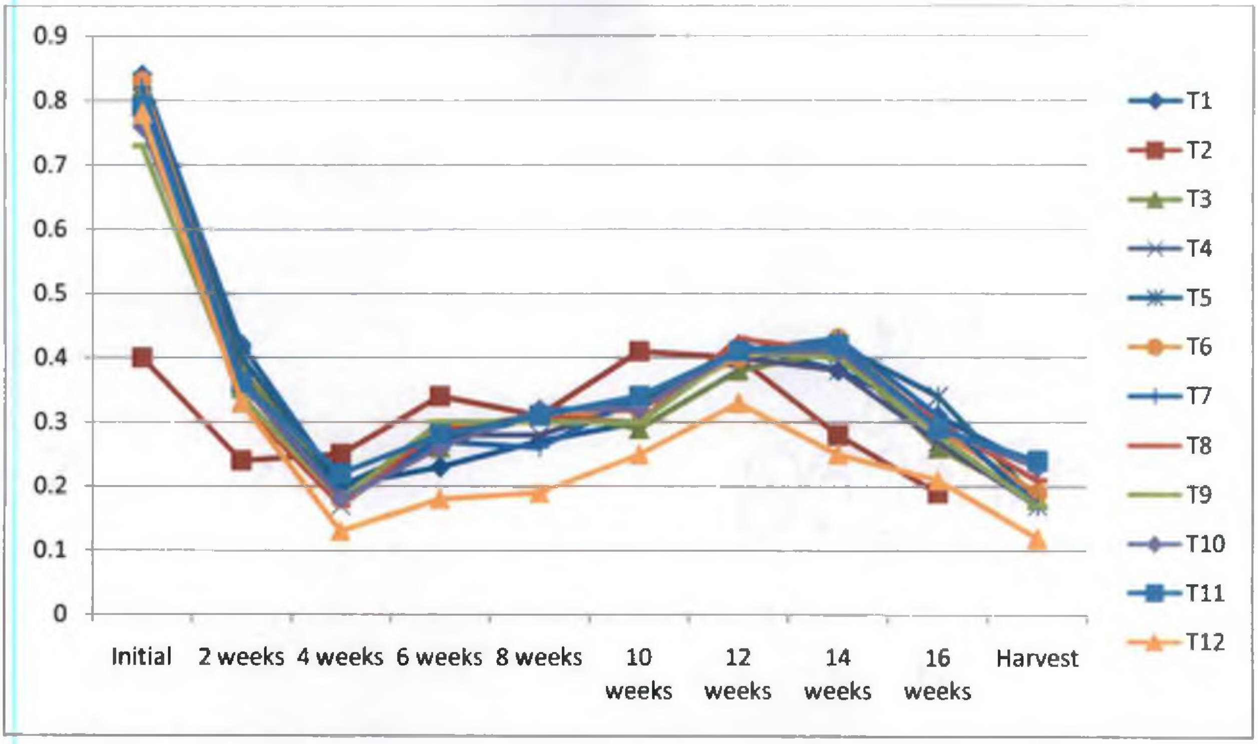

Fig. 5.21 Effect of treatments and soil ameliorants on EC of soil during the experiment

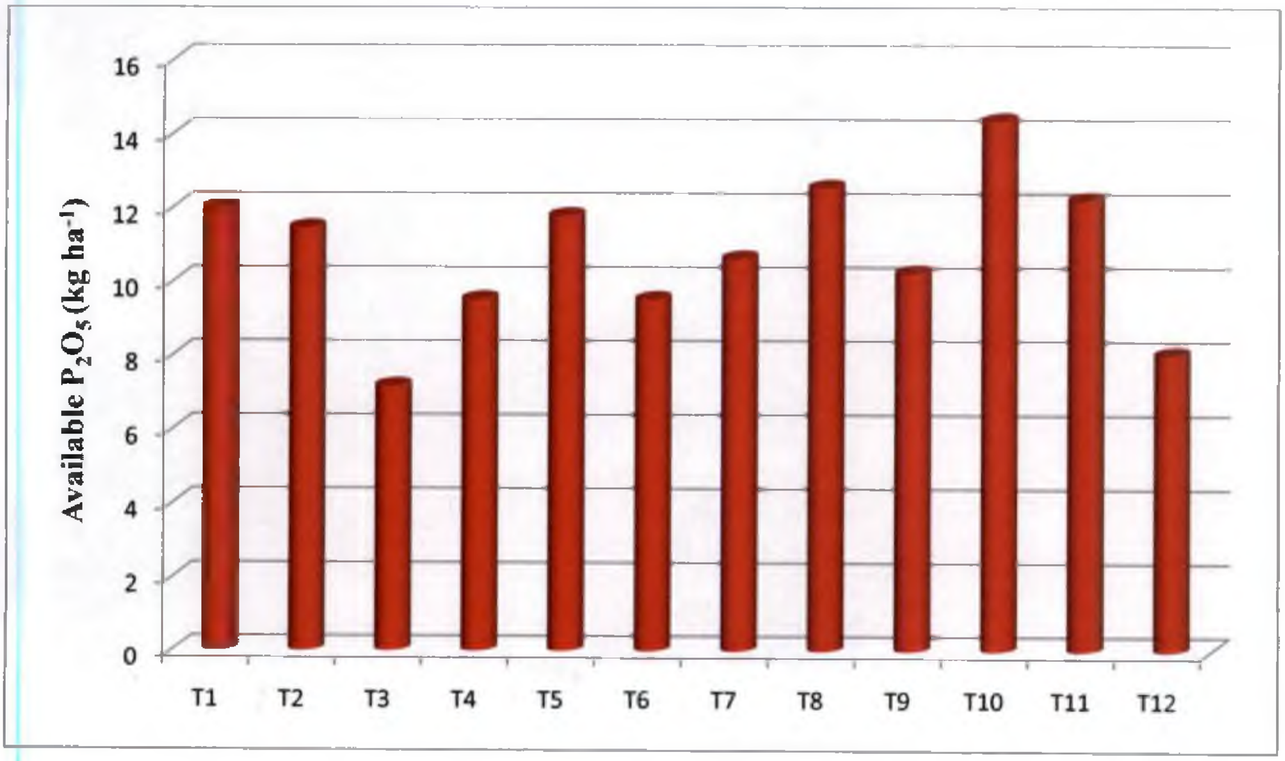

Fig. 5.22 Effect of treatments and soil ameliorants on available P_2O_5 in soil after the experiment

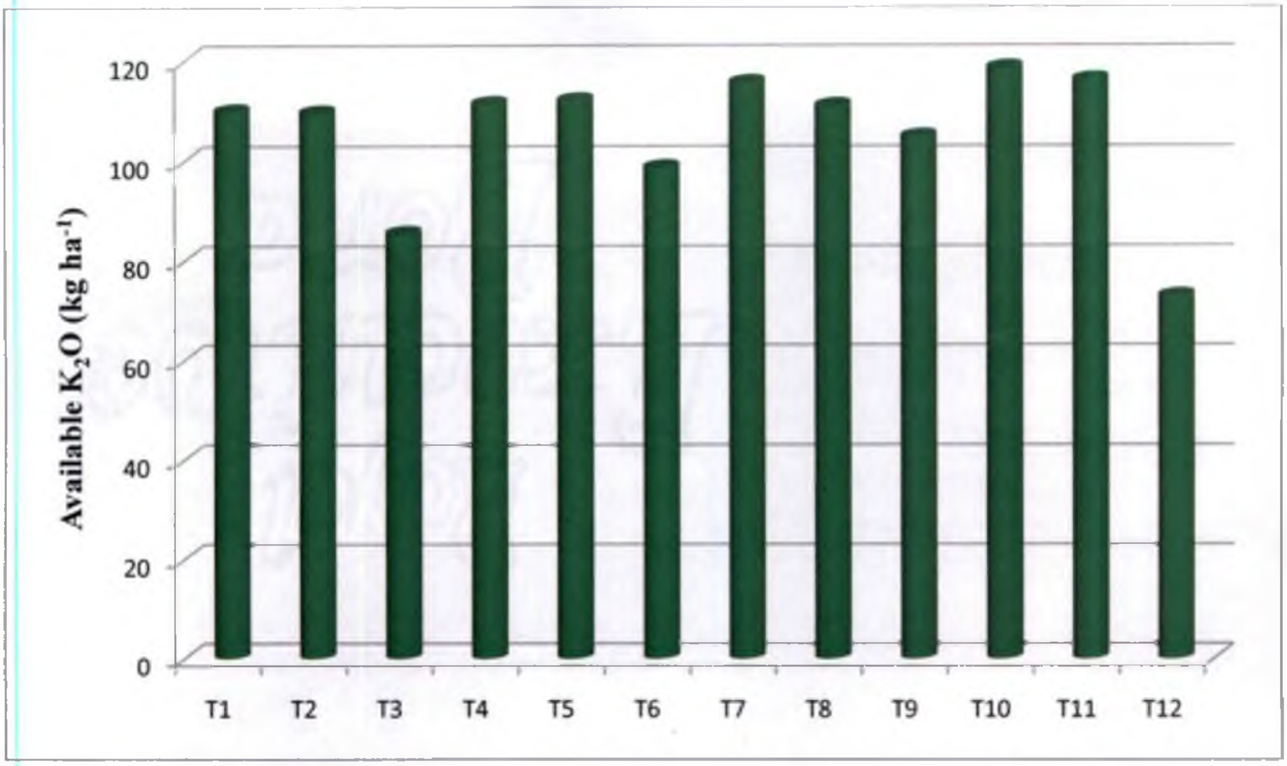

Fig. 5.23 Effect of treatments and soil ameliorants on available K_2O in of soil after the experiment

