RELATIVE EFFICIENCY OF AMELIORANTS ON RICE PRODUCTIVITY IN LATERITIC SOILS OF KERALA

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Relative efficiency of ameliorants on rice productivity in lateritic soils of Kerala"** 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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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

INTRODUCTION

I. INTRODUCTION

Substantial portion of rice growing areas in India is comprised of acid soils. More than 68% of the Kerala soils are laterite, which is predominantly acidic. Soil acidity and associated infertility and mineral toxicities are major constraints to agricultural production. In Kerala, except a small area of black soil in Chitoor, entire soil is acidic. Highly acidic *Kari* soils with pH as low as 2.6 is found at Kallara in Kerala (Marykutty and Aiyer, 1987).

The chemical constraints for higher yield in laterite soils are identified as low cation exchange capacity and organic matter content, high acidity, Fe and Al toxicity, high phosphorous fixation and poor nutrient status. Phosphorous become immobile and unavailable to plant due to low pH and dominance of active forms of Al and Fe (Dixit, 2006). Proper amelioration can modify the soil environment which may positively influence the availability of nutrients. Liming is a dominant and effective practice to overcome constraints and improve crop production on acid soils. Lime is called the foundation of crop production or 'workhorse' in acid soils. Lime requirement for crops grown on acid soils is determined by the quality of liming material, status of soil fertility, crop species and cultivar within species, crop management practices, and economic considerations. Soil pH, base saturation, and aluminum saturation are important acidity indices which are used as the basis for determination of liming rates for reducing plant constraints on acid soils (Fageria and Baligar, 2008).

Liming of acidic red and laterite soil not only ameliorate soil acidity related problem but also supplies and increases uptake of Ca (Samui and Mandal, 2003). Liming the soil decrease available Fe and Mn and increase pH to a great extent, and reduce iron toxicity (Patra and Mohanty, 1994).

The addition of lime, basic slag, or MnO_2 exerted a significant effect on the decrease of the S content, increase of the soil solution pH, and optimization of elemental concentrations in the plants and soil solutions (Khan *et al.*, 1994).

Iron toxicity is a syndrome of disorder associated with large concentrations of reduced iron (Fe^{2+}) in the soil solution. It only occurs in flooded soils and hence affects primarily the production of lowland rice. The typical visual symptom associated with iron toxicity is the 'bronzing' of the rice leaves and substantial yield losses (Becker and Asch, 2005).

Liming enhances the extractability of Mn and Fe and improves soil pH and other nutrient conditions. Conclusively, $Ca(OH)_2$ could be a good material to restore nutrient balance in rice soil(Lee *et al.*, 2011).

Calcium is referred to as 'liming element' because it is added to amend soil pH and plays a greater role in neutralizing the acid forming effects of H^+. Several natural materials, industrial by-products and commercial products are available as soil ameliorants. The correction of soil pH, reduction of toxic accumulation of native elements and supplementation of secondary nutrients may enhance the growth and productivity of rice grown in lateritic lowlands.

The present investigation aims at studying the relative efficiency of natural soil ameliorants such as lime and dolomite and a commercial ameliorant 'Mangala setright' on growth and yield of rice grown in laterite soil. This study was taken up with the following major objectives.

1. To assess the relative efficiency of various soil ameliorants such as lime, dolomite, 'Mangala setright' a commercial product on growth and yield of rice.
2. To study the effect of the ameliorants on the native elements *viz.*, Fe, Mn, Al which are in toxic concentrations in soil, and uptake of applied nutrients.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

2.1 Laterite soils

Laterite and lateritic soils are formation peculiar to India and some other tropical countries with intermittently moist climate. In India they cover a total area of about 248000 km^2 (Ray and Choudari, 1980). The high rainfall and temperature conditions of Kerala state are conductive for the laterisation process leading to the development of highly weathered, leached and infertile soils. Laterite soils cover nearly 60 per cent of the total area of the state occupying the mid land and mid upland regions. Laterite and lateritic soils are the weathering products of rock in which several course of weathering and mineral transformations took place. This involved removal of bases and substantial loss of combined silica of primary minerals (Soil survey, 2007).