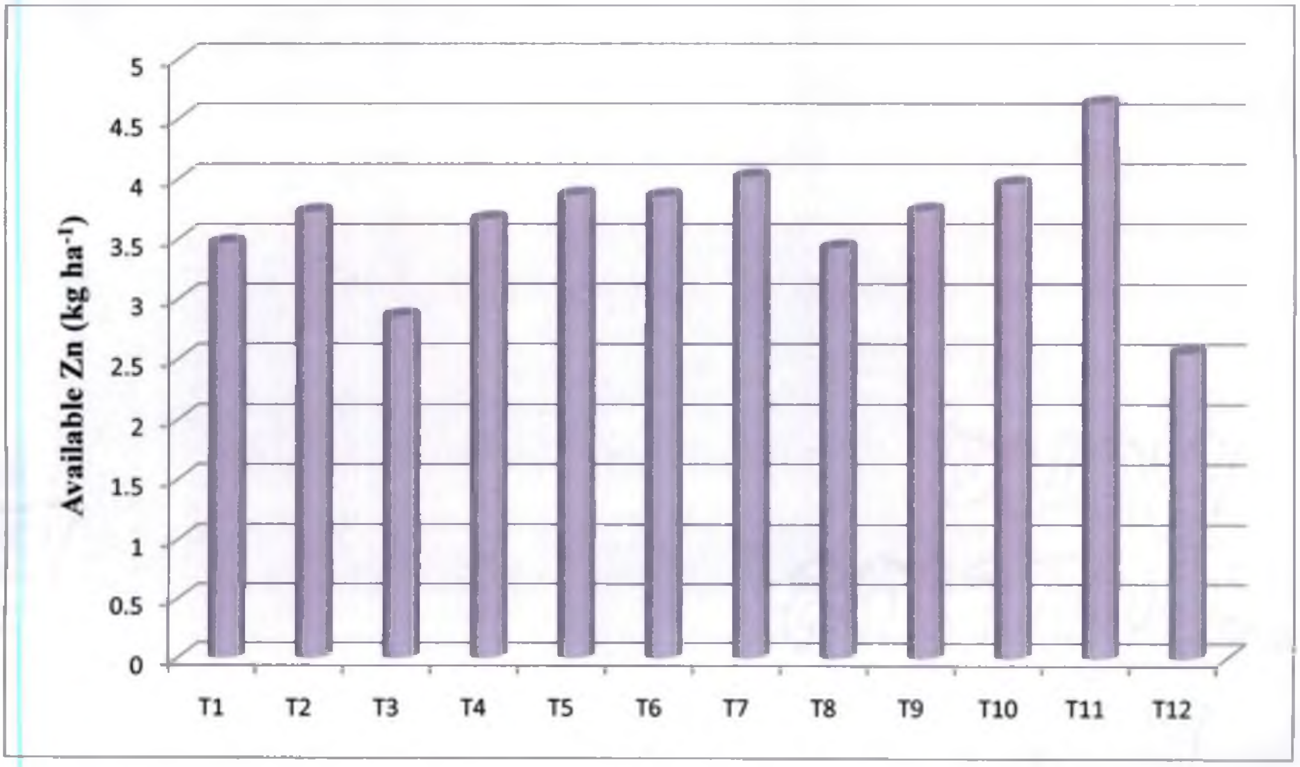

Fig. 5.24 Effect of treatments and soil ameliorants on available zinc in soil after the experiment

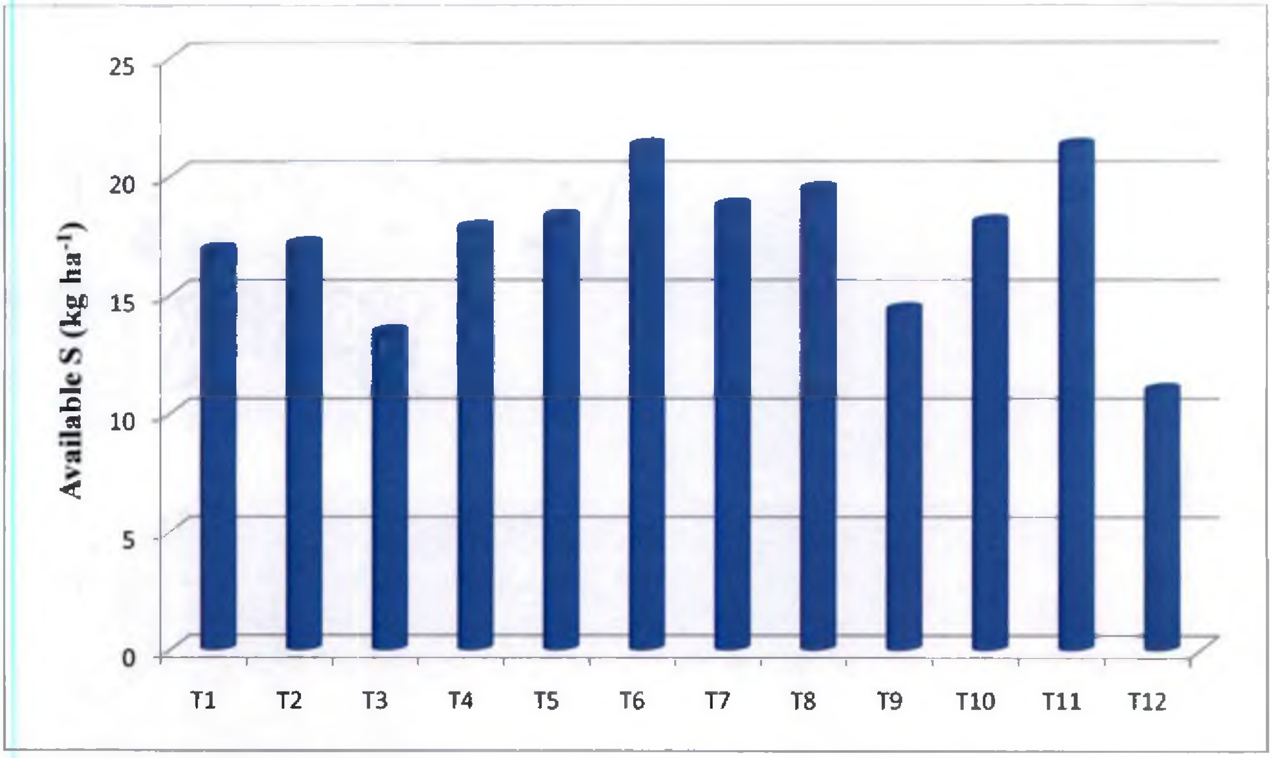

Fig. 5.25 Effect of treatments and soil ameliorants on available sulphur in soil after the experiment

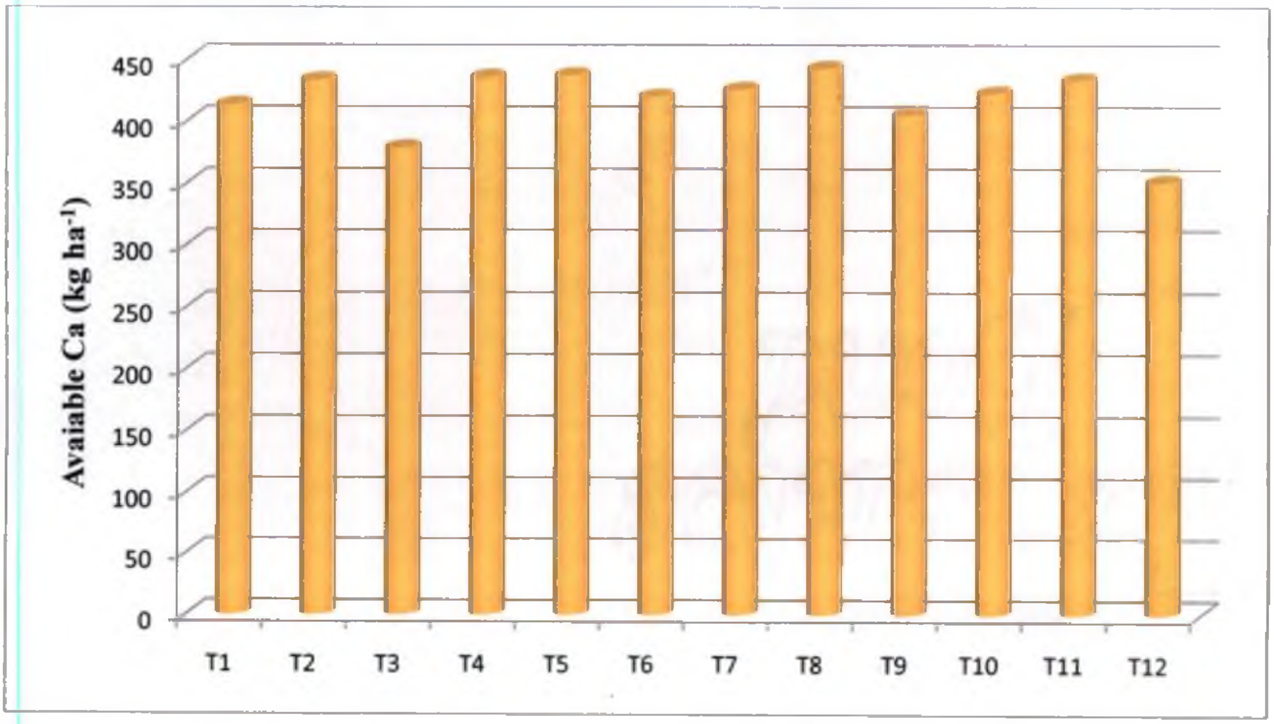

Fig. 5.26 Effect of treatments and soil ameliorants on available calcium in soil after the experiment

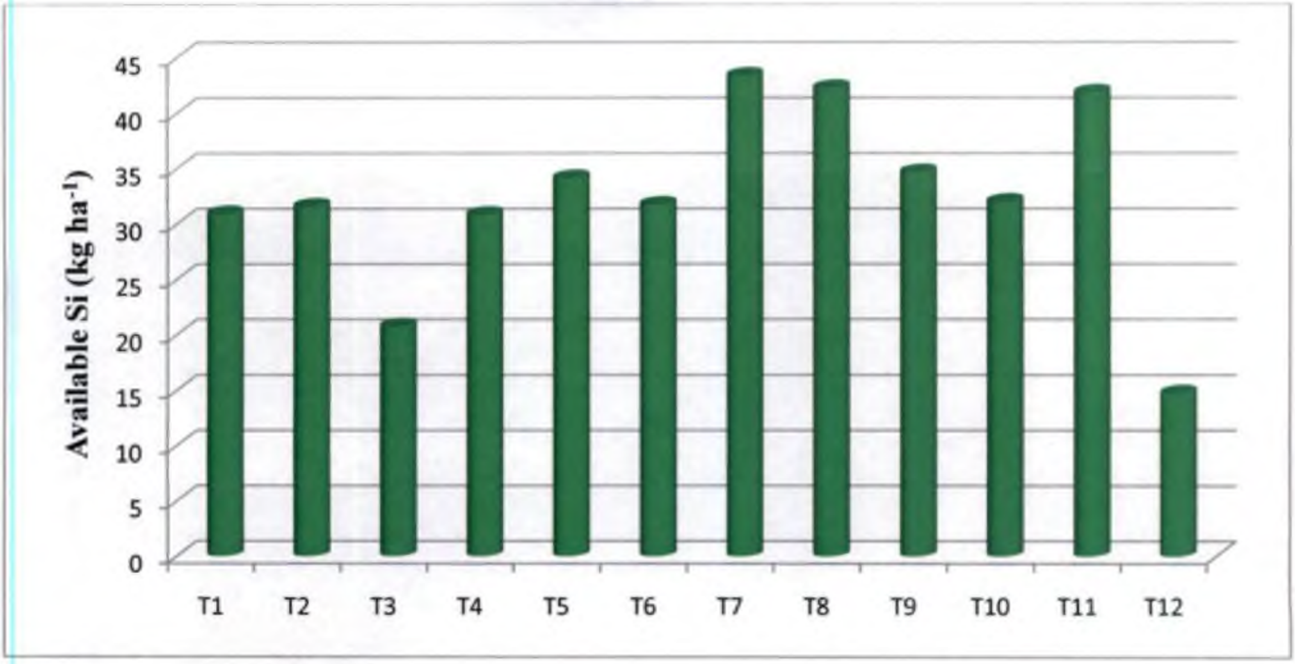

Fig. 5.27 Effect of treatments and soil ameliorants on available silicon in soil after the experiment

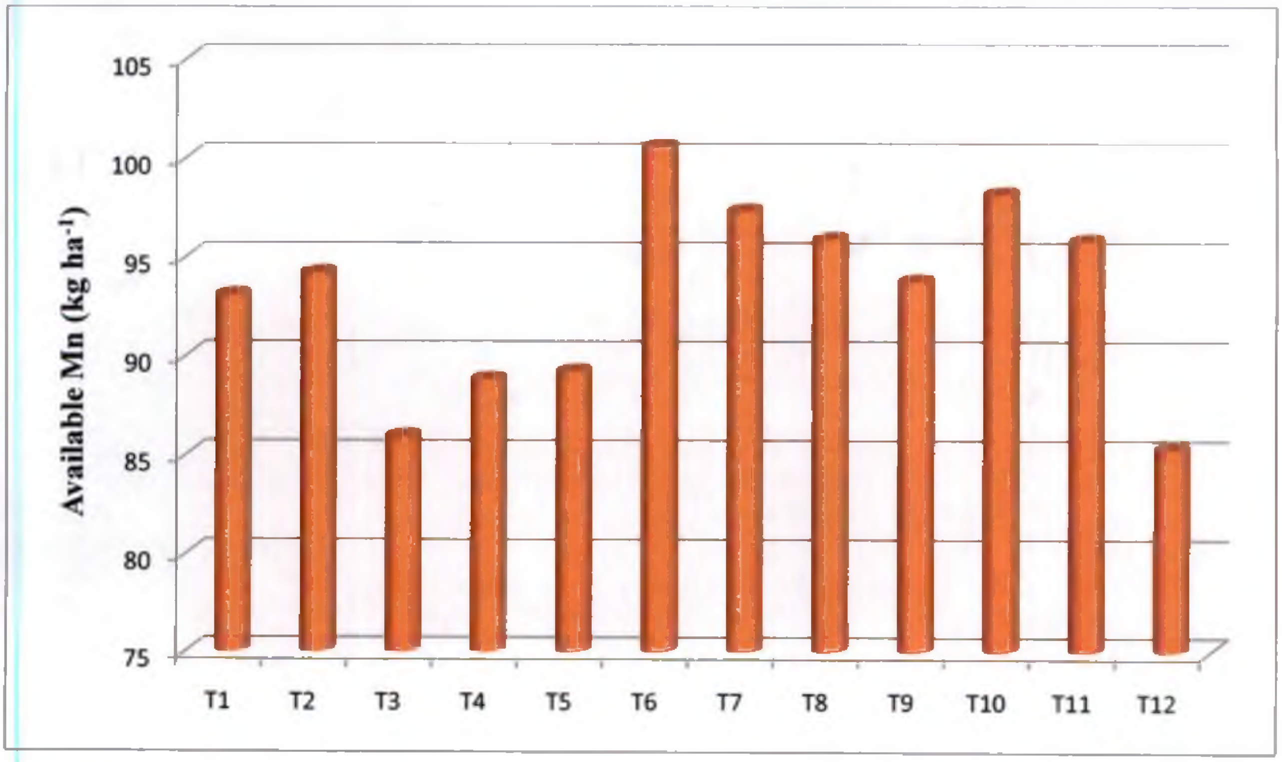

Fig. 5.28 Effect of treatments and soil ameliorants on available manganese in soil after the experiment

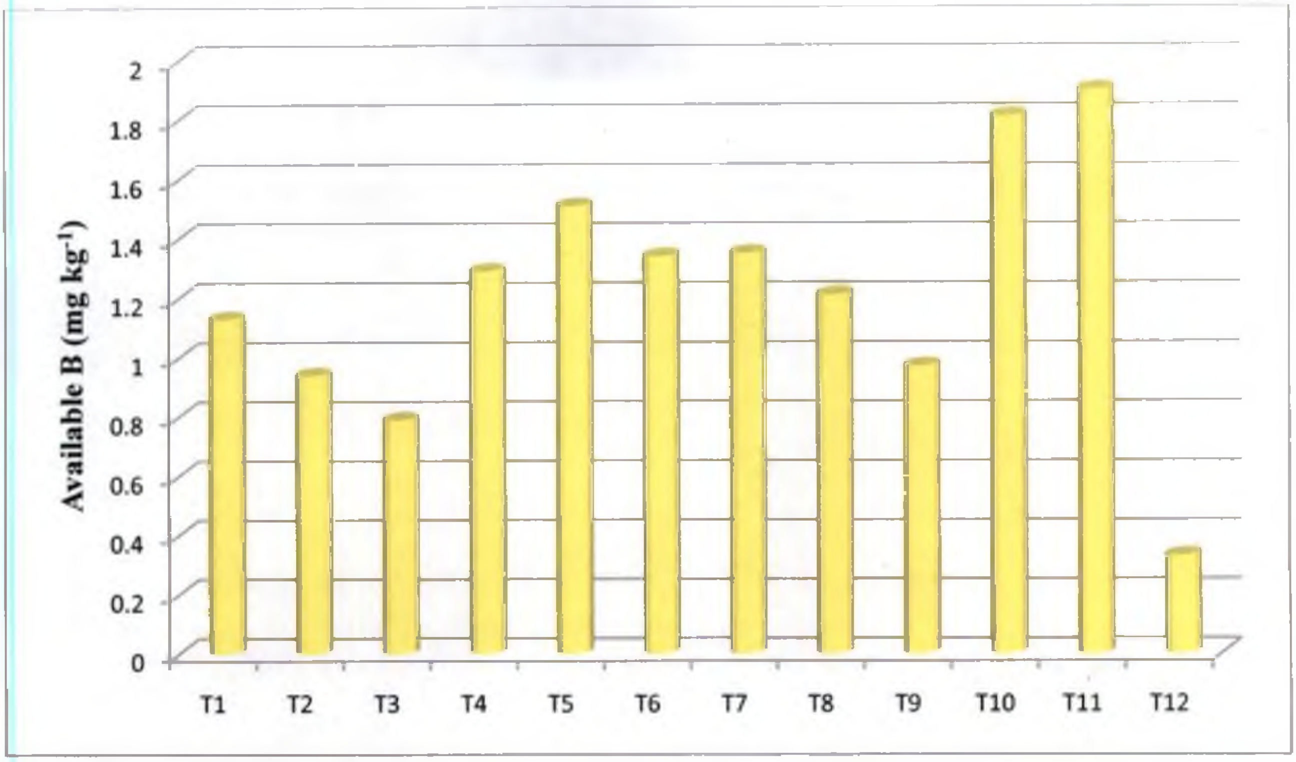

Fig. 5.29 Effect of treatments and soil ameliorants on available boron in soil after the experiment

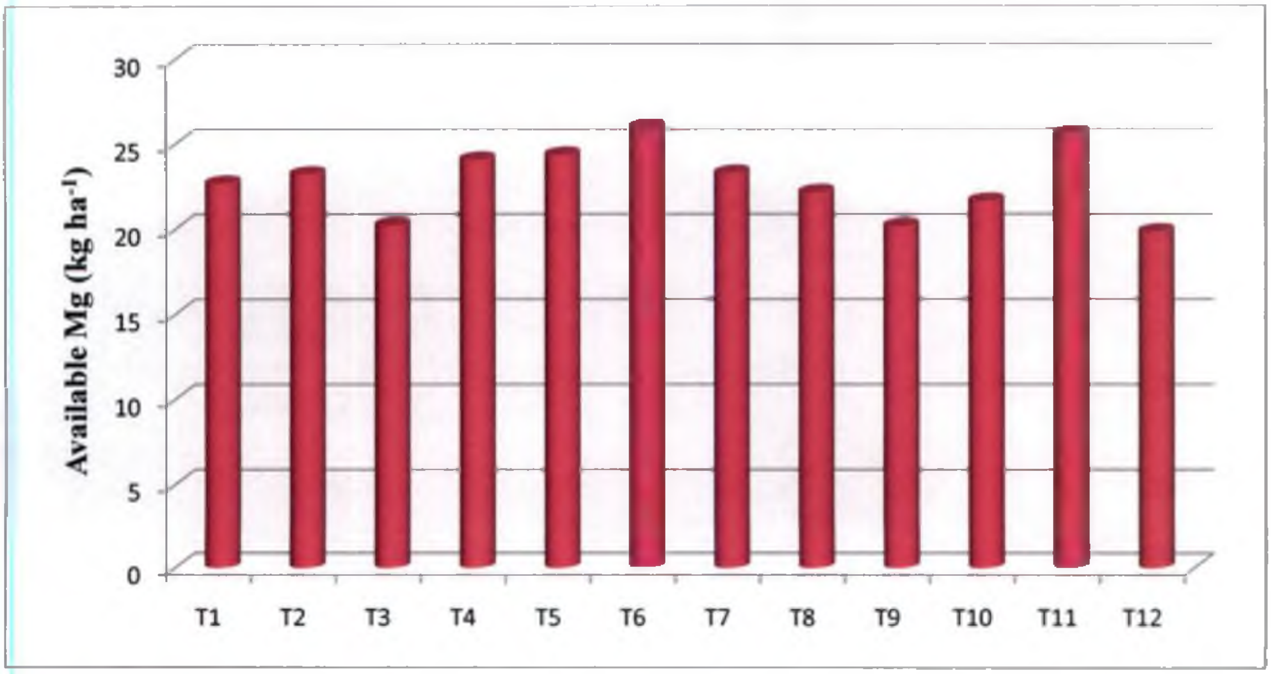

Fig. 5.30 Effect of treatments and soil ameliorants on available magnesium in soil after the experiment

reduced levels of Fe and Mn. The treatment effect was aggravated by the role of boron (Fig 5.29) in reducing spikelet sterility and increasing seed setting and grain formation.

The availability of major nutrients was found to be higher in presence of lime and FYM. As per the package of practice of Kerala Agricultural University, the sufficiency range for Mg in laterite soils of Kerala is above 120 mg kg^{-1}, below which it is deficient (KAU, 2011). The available Mg content (Fig. 5.30) of soil in the experiment was in the range of 19-25 mg kg^{-1} which is in the deficiency range even after application of magnesium. This might be the reason for the fact that application of magnesium failed to reduce the Fe and Mn content of soil.

Thus the combined application of magnesium, boron and silica and individual application of silica as sodium silicate and boron application along with nutrients and lime as per POP were found to be effective in ameliorating the harmful effects of Kole land soil and to solve the problem of acidity and toxicity of Fe and Mn as evidenced by the data in the experiment.

The perusal of the yield data revealed that there was no significant variation between these treatments. The straw yield was also comparable in combined application and application of sodium silicate. The economics of cultivation revealed that application of sodium silicate or borax did not produce any variation in B:C ratio. However, an increase of Rs. 5,640/- ha^{-1} in gross return was noticed due to combined application compared to sodium silicate and borax application with increased B:C ratio.