Kerala state, located in South-western part of India, is known in earth science literature as the 'type locality' of 'laterite', a name first coined by Buchanan (1807) at Angadipuram of Malappuram district of the state. The high rainfall and temperature conditions of the state are conducive for the laterisation process leading to the development of highly weathered, leached and infertile soils. Laterite soils of the state, often referred to as middle valley laterites, accounts for more than 60 per cent of the rice soils in Kerala. Alexander and Cady (1962) defined laterite as highly weathered material rich in secondary oxides of iron, aluminium or both. It is nearly void of bases and primary silicates, but it may contain large amounts of quartz and kaolinite. According to Venkataraman and Krishnan (1992) the developments of the soil profile and its physical and chemical composition have a significant bearing on crop performance. These were either the result of or were very greatly affected by weather. In soils of high rainfall region, there would be a large accumulation of iron oxide (indicating ferralisation). Since ferralisation and desilicification were associated with laterisation, the overall effect was the formation of a lateritic type of soil characterized by acidic reaction, low base status and presence of plinthitic gravel.

2.2 Rice production in lateritic soils

The productivity of rice in laterite soils is low because of their acidity and deficiencies in a few essential nutrients viz., nitrogen, phosphorus, calcium, zinc, boron, molybdenum etc. The soils are inherently acidic and infertile with high phosphate fixation. According to Singh (2005), acid and lateritic soils have high available iron content and consequently iron toxicity during excessive rains influencing rice yield. Patnaik (1971) reported that low productivity of laterite and allied soils could generally be attributed to low pH, low base saturation, low available P, high P fixing capacity and toxicity of Fe and Al. He further reported that moderate to high acidity of laterite soils also causes serious problems in major rice growing areas. Due to the lateritic nature of the soils, phosphorus and potassium nutrition of rice was adversely affected leading to the non responsiveness to P and K. According to Santos (1966), the low yield of rice in acid soils were not due to Ca deficiency; but due to decreased availability of P and toxic levels of Al and Fe. Bridgit and Potty (1992) found that individually all the elements in the plant system were higher than what is required to produce a yield above 7000 kg ha^{-1} when rice was grown in laterite soils. The low yield in laterite soils therefore had been not due to deficiency of major elements, but due to excess of native elements like Fe, Mn and Zn getting absorbed into the plant and inhibiting the expression of yield. Marykutty *et al.* (1992) reported that Ca+Mg/K ratio was the determinant factor in deciding the yield expression of rice in laterite soils. The trend of increasing yield could be observed when the ratio got narrowed. According to John *et al.* (2001) toxicities of Fe, Al, and Mn are limiting the crop production in laterites and these nutrient imbalances are to be rectified for sustaining crop production. Potty *et al.* (1992) have reported that rice growth and yield in laterite soils were poor due to the absence of higher levels of N and P as well as due to the excess amount of soil Fe.

According to Bhadoria *et al.* (2003) the uptake of N, P and K by rice plants supplied with recommended doses of FYM was significantly greater than all other commercial manures and inorganic fertilizer. The tolerance of rice plants to attack by pathogens and pests, measured in terms of grain yield was highest in the treatment with FYM. It was observed that Ca application could effectively check iron content, which is the main yield limiting factor in laterite soils, but it could not contain the adverse effects of Mn and Zn which directly interfered with N metabolism (John *et al.*, 2004). Rathish (2010) reported that incorporation of paddy straw and cowdung along with N and S significantly influenced the yield attributing characters of rice cultivated in laterite soil.

2.3 Soil acidity in lateritic soils

Soil acidity is a major factor limiting crop yield in vast areas of the world. Several authors have published evidence on the extent of acidity on natural forest, areas under cultivation and grassland vegetation. Sumner *et al.*, (2003) estimated that the total area of top soils affected by acidity throughout the world vary from 3.777 x 109 to 3.950 x 10^9 ha, representing approximately 30% of the ice-free land area of the world. The total area affected by subsoil acidity was estimated at 2.918 x 10^9 ha (Eswaran, *et al.*, 1997), meaning that approximately 75% of the acid soils of the world suffer from subsoil limitations due to acidity.

Acidity can be classified as active (in which only H^+ is referred to in the soil solution) or exchangeable acidity which includes Al^{3+}. Measurement of acidity in water and soil is commonly achieved from pH scale. The term pH stands for the potential (p) of the hydrogen ion (H^+) in water. It is measured based on a scale from 0 to 14.The value of pH varies with depth and from one spot in the field to another. Soils may have different pH value due to factors like climate, living organism, parent material, topography and time. Sumner, *et al.* (2003) have categorised acid soils into two classes, the naturally occurring acid soils and the anthropogenically derived acid soils.The anthropogenic acid soils exist from either acid deposition, intensively managed row-crop agriculture or from pasture systems (Sverdrup *et al.*, 1994); (Bouman *et al.*, 1995) and (Johnston *et al.*, 1986. The naturally occurring acid soils are those formed due to intensive weathering, soil form from parent materials poor in basic cations and acid sulphate soils (Benham, 1997); Uexkull and Mutert, (1995).