Summary

VI. Summary and Conclusion

The present study entitled "Soil amelioration and nutrient management of rice in kole lands" was carried out in farmer's field at Ponnamutha Kole padavu of Venkitangu Panchayath from November, 2013 to March, 2014 to provide a nutrient management strategy for soil amelioration and balanced supply of nutrients for enhanced productivity of rice in kole lands. The variety used was Uma, the design of the experiment was RBD with three replications. There were 12 treatments comprising of soil test based nutrient package, nutrients as per POPR, different doses of K, individual applications of magnesium and boron, different sources of silica and combined application of nutrients and soil ameliorants. The nutrients and soil ameliorants were added as per treatment in the technical programme. FYM, lime and silica were applied at the time of ploughing. Nitrogen was applied in three equal split doses, phosphorus as basal, potassium in two equal split doses and boron was applied as borax in two split doses.

The cultural operations were carried out as per Package of Practice recommendations of KAU. Biometric observations on plant height, tiller count, dry matter production, leaf area index, number of spikelets per panicle, percent of filled grain, thousand grain weight, grain and straw yield and physiological characters like chlorophyll content, etc were recorded. Scoring of pests and diseases was done for major pests and diseases of rice were also done during the cropping period.

Soil samples were analyzed for major and micro nutrients and silica before and after the experiment. Plant samples at 30, 60 DAS and grain and straw at harvest were taken and analyzed for major and micro nutrients and silica. Uptake of nutrients by grain and straw and total uptake were computed. Economics of cost of cultivation was also calculated for each treatment. The results of the study are summarized and listed here.

1. The individual application of boron alone and combined application of magnesium, boron and silica recorded significantly taller plants. However, silica application irrespective of source also recorded comparable height at harvest.

2. The combined application of magnesium, boron and silica recorded highest tiller count at 30 DAS followed by boron application. The tiller count increased from 30 DAS to 60

DAS and it was highest in calcium silicate applied treatment at 60 DAS. At harvest more productive tillers were observed by the combined application of magnesium, boron and silica followed by individual application of boron and silica either as sodium silicate or calcium silicate.

3. The combined application of magnesium, boron and silica showed the highest LAI followed by boron application and silica application either as sodium silicate or calcium silicate and it was lowest in control treatment.

4. The combined application of magnesium, boron and silica and application of boron alone recorded comparatively higher chlorophyll a, chlorophyll b and total chlorophyll content of leaves and the lowest was recorded in control treatment. Sodium silicate application was comparatively better than Calcium silicate application in chlorophyll production.

5. The combined application of magnesium, boron and silica produced highest dry matter production at 30 DAS. At 60 DAS combined application of magnesium, boron and silica, individual application of magnesium, boron and sodium silicate recorded higher dry matter production.

6. The combined application of magnesium, boron and silica and application of sodium silicate alone significantly influenced the panicles/m^2, spikelets/panicle and 1000 grain weight. Application of boron alone also positively influenced all the yield attributing characters and resulted in the highest percentage of filled grains.

7. The combined application of magnesium, boron and silica and individual application of boron and sodium silicate recorded the highest grain yield which was comparable with calcium silicate application. The highest straw yield was noticed due to the highest dose of 110 kg ha^{-1} of K followed by magnesium application alone. The HI was higher in treatments with combined application of soil ameliorants and nutrients and also in FYM application along with NPK.

8. The B:C ratio was highest by sodium silicate application followed by individual application of boron and combined application of magnesium, boron and silica.

9. The combined application of magnesium, boron and silica and individual application of boron and silica irrespective of source did not produce significant difference in N content of plant at 60 DAS. In case of N content of grain, sodium silicate application alone and combined application of magnesium, boron and silica recorded the highest. Calcium silicate application recorded the highest N content in straw. Combined application of magnesium, boron and silica also produced significant effect on N uptake.

10. The highest P content at 60 DAS was observed due to combined application of magnesium, boron and silica. In case of grain P content, the highest dose of K @ 110 kg ha^{-1} recorded the highest P content. Soil test based nutrient application recorded highest P content in straw. Combined application of magnesium, boron and silica and application of boron alone recorded higher uptake of P.

11. The application of magnesium recorded the highest K content at 60 DAS and in grain and straw at harvest followed by higher doses of K application. Combined application of magnesium, boron and silica also produced significant effect on K uptake.

12. The application of silica as calcium silicate recorded highest Ca content at 60 DAS and in grain and straw at harvest followed by higher doses of K application. Calcium silicate application recorded higher uptake of Ca.

13. Throughout the growth stages, application of magnesium showed a higher content of Mg in the plant. The highest Mg content was noted by combined application of magnesium, boron and silica and it also influenced the uptake of Mg.

14. Application of highest dose of K @110 kg ha^{-1} recorded highest S content at 60 DAS. In case of grain, magnesium application recorded highest S content. Application of boron recorded highest S content in straw and also influenced the uptake of S.

15. The highest Fe content at all stages of plant and Fe uptake were noticed in control plot followed by POPR application without FYM. The lowest Fe content was recorded by combined application of magnesium, boron and silica.

16. The highest Mn content at all stages of plant was recorded in control plot followed by POPR application without FYM and it also recorded the highest Mn uptake.

17. Zn content was higher by combined application of magnesium, boron and silica at all stages of growth. Application of boron also showed comparatively better Zn content in plant and also influenced Zn uptake.

18. Individual application of boron or combined application of magnesium, boron and silica recorded significantly higher B content at 60 DAS and in grain and straw at harvest. Combined application of magnesium, boron and silica resulted in significantly higher B uptake.

19. The application of sodium silicate recorded significantly higher Si content at 60 DAS and in grain and straw at harvest. Combined application of magnesium, boron and silica recorded higher uptake of Si.

20. The combined application of magnesium, boron and silica and individual application of boron and silica irrespective of source significantly influenced pH, EC and organic carbon of soil after the experiment.

21. The combined application of magnesium, boron and silica recorded highest available N and individual application of boron recorded highest available P_2O_5 and K_2O in soil after the experiment.

22. Application of silica as calcium silicate recorded highest available Ca and application of magnesium recorded highest available Mg and available S in soil after the experiment.

23. Available Fe in soil after the experiment was highest in control plot and it recorded lowest by combined application of magnesium, boron and silica. Application of magnesium recorded highest available Mn content in soil after the experiment.

24. Combined application of magnesium, boron and silica recorded highest available Zn in soil after the experiment.

25. Available B in soil after the experiment was higher by combined application of magnesium, boron and silica and individual application of boron.

26. Combined application of magnesium, boron and silica and individual application of sodium silicate recorded higher amounts of available Si in soil after the experiment.

CONCLUSION

- Borax application had significant effect on yield attributes especially per cent filled grains, grain size and weight and ultimately grain yield. Application of boron also reduced the toxicity of Fe and Mn and increased nutrient uptake by the plant. The treatment also contributed towards higher B:C ratio for rice cultivation in Kole lands. Borax application along with POPR was found to be the best nutrient management schedule for rice in Kole lands in terms of yield, nutrient uptake and B:C ratio.

- Silica application as sodium silicate was better for increased growth and yield of rice and also reduced Fe and Mn content of soil and increased the availability of other nutrients. The importance of silica application on disease resistance was also evident. The increased K availability and nutrient absorption due to silica application was also noticed in the treatment. Silica application as sodium silicate along with POPR was also found to be a good nutrient management schedule for higher productivity in Kole lands with respect to yield, nutrient uptake and B:C ratio.

- Combined application of magnesium, boron and silica increased the growth and yield attributes like number of panicles, number of grains per panicle and grain size and contributed towards increased yield. The treatment also reduced the uptake of Fe and Mn in the acidic situation and resulted in the highest nutrient absorption and uptake by the plant which also created favourable environment for increased yield.

- Magnesium application also resulted in higher yield than POPR due to significant influence on yield characters and yield.

- Application of nutrients as per POPR with FYM increased the growth and yield of rice significantly than POPR without FYM. The effect of application of FYM had profound influence on increased nutrient absorption and yield.

- Application of higher doses of K especially the highest dose of 110 kg ha^{-1} resulted in higher yield.

- Soil test based nutrient application and Package of practice recommendation was comparable in growth characters and yield of rice.

FUTURE LINE OF WORK

- The nutrient dynamics due to application of nutrients and soil ameliorants to be studied in soils of Kole lands.

- The role of nutrients and soil ameliorants towards soil amelioration and yield increase of rice to be reported for confirmative results in Kole lands.

- The different levels of boron and silica on growth and yield of rice to be persuaded in Kole lands.

- The effect of silica application on pest and disease resistance to be explored. Nutrient deficiency studies to be undertaken in pest disease prone areas for conclusive results.

References

REFERENCES

Abu, M. B., Tucker, E. S., Harding, S. S., Sesay, J. S. 1989. Cultural practices to reduce iron toxicity in rice. *Int. Rice Res. Newsl.* **14**: 19.

Ahamad, W., Niaz, A., Kanwal, S., Rahmatullah and Rasheed, M. K. 2009. Role of boron in plant growth: A Review. *J. Agric. Res.* **47**(3): 329-338.

Ahmad, A., Afzal, M., Ahmad, A. U. H., Tahir, M. 2007. Effect of foliar application of silicon on yield and quality of rice (*Oryza sativa* L.) *Cercetari Agronomice in Moldora* **60**(3): 155.

Alam, S., Kamei, S., and Kawai, S. 2003. Amelioration of manganese toxicity in young rice seedlings with potassium. *J. Plant Nutr.* **26**(6): 1301-1314.

Anilakumar, K., Potty, N.N. and Bridgit, T.K. 1992. Nutritional inhibition of rice productivity in laterite soils. *Oryza* **29**: 37-39.

Arivazhagan, K. and Ravichandran, M. 2005. Interaction of nitrogen and potassium on yield and yield attributes in rice cv. IR 20. *Adv. Plant Sci.* **18**: 425-427.

Arnon, D.I. and P.R. Stout. 1939. The essentiality of certain elements in minute quantity for plants with special reference to copper. *Plant Physiol.* **14**: 371-375.

Aslam, M., Mahmood, I. H., Qureshi, R. H., Nawaz, S., and Akhtar, J. 2002. Salinity tolerance of rice as affected by boron nutrition. *Pak J. Soil Sci.* **21**: 110-118.

Audeberta, A. and Sahrawata, K. L. 2000. Mechanisms for iron toxicity tolerance in lowland rice. *J. Plant Nutr.* **23**(11&12): 1877-1855.

Bahmaniar, M. A. and Ranjbar, G. A. 2007. Response of rice cultivars to rates of nitrogen and potassium application in field and pot conditions. *Pak J Biol. Sci.* **10**(9): 1430-1437.

Barbier, E. B. 1977. Valuing environmental functions. Tropical wetlands. *Land Eco.* **70**(2): 155-173.

Baxter, J. C. and Osman, M. 1998. Evidence for the existence of different uptake mechanisms in soyabean and sorghum for Fe and Mn. *J. Plant Nutr.* **11**: 51-61.

*Berger, K. C. and Truog, E. 1945. Boron availability in relation to soil reaction and organic matter content. *Soil Sci. Am. Proc.* **1**: 113-116.

Benckiser, G., Santiago, S., Neue, H. U., Watanabe, I., and Ottow, J. C. G. 1984. Effect of fertilization on exudation, dehydrogenase activity, iron- reducing populations and Fe2+ formation in the rhizosphere of rice (*Oryza sativa* L.) in relation to iron toxicity. *Plant Soil* **79**: 305-316.

Bhatt, R. 2011. Identification and amelioration of micronutrients in rice-wheat cropping system. *IMMA News* **4**(1): 12-14.

Bhiah, K. M., Guppy, C., Lockwood, P., and Jessop, R. 2010. Effect of potassium on rice lodging under high nitrogen nutrition. In: Proceedings of 19th World Congress of Soil Science, Soil Solutions for a Changing World, August 1-6, Brisbane, Australia.

Bingham, F. T. 1982. Boron. In: methods of soil analysis, part 2 ed. A.L. page. WI: American Society of Agronomy, Madison, 438p.

Binilkumar, A.S., Birolb, E., Bennette, J., and Ramanathan, A. 2010. Heterogeneity Across Stake holders Preferences for Wetland Attributes: The Case of Kole Wetland in India, proceedings of the Fourth World Congress of Environmental and Resource Economists, June 27 to July 2, 2010, Montreal, Cannada.

*Bray, R. H. and Kurtz, L. T. 1945. Determining total organic and available forms of phosphate in soil. *Soil Sci.* **59**: 39-45.

Bridgit, T. K. 1999. Nutritional balance analysis for productivity improvement of rice in iron rich lateritic alluvium. Ph.D. Thesis, Kerala Agricultural University, Thrissur.

Bridgit, T. K. and Potty, N. N. 2004. Regulatory role of potassium on rice productivity in laterite soils. In: John, P. S., Menon, M. V. and Mathew, J. (eds.), *Input Use Efficiency in Agriculture- Issues and Strategies.*Proceedings of an ICAR national symposium, Kerala Agricultural University, Thrissur, Kerala, pp.55-56.

Brohi, A. R., Karaman, M. R., Topbas, M. T., Aktas, A. and Savasli, E. 2000. Effect of potassium and magnesium fertilization on yield and nutrient content of rice crop grown on artificial siltation soil. *Turkish J. Agric. For.* **24**(4): 429-435.

Bulbule, A.V. and Despande, P. B. 1989. Growth and nutrient content of rice cultivars grown in culture solutions with high levels of iron. *Oryza.* **26**: 363-367.

CACP. 2010. Reports of the Commission for Agricultural costs and prices for the crops. District Planning Committee Thrissur District Plan: Part 1 Vol1: 34-35.

Cakmak, I. and Engels, C. 2002. Role of mineral nutrients in photosynthesis and yield formation. In: Rengel, Z (ed.). *Mineral Nutrition of Crops- Fundamental Mechanisms and Implications.* CBS Publishers & Distributions, New Delhi, pp.141-168.

Chang, C. S. and Sung, J. M. 2004. Nutrient uptake and yield responses of peanuts and rice to lime and fused magnesium phosphate in an acid soil. *Fld. Crops Res.* **89**: 319-325.

Cheng, B. T. and Quellette, G. J. 1971. Manganese availability in soil. *Soils Fertil.* **34**: 589-595.

Chesnin, L. and Yien, C. R. 1951. Turbidimetric determination of available sulphates. *Proc. Soil Sci. Soc. Am.* **15**: 149-151.

Choudhury, A. T. M. A. and Khanif, Y. M. 2002. Effects of magnesium fertilization on rice yield, magnesium and potassium uptake by rice at variable applied potassium levels. *Pakistan Journal of Scientific and Industrial Research.* **45**(5): 345-349.

Cong, P. T., Dung, T. D., Hein, N. T., Choudhury, A. T. M. A., Rose, M. T., Kecskes, M. L., Deaker, R., and Kennedy, I. R. 2011. Effects of a multistrain biofertilizer and phosphorous rates on nutrition and grain yield of paddy rice on a sandy soil in southern Vietnam. *J. Plant Nutr.* **34**: 1058-1069.

Coumaravel, K., Basker, A., Balachandar, M., and Sankar, R. 2004. Fertilizer optimization for rice cultivars through leaf colour technology. In: John, P.S., Menon, M.V., and Mathew, J. (eds.), *Input Use Efficiency in Agriculture Issues and Strategies.* Proceedings of ICAR national symposium, Thrissur, Kerala, pp.149.

Das, K. N., Bordoloi, P. K. and Bora, N. 1997. Tolerance level of iron in irrigation water for rice crop. *Int. J. Trop. Agric.* **15**: 159-166.

Datnoff, L. E., Asha, M., Brunings., and Rodrigues, F. A. 2005. Silicon effects on components of host resistance: An overview and implications for integrated disease management. III silicon in agriculture conference, Uberlandia, 22- 26 October 2005, Brazil, pp.26-32.

De Datta, S. K. 1981. *Principles and Practices of Rice Production.* John Wiley and Sons, Singapore. 618p.

Debnath, P. and Gosh, S. K. 2012. Critical limit of available boron for rice in alluvial zone soils of West Bengal. *India Res. J. Agric.* **46**(3): 275-280.

Debnath, P., Chandra, G. and Ghosh, K. S. 2009. Critical limit of available boron for rice under red and laterite zone of West Bengal, India. *SAARC J. Agric.* 7(1): 99-105.

Deepa, T. 2002. Water and fertilizer use efficiency in drip fertigated banana. Ph.D. Thesis, Kerala Agricultural University, Vellanikkara. Thrissur, 255p.

*Deguchi, M. and Ota, Y. 1957. Re examination on the effect of liming on paddy rice. Influence of Ca ion on plant growth and heading. *J. Sci. Soil Manure.* **28**: 413-415.

Ding, Y., Luo, W., and Xu, G. 2006. Characterisation of magnesium nutrition and interaction of magnesium and potassium in rice. *Annals of Applied Biol.* **149**(2): 111-123.

Dixit, S. P. 2006. Effect of lime and phosphorous on yield and nutrients uptake by maize in mountain acidic soils of HP. *Ann. Agric. Res. New Ser.* **27**(3): 277-282.

Dobermann, A. and Fairhurst, T. H. 2000. *Rice: Nutrient disorders and Nutrient Management*. Handbook Series. International Rice Research Institute. Oxford Graphic Printers Pvt Ltd. 191p.

Dunn, D., Stevens, G., and Kendig, A. 2005. Boron Fertilization of Rice with Soil and Foliar Applications [On line]. Available at http://plantsci.missouri.edu/deltacrops/pdfs/RiceBoron.pdf. [12 March 2014].

Dutta, S., Ghose, T. J., and Dey, P. C. 2013. Influence of potash levels on growth, yield, nutrient uptake and economics in irrigated summer rice of Assam. *Oryza* **60**(4): 334-339.

*Duncan, C. B. 1955. Multiple range and multiple F-tests. *Biometrics* **11**: 1-42.

Ehsan-Ul-Haq M., Kausar, R., Akram, M., and Shahzad, S. M. 2009. Is boron required to improve rice growth and yield in saline environment? *Pak. J. Bot.* **41**: 1339-1350.

Emmert, F. H. 1961. The bearing of ion interactions on tissue analysis results. *J. Pl. Analysis Fert. Problems.* **1**: 231-243.

Epstein, E. and Bloom, A. J. 2005. *Mineral nutrition of plants: Principles and Perspectives.* Second ed. Sinauer, Sunderland, MA.

Erdei, L. and Zsoldos, F. 1977. Effect of temperature and calcium on K fluxes and content. *Plant Physiol.* **4**: 99-104.

Fageria, N. K. 1976. Critical P, K, Ca and Mg contents in the tops of rice and peanut plants. *Plant Soil.* **45**: 421-431.

Fageria, N. K., Baligar, V. C., and Clark, R. B. 2002. Micro nutrients in crop production. *Adv. Agron.* **77**: 185-268.

Fageria, N. K., Carvalho, G. D., Santos, A. B., Ferreira, E. P. B., and Knupp, A. M. 2011. Chemistry of lowland rice soils and nutrient availability. *Commun. Soil. Sci. Plant Anl.* **42**: 1913-1933.

Fageria, N. K., Dos Santos, A. B., and Moraes, M. F. 2010. Influence of urea and ammonium sulphate on soil acidity indices in low land rice production. *Commun. Soil Sci. Plant Anl.* **41**: 1565-1575.

Fageria, N. K., Santos, A. B., Barbosa Filho, M. P., and Guimaraes, C. M. 2008. Iron toxicity in lowland rice. *J. Plant Nutr.* **31**: 1676-1697.

Fenn, L. B., Taylor, R. M., and Matocha, J. E. 1981. Ammonia losses from surface applied nitrogen fertilizer as controlled by soluble calcium and magnesium: general theory. *Soil Sci. Soc. Am. J.* **45**: 777-781.

Fernandez, C. E., Garcia, V. and Garcia, P. 1973. Study on banana nutrition in the Canary Islands. 11. Interaction between Cations. *Fruits.* **28**: 351-355.

F.I.B., 2002. *Farm Guide*, Farm information Bureau, Department Agriculture, Government of Kerala, Thiruvananthapuram, pp 1-29.

Fox, R. L., Hue, N. V., Jones, R. C., Yost, R. S. 1991. Plant- soil interactions associated with acid, weathered soil. *Plant Soil* **134**: 65-72.

Freed, R. 1986. MSTAT Version 4.0. Department of Crop and Soil Sciences, Michigon State University (Director: Dr. Russel Freed).

Freyfogle, E. 2007. *Wetlands of Kerala State.* The environment report. **1**:85-193.

Gaines, T. P. and Mitchell, G. A. 1979. Boron determination in plant tissues by the Azomethine-H method. *Commun. Soil Sci. Plant Anal.* **10**: 1099-1108.

Gaur, M. and Singh, V. 2010. Effect of phosphorous and boron on yield and uptake of nutrients by wheat. *Ann. Agric. Res. New Ser.* **31**(3&4): 119-122.

Gomez, K. A. and Gomez, A. A. 1984. *Statistical Procedures for Agricultural Research* (2nd Ed.). John Wiley and sons, New York, 680p.

Guanghui, X., Ying, W. S., Huaqi, W. and Ming, Z. 2003. Mineral nutrition uptake and fertilization effects of upland rice. *Scientia Agricultura Sinica.* **36**(10): 1171-1176.

Gupta, U. C. 1967. A simplified method for determining of hot-water-soluble boron on podzol soil. *Soil. Sci.* **103**: 424-428.

Gutpa, U. C. 1993. *Boron and its role in crop production.* CRC Press, Inc., Boca Raton, Florida.