According to Sehgal *et al.* (1998) red and laterite soils are acidic and have low CEC and low to moderate base saturation. On acid soils, iron toxicity is one of the most important constraints to rice production, and together with Zn deficiency, which is the most commonly observed micronutrient disorder in wetland rice (Neue et al., 1998).When a soil is submerged, air is excluded and the soil quickly becomes anoxic and reduced. This phenomenon changes physical, biological, and chemical properties of soil (Ponnamperuma, 1972; Kirk, 2004). Soil pH is probably the most important chemical soil parameter (Bloom, 2000). It reflects the overall chemical status of the soil and influences a whole range of chemical and biological processes occurring in the soil. Because of its implications in most chemical reactions in the soil, knowing the actual value of soil pH and monitoring its changes is critical for understanding the physicochemical functioning of the soil (Jaillard *et al.*, 2003). After soil water logging, the pH tends to converge to neutrality irrespective of initial pH, whether acidic or alkaline (Ponnamperuma, 1972; Kirk, 2004). An equilibrium pH in the range 6.5 to 7.5 is usually attained (Ponnamperuma, 1972). The increase in pH of acidic soils is mainly determined by reduction of Fe and Mn oxides, which consume H^+ ions. Rice grown in acidic soils of $pH<4.0$ commonly encounter relatively severe mineral stresses. The H^+ associated with soil acidity has indirect effects on mineral elements in low pH soils so that deficiencies of P, Ca, Mg, K, and Zn and toxicities of Al and Mn commonly appear (Clark et al., 1999). Of the deficiencies/toxicities that plants may encounter when grown in acidic soil, Al toxicity is considered to be the major disorder (Foy, 1992). Aluminium is highly soluble at low pH and is toxic to plants at relatively low concentrations. It also interacts with other mineral nutrients essential to plant growth, especially P, Ca, and Mg, so that these essential nutrients often become more limiting. Not only is excess Al damaging to root growth and development (Foy, 1992), but Al as well as Fe oxides so prevalent in acidic soils (Manning and Goldberg, 1996) adsorb P and make it unavailable to plants. Poor fertility of acid soils is due to a combination of mineral toxicities (aluminum and manganese) and deficiencies (phosphorus, calcium, magnesium, and molybdenum). However, Al toxicity is the single most important factor, being a major constraint for crop production on 67% of the total acid soil area (Eswaran et al., 1997).

2.4 Amelioration of lateritic soils

Acidity and Al toxicity in surface soil can be ameliorated through liming. A liming material is defined as a material whose Ca and Mg compounds are capable of neutralizing soil acidity (Barber and Adams, 1984). Liming is a dominant and effective practice to overcome constraints and improve crop production on acid soils. Lime is called the foundation of crop production or 'workhorse' in acid soils. Lime requirement for crops grown on acid soils is determined by the quality of liming material, status of soil fertility, crop species and cultivar within species, crop management practices, and economic considerations.

Several authors like Chang (1961), Attanandana and Vacharotayan (1986), Shamshuddin, *et al.* (1986) have mentioned about other products and by-products which may be used to decrease soil acidity such as pure $CaCO_3$, quick lime/ burned lime/ oxide lime, calcitic agricultural lime (CaCO3 + impurities), dolomitic agricultural lime, ground oyster shells, marl or selma chalk, hydrated lime /builders lime, basic slag, wood stove or fire place ashes, boiler wood ash, filter cake etc.

Ground lime or aglime, mostly in the form of $CaCO_3$ or $CaCO_3 + MgCO_3$, has been the traditional material for liming in acid soils. The fundamental reasons for using aglime are to increase soil pH (neutralize soil acidity), and add calcium and magnesium to the soil. However, it must be ground very finely since carbonates are not easily soluble in water. The quantity of lime applied depends upon type of soil, quality of liming material, crop species/cultivar, and cost.