Haldar, H. M. and Mandal, L. N. 1979. Effect of P and Zn on the growth and P, Zn, Cu, Fe and Mn nutrition on rice. *Plant Soil* **59**: 415-420.

Hariguchi, T. and Kitagishi, K. 1976. Studies on rlce seed prolease. 6. Metal ion activation of rice seed peptidase. *J. Sci. and Soil Manure*, Japan. **22**: 73-80.

Havlin, J. L., Beaton, J. D., Tisdale, S. L., and Nelson, W. L. 2006. *Soil Fertility and Fertilizers: An Introduction to Nutrient Management.* Prentince Hall of India Private Ltd., New Delhi, 515p.

Hermans, C., Johnson, G. N., Strasser, R. J., and Verbruggen, N. 2004. Physiological characterisation of magnesium deficiency in sugar beet: acclimation to low magnesium differentially affects photosystems I and II. *Planta* **220**: 344-355.

Hodson, M. J., White, P. J., Mead, A., and Broadley, M. R. 2005. Phylogenetic variation in the silicon composition of plants. *Ann. Bot.* **96**: 1027-1046.

Hosseini, S. M., Maftown, M., Karimian, N., Ronaghi, A., and Emam, Y. 2005. Effect of different levels of boron and zinc and two zinc sources on rice growth and chemical composition. *Iranian J. Agric. Sci.* **36**(4): 869-883.

Hussain, M. M. Khan, M. A., Khan, B., Farooq, M., and Farooq, S. 2012. Boron application improves growth, yield and net economic return of rice. *Rice Sci.* **19**(2): 324-328.

IRRI. 1996. *Almanac* (2^{nd} Ed.), International Rice Research Institute. P.O. Box 993, 1099 Manila, Philippines, 181p.

Jackson, M. L. 1958. *Soil Chemical Analysis*. Printice hall Inc, New Jersey, 498p.

Jacob, S. 1987. Characterisation of laterite soils from different parent materials in Kerala. M.Sc. (Ag.) Thesis, Kerala Agricultural University, Thrissur.

Jana, P. K., Ghatak, R., Sounda, G., Ghosh, R. K., and Bandyopadhyay, P. 2005. Effect of boron on yield, content and uptake on NPK by transplanted rice at farmer's field on red and laterite soils of West Bengal. *J. Int. Acad.* **9**: 341-344.

John, P. S., George, M., Johnkutty, I., and George, J. 2004. Direct and residual effect of sulphur fertilization in rice- sesamum cropping system. In: John, P. S., Menon, M. V., and Mathew, J. (eds.), *Input Use Efficiency in Agriculture: Issues and Strategies.* Proceedings of ICAR national symposium, Thrissur, Kerala, pp.149.

Johnkutty, I. and Venugopal, V.K. 1993. Kole lands of Kerala. Directorate of Research, Kerala Agricultural University, Thrissur, 68p.

Junior, Z. L. A., Fontes, R. L. F. and Avila, V. T. 2009. Silicon application to increase rice resistance to brown spot. *Pesquisa Agropecuaria Brasileira.* **44**(2): 203-206.

Kalita, S. M., Bhuiyan, M. M. A., Ahmed, F. and Mandal, R. 2007. Effect of boron fertilization on the growth and yield of rice. *J. Phtol. Res.* **20**(2): 179-182.

Katyal, J. C., Rattan, R. K., and Datta, S. P. 2004. Management of zinc and boron for sustainable food production in India. *Fert. News* **49**(12): 83-99.

KAU. 2011. *Package of Practices Recommendations Crops* (12[th]Ed.). Kerala Agricultural University, Thrissur, 334 p.

Kavitha, M. P., Balasubramanian, R., Babu, R. and Pandi, V. K. P. 2008. Effect of nitrogen and potassium management on yield attributes, yield and quality parameters of hybrid rice. *Crop Res.* **35**(3): 172-175.

Kobayashi, H., Masaoka, Y., and Sato, S. 2005. Effects of excess magnesium on the growth and mineral content of rice and *Echinochloa. Plant Production Science.* **8**(1): 38-43.

Koendoefer, G. H., Snyder, G. H., Ulloa, M., Powell, G., and Datnoff, L. E. 2001. Calibration of soil and plant silicon analysis for rice production. *J. Plant Nutr.* **24**: 1071-1084.

Kovda, V. A. 1973. The bases of learning about soils. Moscow: Nayka, 2 v.

Krasaesindhu, P. and Sims, J. L. 1972. Response of rice to nitrogen and calcium nutrition. *Soil Sci. Soc. Am. J.* **36**(3): 457-461.

Krishnakumar, S., Nagarajan, R., Natarajan, S. K., Jawahar, D., and Pandian, B. J. 2005. NPK fertilizers for hybrid rice (*Oryza sativa* L.) productivity in Alfisols of southern districts of Tamilnadu. *Asian Journal of Plant Sciences.* 4(6): 574-576.

K.S.I., 2000. *Handbook of Statistics*, 2000. Kerala Statistical Institute, Thiruvananthapuram, p129.

Kumara, B. H. Yogendra, N. D. Prakash, N. B., Anantha, M. S., and Chandrasekhar, N. 2013. Effect of calcium silicate and need based nitrogen management in aerobic rice. *Oryza* **60**(4): 358-364.

Lakshmikanthan, K. 2000. Efficacy of Si and K in the amelioration of iron in rice culture. M.Sc(Ag) Thesis, Kerala Agricultural University, Thrissur,174p.

Latheef, N. 2013. Relative efficiency of soil and foliar applied nutrients in irrigated rice of Palakkad. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, 174p.

Liang, Y. C., Zhu, Y. G., Xia, Y., Li, Z., and Ma, Y. 2006. Iron plaque enhances phosphorus uptake by rice (*Oryza sativa*) growing under varying phosphorus and iron concentrations. *Ann. Appl. Biol.* **149**: 305-312.

Ma, J. F and Takahashi, E. 2002. Silicon sources for agriculture. *In* Soil, Fertilizer and Plant Silicon Research in Japan, *Elsevier*, p. 5-26.

Ma, J. F., Mitani, N., Nagao, S., Konishi, S., Tamai, K., Iwashita, T., and Yano, M. 2004. Characterization of the silicon uptake system and molecular mapping of the silicon transporter gene in rice. *Plant Physiol.* **136**: 3284-3289.

Ma, J., Nishimura, K., and Takahashi, E. 1989. Effect of silicon on the growth of rice plant at different growth stages. *J. Soil Sci. Plant Nutr.* **35**: 347-356.

Ma, J. F., Tamai, K., Ichii, M., and Wu, G. F. 2002. A rice mutant defective in active silicon uptake. *J. Plant Physiol.* **130**: 2111-2117.

Maekawa, K. Watanabe, K., Aino, M., and Iwamoto, Y. 2001. Suppression of rice seedlings blast with some silicic acid materials in nursery box, *Jpn. J. Soil Sci. Plant Nutr.* 72: 56-62.

Malidareh, A. G. 2009. Silicon application and nitrogen on yield and yield components in rice (*Oryza sativa*) in two irrigation systems. *World Academy of Sci. Engr. and Tech.* **78**: 88-95.

Mandal, K. G., Ghosh, P. K., Waiyari, R. H., Hati, K. M., Bandyopadhyay, K. K. and Misra, A. K. 2002. Practical implication of nutrient x nutrient interaction to boost oilseeds productivity in India. *Fert. News.* **47**(7): 13-18 and 21-26.

Mandal, S. S. and Dasmahapatra, A. N. 1983. Studies on correlation between K and grain yield. *Indian Potash J.* **8**(1): 20-24.

Manzoor, Z., Awan, T. H., Ahmad, M., Akhter, M. and Faiz, F. A. 2008. Effect of split application of potash on yield and yield related traits of Basmati rice. *Journal of Animal and Plant Sciences.* **18**(4):120-124.

Marschner, H. 1995. *Mineral Nutrition of Higher Plants*, 2nd, San Diego, CA: Academic.

Mathew, G. 2002. Nutritional constraints of rice- legume system in laterite soils of humid tropics. Ph.D. Thesis, Kerala Agricultural University, Vellanikkara, Thrissur, India. 249p.

Mathew, G. and John, P. S. 2004. Effect of crop residue recycling and silica addition on yield improvement of rice in laterite soils. In: John, P. S., Menon, M. V. and Mathew, J. (eds.), *Input Use Efficiency in Agriculture- Issues and Strategies.* Proceedings of an ICAR national symposium, Kerala Agricultural University, Thrissur, Kerala, pp. 135-136.

Mauad M., Crusciol, C. A. C. Filho, H. G., and Correa, J. C. 2003 - Nitrogen and silicon fertilization of upland rice. *Scientia Agricola.* **60**(4):761-765.

Mehraban, P., Zadeh, A. A. and Sadeghipour, H. R. 2008. Iron toxicity in rice (*Oryza sativa* L.) under different potassium nutrition. *Asian J. Plant Sci.* 7(3):251-259.

Melo, D. S. P., Monteiro, F. A., and De Bona, F. D. 2010. Silicon distribution and accumulation in shoot tissue of the tropical forage grass *Brachiaria brizantha. Plant Soil.* **336**: 241-249.

Mengel, K. and Kirkby, E. A. 1982. *Principles of Plant Nutrition.* IPI, Switzerland, 427-453pp.

Mengel, K. and Kirkby, E. A. 1987. Principles of concentration of K and Mg in nutrient solutions in sorghum. *Agron. J.* **74**: 41-46.

Mengel, K., Secer, M., and Koch, K. 1981. Potassium effect on protein formation and amino acid turnover in developing wheat grain. *Agron. J.* **73**: 74-78.

Mithra, G. N., Sabu, S. K. and Dev, G. 1990. Potassium chloride increase rice yield and reduces symptoms of iron toxicity. *Better Crops Int.* **6**(2):14-15.

Mobasser, H. R., Malidarh, G. A., and Sedghi, H. 2008. Effects of silicon application to nitrogen rate and splitting on agronomic characteristics of rice (*Oryza sativa* L.). *Silicon in Agriculture*: 4th International Conference 26-31 October, South Africa: 76.

Moormann, E. R. 1963. *Acid* sulphate soils of tropics. *Soil Sci.* **95**: 271-275.

*Mureta, Y. 1969. Physilogical response to nitrogen in plants. In: *Physiological aspects of crop yield.* American Society of Agronomy. *Crop Sci. Soc. Am.* Madison, Wisconsion.

Muralidharan, P. and Jose, A. I. 1994. Effect of Boron and Molybdenum on yield and uptake of nutrients in rice. *J. Tropic. Agric.* **32**(2): 157-158.

Muthukumararaja, T., Sriramachandrasekharan, M. V., and Ravichandran, M. 2009. Growth and sink potential of rice as influenced by sulphur and potassium fertilization. *Plant Arch.* **9**: 83-85.