The bulk of agricultural lime comes from ground limestone, and can be calcite ($CaCO_3$), dolomite ($CaCO_3$, $MgCO_3$), or a mixture of the two. Other materials are used to neutralize soil acidity, including marl, slag from iron and steel making, flue dust from cement plants, and refuse from sugar beet factories, paper mills, calcium carbide plants, rock wool plants, and water softening plants (Thomas and Hargrove, 1984). However, total use of these materials is relatively small, and they are generally applied only in areas close to their source. Soil pH, base saturation, and aluminum saturation are important acidity indices which are used as a basis for determination of liming rates for reducing plant constraints on acid soils (Fageria and Baligar, 2008). Rice favours a pH between 4 to 8 with an optimum value of around 6.

2.4.1 Interactions of nutrients with lime

Leaching, lime and basic slag treatments led to a decrease in Fe, Mn, and Zn concentrations in the plants and soil solutions (leachates). The addition of lime, basic slag, or MnO_2 exerted a significant effect on the decrease of the S content, increase of the soil solution pH, and optimization of some element concentrations in the plants and soil solutions (Khan *et al.*, 1994). Lime enhanced the extractability of Mn and Fe. Differences of their levels between control and dolomite amended plots were greater as the flooding period increased. The reduction in leaching and runoff loss of P by the amendment $Ca(OH)_2$, was mainly effected by the conversion of water soluble P into calcium bound P forms. Lime application rate at 50 mg kg^{-1} gave soil pH values favourable for crop production and this also permitted the highest release of available P (Anetor and Akinrinde 2006). Liming improved soil pH and other nutrient conditions. Conclusively, $Ca(OH)_2$ could be a good material to restore nutrient balance in rice soil(Lee *et al.*, 2011). Effectiveness of the basic slag improved when it was applied in combination with FYM or poultry manure. Basic slag can, therefore, be advocated for use in the acidic red and lateritic soils for economically improving their productivity (Bhat *et al.*, 2010).

Liming the soil decreased available Fe and Mn and increased pH to the greatest extent, and reduced iron toxicity (Patra and Mohanty, 1994). Iron toxicity is a syndrome of disorder associated with large concentrations of reduced iron (Fe^{2+}) in the soil solution. It only occurs in flooded soils and hence affects primarily the production of lowland rice. The typical visual symptom associated with these processes is the 'bronzing' of the rice leaves and substantial associated yield losses (Becker and Asch, 2005). The content of Ca, Mg, and Mn in flag leaves and rice yield increased with limestone surface application (Soratto *et al.*, 2007). The grain yield of paddy was found to be the highest in the plots which received lime @ 2 t ha^{-1} with leaching and the next best was gypsum @ 2 t ha^{-1} with leaching (Previna and Basker, 2012). The increase in soil pH due to lime application in the Zn-treated soil samples resulted in the redistribution of Zn into sparingly available forms (Nascimento *et al.*, 2007). As $CaCO_3$ content increases the solubility and availability of Mn decreases (Papadopoulos *et al.*, 2009). Liming decreases boron availability in soils because higher pH levels favour the $B(OH)_4$ form. In this form, clay minerals as well as Al and Fe oxides adsorb B (Dunn *et al.*, 2005).

2.5 Mineral nutrition

2.5.1 Nitrogen

Nitrogen is found in plants (and animals) as a part of protein. N is an essential constituent of amino acids, nucleic acids, nucleotides and chlorophyll and is closely related to photosynthetic rate (Coumaravel *et al.*, 2004). Nitrogen is one of the most important nutrients for plant growth and a major factor that limits agricultural yield (Xia *et al.*, 2011). Optimum nitrogen fertilization plays a vital role in growth and development of rice plants. Its growth and yield seriously hampered at lower nitrogen supply. Prasad (2007) reported that the total N content in Indian soils (0-15 cm layer) varies from 0.02-0.1%. Nitrogen has a positive influence on the production of effective tillers per plant yield and yield attributes (Isalam *et al.*,2009). Nitrogen contributes to carbohydrate accumulation in culm and leaf sheaths during the pre-heading stage and in the grain during the ripening stage of rice (Swin and Sandip, 2010). The optimum ranges of N content in rice at tillering, flowering and maturity is 2.9-4.2, 2.2-3.0 and 0.6-0.8% respectively. The critical level of deficiency of nitrogen at tillering stage is <2.5%. The deficiency of nitrogen led to yellowing of older leaves and stunted growth. It also resulted in reduced tillering and grain yield (Dobermann and Fairhurst, 2000).