Muthuswamy, P., Raj, D. and Krishnamurthy, K. K. 1974. Uptake of nitrogen, phosphorous and potassium by high yielding paddy varieties at different growth stages. *Indian J. Agric. Chem.* **7**: 1-5.

Nayar, P. K., Misra, A. K. and Patnik, S. 1975. Rapid microdetermination of silicon in rice plant. *Plant Soil.* **42**: 491-494.

Nogushi, J. and Sugawara, T. 1966. Potassium and Japonica Rice. International Potash Institute, Bern, Switzerland, 295p.

Obatolu, C. R. 1999. Correction of magnesium deficiency in tea plants through foliar applications. *Commun. Soil. Sci. Plant. Anl.* **30**(11&12): 1649-1655.

Ologunde, O. O. and Sorensen, R. C. 1982. Influence of concentration of K and Mg in nutrient solutions in sorghum. *Agron. J.* **74**: 41-46.

Olsen, S. R., and Watanabe, F. S. 1979. Interaction of added gypsum in alkaline soils with uptake of iron, molybdenum, manganese and zinc by sorhum. *Soil Sci. Soc. Am. J.* **43**: 125-130.

Ottow, J. C. G., Benckiser, G., and Watanabe, I. 1982. Iron toxicity of rice as a multiple nutritional soil stress, in Proc. Int. Symp. *On Distribution, Characteristics and Utilization of Problem Soils.* Tropical Agriculture Research Center, Ibaraki, pp. 167-179.

Padmaja, P. and Verghese, E. J. 1966. Effect of Calcium and Silicon on the uptake of plant nutrients and quality of straw and grain of paddy. *Agric. Res. J. Kerala* **4**(1): 31-38.

Panda, B. B., Sharma, S. G., Mohapatra, P. K., and Das, A. 2012. Iron stress induces primary and secondary micronutrient stresses in high yielding tropical rice. *J. Plant Nutr.* **35**: 1359-1373.

Panda, S. C. 2005. Agronomy (Indian Reprint, 2012). Agrobios, Chopasani Road, Jodhpur, 833p.

Papadopoulos, F., Prochaska, C., Papadopoulos, A., Eskridge, K., and Kalavrouziotis, I. 2009. Mn and Zn micronutrients concentration in acidic soils and source identification using multivariate statistical methods. *Commun. Soil Sci. Plant Anl.* **40**: 2357-2371.

Pathirana, R., Chadrasiri, P., Sirisena, S. G. Data, R. A., Grundon, N. J., Rayment, G. E. and Probert, M. E. 1995. Response of rice cultivars to increased iron and aluminium concentrations. Proceedings of the third international symposium on plant- soil interactions, Queensland, Australia, pp.413-417.

Patnaik, S. 1971. Laterite soils of India. FAO/UNDP seminar on soil survey and soil fertility research. New Delhi, *FAO World Soil Resources Reports* **41**: 52-56.

Patrick, W. H. Jr. 1996. Apparatus for controlling the oxidation- reduction potential of waterlogged soils. *Nature* **212**: 1278-1279.

Pendias, K. A. and Pendias, H. 2001. *Trace Elements in Soils and Plants.* 3rd Edition. CRC Press, Baca Raton, London, New York. 403p.

Piper, 1966. Aging of crystalline precipitates. *Analyst.* 77: 1000-1011.

Ponnamperuma, F. N. 1978. Electrochemical changes in submerged soils and the growth of rice. International Rice Research Institute, Los Banos, Phillipines, pp.421-441.

Ponnusamy, K. 2006. Farmers participatory assessment of zinc in increasing yield. *Indian Fmg.* **56**(6): 9-10.

Prasad, R. 2007. *Crop Nutrient- Principles and Practices.* New Vishal Publications. New Delhi. 272p.

Prasad, R. and Power, J. F. 1997. *Soil Fertility Management for Sustainable Agriculture.* CRC Lewis, Boca Raton, FL, USA, 347p.

Pushparajah, 1998. Nutrient management and challenges in managing red and lateritic soils. *Red and Lateritic Soils.* Vol.1, Oxford and IBH Publishing Co. Pvt., Ltd., New Delhi, pp.293-304.

Rajagopal, C. K., Sheriff, M. M., Selvakumari, G. and Jabarani, N. 1977. Status of available minor nutrient cations in the soils of Kerala. Agric. Res. J. Kerala **15**(2): 165-171.

Rao, P. R., Subrhamanyam, D., Sailaja, B., Singh, R. P., Ravichandran, V., Rao, G. V. S., Swain, P., Sharma, S. G., Saha, S., Nadaradjan, S., Reddy, P. J. R., Shukla, A., Dey, P. C., Patel, D. P., Ravichandran, S., and Voleti, S. R. 2013. Influence of boron on spikelet fertility under varied soil conditions in rice genotypes. *J. Plant Nutr.* **36**: 390-400.

Rao, S., Rao, S. A., Rao, K. V., Venkataeswarulu, B., and Singh, A. K. 2010. Categorisation of districts based on non exchangeable potassium: Implications in efficient K fertility management in Indian Agriculture. *Indian J. Fert.* 6: 40-54.

Rashid, A., Yaseen, M., Ali, M. A., Ahmad, Z., and Ullah, R. 2006. Residual and cumulative effect of boron use in rice-wheat system in calcareous soils of Pakistan. *In*: Proceedings of 18th World Congress of Soil Science; July 9-15, Philadelphia, Pennsylvania, USA: 206.

Rashid, A., Yasin, M., Ali, M. A., Ahmad, Z., and Ullah, R. 2007. *An Alarming Boron Deficiency in Calcareous Rice Soils of Pakistan: Boron Use Improves Yield and Cooking Quality.* p. 103-116In: F. XU et al. (eds.) Advances in Plant and Animal Boron Nutrition. Springer Series Netherlands.

Rashid, A., Yasin, M., Asraf, M., and Mann, R. A. 2004. Boron deficiency in calcareous soil reduces rice yield and impairs grain quality. *Int. Rice Res. Notes* **29**: 58-60.

Ravichandran, M. and Sriramachandrasekharan, M. V. 2011. Optimizing timing of potassium application in productivity enhancement of crops. Karnataka J. Agric. Sci. **24**(1): 75-80.

Ray, S. and Choudari, M. A. 1980. Regulation of flag leaf senescence in rice by nutrient and its impact on yield. *Riso.* **29**(1): 9-14.

Ray, S. K. 2011. Importance of micronutrients under north eastern hill region. *IMMA News* **4**(2): 5-7.

Rehman, H., Farooq, M., Cheema, Z. A., and Wahid, A. 2012. Seed priming with boron improves growth and yield of fine grain aromatic rice. *Plant Growth Reg.* **68**: 189-201.

*Robinson, G. W. 1922. A new method for the mechanical analysis of soil and other dispersions. *J. Agric. Sci.* **12**: 306-321.

Sahrawat, K. L., Diatta, S., and Singh, B. N. 2000. Reducing iron toxicity in lowland rice through an integrated use of tolerant genotypes and plant nutrient management. *Oryza* **37**: 44-47.

Sahrawat, K. L., Jones, M. P., and Diatta, S. 1999. Phosphorous, calcium and magnesium fertilization effects on upland rice in an Ultisol. *Commun. Soil Sci. Plant Anl.* **30**(7&8): 1201-1208.

Sakal, R. 2001. Efficient management of micronutrients for sustainable crop production. *J. Indian Soc. Soil Sci.* **49**(4): 593-608.

Sakal, R., Singh, A. P., and Sinha, R.B. 2002. Evaluation of rate and frequency of boron application in cropping systems. *Fert. News* **10**: 37-38.

Saleem, M., Khanif, Y. M., Ishak, F., and Samsuri, A. W. 2009. *Dissolution kinetics of boron fertilizers, boron release in soil and effect on rice.* Proc. 4th Int. Boron Symp. 15-17 October, Eskisehir-Turkey p.467-471.

Saleque, M. A., Timsina, J., Panaullah, G. M., Ishaque, M., Pathan, A. B. M. B. U., Connor, D. J., Saha, P. K., Quayyum, M. A., Humphreys, E., and Mesiner, C. A. 2006. Nutrient uptake and apparent balances for rice-wheat sequences. II. phosphorous. *J. Plant Nutr.* **28**: 157-172.

Samui, R. C and Mandal, B. 2003. Crop response to secondary and micronutrients in red and laterite group of soils. *Fert. News* **48**(4): 39-45.

Sangwan, N., Amandeep., Singh, R., Yadav, S. K. and Kumar, M. 2007. Response of rice (*Oryza sativa*) to NPK levels on yield and yield attributes and nutrients uptake in rice-wheat cropping system at farmer's field. *Haryana journal of Agronomy.* **23**(1&2): 39-42.

Santos, L. S. D., and Oliveira, A. C. D. 2007. Rice iron metabolism: From source to solution. *J. crop sci. Biotech.* **10**: 64-72.

Santosh, C. 2013. Chemistry and transformation of boron in soils of Kerala. Ph.D. Thesis, Kerala Agricultural University, Thrissur, 187p.

Salplarinliana, H., Sharma, S. K. and Singh, P. K. 2006. Effect of nitrogen and potassium levels on the nutrient availability, fertilizer use efficiency and yield of the rice crop. *J. Interacademicia.* **10**(4): 503-507.

Scott, B. J. and Robson, A. D. 1990. Changes in the content and form of magnesium in the first trifoliate leaf of subterranean clover under altered or constant root supply. *Aust. J. Agric. Res.* **41**: 511-519.

Seebold, K.W., Datnoff, L.E., Correavictoria, F.J., Kucharek, T.A., and Snyder, G.H., 2001. Effect of silicon rate and host resistance on blast, scald and yield of upland rice. *Plant Dis.* **84**: 871 -876.

Seng, V., Bell, R. W. and Willett, I. R. 2008. Effect of lime and flooding on phosphorus availability and rice growth on two acidic lowland soils. *Communications in Soil Science and Plant Analysis.* **37**(3 & 4): 313-336.

Shah, S. M. A., Hidayat-ur-Rahman., Rehman, A., Abassi, F. M., Khalil, I. H., and Ali, A. 2008. Characterization of wild rice species in response to leaf folder (*Cnaphalocrosis medinalis*). *Sarhad J. Agric.* **24**(1): 69-74.

Shashidhar H. E., Chandrashekhar, N., Narayanaswamy, C., Mehendra, A. C., and Prakash, N. B. 2008. Calcium silicate as silicon source and its interaction with nitrogen in aerobic rice. *Silicon in Agriculture*: 4th International Conference 26-31 October, South Africa: 93.

Sheela, S. 1975. The distribution, fixation and availability of phosphorus in the Kole soils of Kerala. M.Sc(Ag) thesis, Kerala Agricultural University, Thrissur, 190p.

Shrotriya, G. C. 2007. Magnesium in balanced fertilization. *Indian J. Fert.* **3**(1): 83-88.

Shujie, M. Y. Q. 2012. Distribution of inorganic and organic phosphorous fractions in two phosphorous-deficient soils as affected by crop species and nitrogen applications. *Commun. Soil Sci. Plant Anl.* **43**: 631-644.

Sims, T. J. and Johnson, G. V. 1991. Micronutrient soil tests. In: Mortvealt, J. J., Cox, F. R., Shuman, L. M., and Welch, R. M. (eds.), *Micronutrients in Agriculture.* Soil Science Society of America, Madison, WI, pp.427-476.

Sindhu, P. V. 2003. Effect of nutrient inter- relations on productivity of rice in lateritic soil. M.Sc. (Ag.) Thesis, Kerala Agricultural University, Thrissur, India, 193p.

Singh, B. P. 1992. Characterisation of Fe- toxic soils and affected plants and their correlation in acid Hapalaquents of Meghalaya. Intl. Rice Res. Newsl. 17(2): 18-19.

Singh, G. R. and Singh, T. A. 1987. Influence of organic amendments and oilcakes on ammonia voltalization in field rice. *Int. Rice. Res. Newsl.* **12**(1): 33.

Singh, K. K., Singh, K., Singh, R. S., Singh, R., and Chandel, R. S. 2005. Silicon nutrition in rice- A review. *Agric. Rev.* **26**(3): 223-228.

Singh, K., Sharma, H. C., Sarangi, S. K., and Sudhakar, P. C. 2003. Iron nutrition in rice. *Fert. News* **48**(2): 21-31.

Singh, V. P., Voleti, S. R., and Rao, C. N. 1995. Distribution of free proline in rice grown under low light irradiance. *J. Agron. and Crop Sci.* **175**(3): 207-209.

Sivaperuman, C. and Jayson, E. A. 2000. Birds of Kole wetlands, Thrissur, Kerala. *Zoos Print J.* **15**(10): 344-349.

Somer, I. I. and Shive, J. W. 1942. Iron manganese relation in plant metabolism. *Plant Soil* **17**: 582-602.

Sreedharan, C. and George, C. M. 1969. Effect of micronutrients on paddy in red loam soil of Kerala. *Agric. Res. J. Kerala* **7**(2): 61-66.

Srinivasan, T. 2011. Agriculture-wetland interactions and sustainability of rice cultivation in the Kole land, Kerala. In: Proceedings of the Sixth Biennial Conference of The Indian Society of Ecological Economics (INSEE) on Nature, Economy and Society: Understanding the Linkages to be held at the Centre for Economic and Social Studies (CESS), Hyderabad, October 20 to October 22, 2011: 12-24.

Su, S. R. 1976. Use of industrial wastes for recycling plant nutrients in Taiwan. *Soils. Fert. Taiwan,* pp.19-29.

Subbiah, B. V. and Asija, G. L. 1956. A rapid procedure for assessment of available nitrogen in rice soil. *Curr. Sci.* **25**: 259-260.

Suswanto, T., Shamshuddin, J., Omer, S. S. R., Mat, P., and The, C. B. S. 2007. Effect of lime and fertilizer application in combination with water management on rice (*Oryza sativa* L.) cultivated on acid sulphate soil. *Malayasian J. Soil Sci.* **11**: 1-16.

Tadano, T. and Yoshida, S. 1978. Chemical changes in submerged soils and their effect on rice growth. Soils and Rice. International Rice Research Institute, Phillipines, pp. 399-420.

Takahashi, E. 1995. Uptake mode and physiological functions of silica. *In: Science of the rice plant.* FAO Policy Research Centre, Tokyo, pp. 420-433.

Tanaka, A., Tadano, T., and Akiyama, Y. 1997. Comparative studies on plant nutrition: Adaptability to heavy metals among crop species. *J. Sci. Soil manure.* **48**: 352-361.

Tisdale, S. L., Nelson, W. L., Beaton, J. N., and Havlin, J. L. 1993. *Soil Fertility and Fertilizers.* India Reprint 1997. Prentince Hall of India Private Ltd., New Delhi, 634p.

Tomar, N. K. 2000. Dynamics of phosphorus in soil. *J. Indian Soc. Soil Sci.* **48**: 640-672.

Uraguchi, S. and Fujiwara, T. 2011. Significant contribution of boron stored in seeds to initial growth of rice seedlings. *Plant Soil* **340**: 435-442.

Vallalkannan, S. 2004. Nutritional resource use efficiency in rice production. Ph. D. thesis, Kerala Agricultural University, Thrissur, India, 120p.

Venkatasubbiah, V., Ramasubbareddy, G., Rao, Y. Y., Seshaiah, R. K. and Rao, S.I. V. 1982. Effect of graded levels of potash application on yield and its component on high yielding Jaya rice depleted soil. *Indian Potash J.* 7(4): 2-6.

Verma, S. C., Singh, M. P. and Sharma, S. N. 1979. Effect of rate and method of potash application on early and late dwarf rice varities. *Indian Potash J.* 4(2): 2-6.

Vijayan, G. and Sreedharan, C. 1972. Effect of levels and tonnes of application of potash on IR 8. *Oryza.* 9: 57-64.

Walkely, A. and Black, C. A. 1934. An examination of Degtjareff methods for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* **37**: 29-38.

Wang S. Q., Gu, C. M., Zhao, H. H., Zhao, L. M., Wang, L. P., and Wang, H. 2010. *Research and Application Prospects of Micro-silicon Fertilizer on Rice Production.* Rice Research Institute of Heilongjiang Academy of Land Reclamation Sciences, Jiamusi Heilongjiang, China.

Wattanabe, F. S. and Olsen, S. R. 1965. Test of an ascorbic acid method for determing phosphorous in water and sodium bicarbonate extracts from soil. *Soil Sci. Soc. Am. Proc.* **29**: 39-45.

Yadav, L. R. and Choudhary, G. L. 2012. Effect of fertility levels and foliar nutrition on profitability, nutrient content and uptake of cowpea (*Vigna unguiculata* (L.) Walp). *Legume Res.* **35**(3): 258-260.

Yamauchi, M. and Winslow, M. D. 1989. Effect of silica and magnesium on yield of upland rice in the humid tropics. *Plant Soil.* **113**: 265-269.

Yan, L. and Chu, Q. S. 1996. Magnesium requirement and magnesium fertilizer application of rice. *J. Fujian Agric. Univ.* **25**(1): 78-82.

Yoshida, S., Forno, A. S., Cook, H. J., and Gomez, A. K. 1972. *Laboratory manual on physiological studies.* International Rice Research Institute, Manila, Phillipines, pp. 36-37.

Zayed, B. A., Salem, A. K. M., and El Sharkawy, H. M. 2011. Effect of different micronutrient treatments on rice (*Oryza sativa* L.) growth and yield under saline soil conditions. *Wld. J. Agric. Sci.* 7(2): 179-184.

Zhiming, Y., Jingcan, H., Minglang, C., and Xuehua, C. 2007. Nitrogen and phosphorous application on hybrid rice. *Fujian J. Agric. Sci.* **21**(1): 5-9.

*Originals not seen

Appendix

APPENDIX-1

Monthly weather data during the cropping period at COH, Vellanikkara from Nov 2013 to March 2014

(Latitude 10^{0}31'N, Longitude 76^{0}13' and Altitude 40.29MSL)

Month	Temperature (^{0}C)		Relative Humidity (%)		Rainfall (mm)	Mean evaporation (mm)	Rainy days	Sunshine hours (hrs/day)	Mean wind speed (Km/hr)
	Maximum	Minimum	Morning	Evening					
November	32.6	23.9	87	60	82.0	2.7	5	187.2	3.0
December	31.9	22.3	77	45	0.5	2.4	0	254.7	5.5
January	32.9	23.0	66	36	0.0	4.6	0	277.6	6.9
February	34.7	22.9	75	37	0.0	9.1	0	240.8	4.5
March	36.7	24.2	76	34	0.0	9.5	0	264.2	3.9

APPENDIX-2

Details of cost of cultivation

Sl. No.	Particulars	Men/ha (Rs.420/day)	women/ha (Rs.310/day)	Amount (Rs/ha)
	Field operations			
1	Ploughing (machine)	-	-	5200/-
2	Bund formation	8	-	3360/-
3	Seed treatment	-	4	1240/-
4	Sowing	2	1	1150/-
5	Fertilizer application	1	1	730/-
6	Water management	3	-	1260/-
7	Weeding (Thrice)	-	60	18,600/-
8	Plant protection chemical spraying	4	-	1680/-
9	Harvesting (Combine harvester)	-	-	5900/-

APPENDIX-3

Details of cost of inputs

Sl. No.	Particulars	Amount (Rs/kg)
1	Seed	36/-
2	FYM	2/-
3	Lime	10/-
4	Urea	8/-
5	Rajphos	9/-
6	MOP	18/-
7	Magnesium sulphate	14/-
8	Sodium silicate	18/-
9	Calcium silicate	73/-
10	Borax	115/-

SOIL AMELIORATION AND NUTRIENT MANAGEMENT OF RICE IN KOLE LANDS

By

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(2012-11-147)

ABSTRACT OF THE THESIS

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ABSTRACT

The study on "Soil amelioration and nutrient management of rice in Kole lands" was conducted during 2013-2014 at Ponnamutha Kole padavu of Venkitangu panchayath in farmer's field. The objective of the experiment was to study the effect of soil ameliorants and nutrients *viz.* K, Ca, Mg, B and Si on growth, nutrient uptake and yield of rice and to develop a nutrient management schedule for higher productivity of rice in Kole lands.

The experiment was laid out in RBD with three replications and there were twelve treatments comprising of soil test based nutrient package of NPK, nutrients as per Package of practice recommendations (POPR), different doses of K, individual applications of magnesium and boron, different sources of silica and combined application of nutrients and soil ameliorants. FYM, lime and silica were applied at the time of ploughing. Nitrogen was applied in three equal split doses, phosphorus as basal, potassium and boron in two equal split doses. Observations on growth characters, yield attributes and yield were recorded. Nutrient contents of plant and soil were determined using standard procedures.

The growth characters of rice such as plant height, number of tillers, chlorophyll content and dry matter production were significantly improved by combined application of magnesium, boron and silica followed by application of silica as sodium silicate resulting in increased number of panicles/m^2 and number of spikelets/m^2 and ultimately the yield and B:C ratio. Application of boron along with POPR also positively influenced all the yield attributing characters with highest per cent filled grains and increased yield.

The nutrient content of major and micronutrients in plant Fe and Mn showed an increase over other treatments while Fe and Mn content decreased due to combined application of magnesium, boron and silica along with other nutrients as per POPR. Application of silica improved the soil nutrient status enabling increased uptake of nutrients and enhanced yield. The combined application of magnesium, boron and silica and individual application of boron and silica with POPR significantly influenced the pH, EC and available nutrient status of soil. The application of lime and silica had regulated the soil pH and decreased the Fe and Mn content of soil.

The combined application of magnesium, boron and silica and individual application of silica as sodium silicate and boron along with FYM, NPK and lime as per POPR were found to be effective in ameliorating the harmful effects of Kole land soil which ultimately led to enhanced yield.

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