Aulakh and Malhi (2005) repoted that N interacts positively with most of the plant nutrients. Nitrogen promoted phosphorus uptake by increasing top and root growth, altering plant metabolism and increasing the solubility and availability of P (Tisdale *et al.*, 1993). Dwivedi *et al.* (2003) reported that the combined application of N and P increased NUE of rice from 22.4 kg grain to 25.5 kg grain. Ca and Mg saturation decreased with increasing N rates by ammonium sulphate and urea fertilizers (Fageria *et al.*, 2010).

Babu and Reddy (2000) reported a higher grain yield of 3826 kg ha^{-1} with the application of 5 t FYM/ha + 50 kg N ha^{-1}. Masthanareddy *et al.* (2009) reported that the application of 200 or 250 kg N ha^{-1} significantly increased N content, N uptake and grain yield. Aulakh *et al.* (2010) reported that flooded rice responded to N rates up to 120 kg N ha^{-1} on sandy loam soils in India. Application of 150 kg N ha^{-1} in four splits - 1/6 at 15 DAS, 1/3 at tillering, 1/3 at PI, 1/6 at flowering recorded higher tiller (361 m^{-2}), plant height (77 cm), dry matter at flowering (5.2 t ha^{-1}) and grain yield (2827 kg ha^{-1}) over four equal splits where the grain yield was 2673 kg ha^{-1}. Yadav *et al.* (2009) suggested that application of N in three splits – ½ basal, ¼ at tillering and ¼ at panicle initiation produced significantly higher yield, yield attributing traits and protein production.

2.5.2 Phosphorous

Phosphorus is the second major plant nutrient. It is a component of the complex nucleic acid structure of plants, which regulates protein synthesis. It is, therefore, important in cell division and development of new tissue. It is also an important structural component of many cell inclusions and enzymes and also stimulates root growth and associated with early maturity of crops (Khan *et al.*, 2007). It is also associated with complex energy transformations in the plant. P is mobile within the plants and promotes tillering, root development, early flowering and ripening. Nucleic acids can actually promote heading in rice as they control vegetative growth through protein biosynthesis and reproductive growth through flower initiation (Fujiwara, 1964). Nitrogen has a stimulating effect on phosphorus uptake by plants. Nitrogen, especially NH_4^+, can stimulate the uptake of phosphorus in plants due to the stimulated uptake of phosphorus through plasma membrane H^+ ATPase (Houqing *et al.*, 2012).

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

Application of P fertilizer is one of the most important factor for higher crop yields; the phosphorus accumulation in cultivated soils is a concern for non-point environmental pollution and for efficiency of phosphorus resources because of excessive phosphorus input (Li *et al.*, 2010). But in many areas phosphorus deficit is a most important restrictive factor in plant growth and recognition of mechanisms that increase plant phosphorus use efficiency is important (Sisie and Mirshekari, 2011). Rice removes about 2 to 3 kg P for 1 t of grain produced. Although the rice requirement for P is much less than that for N, the continuous removal of P exploited the soil P reserve if the soil is not replenished through fertilizer or manure application. Chemical P fertilizer is a costly agricultural input for rice framers of the developing world (Saleqe *et al.*, 2004). Raising rice yields beyond the present level of 5.5 t/ha will require in-crop application (Singh *et al.*, 2002). Application rates close to or slightly above the amount of phosphate taken up by the crop appear to be sufficient even for high yields and continuous cultivation of rice. An analysis of 3.65 million soil samples from different states of India showed that 42% soil samples were low, 38% medium and 20 % high in available P. Thus nearly 80% of Indian soils are low to medium in available P and need adequate P fertilization (Tandon, 2004).

Saleque and Krik (1995) reported that rice plants growing in flooded soil were able to solubilize P and thereby increase their P uptake by including an acidification in rhizosphere. About 2.5–3.5 kg P is required to produce one ton of rice and it depletes about 7–8 kg P ha^{-1} when P fertilizer is not used (Saleque *et al.*, 2006). The optimum ranges of P content in rice at tillering, flowering and maturity is 0.20-0.40, 0.20-0.30 and 0.10-0.15% respectively. P fertilization increased grain yield significantly up to 60 kg P_2O_5 ha^{-1} (Cong *et al.*, 2011). The critical level of deficiency of P at tillering stage is <0.10 %. P deficient plants are stunted with reduced tillering. It also leads to reduced number of leaves, panicles and grains per panicle (Dobermann and Fairhurst, 2000).

2.5.3 Potassium

Among the major plant nutrients, potassium is the most abundant plant nutrient in soils. It constitutes an average of 1.9% of the earth's crust. Potassium is known to exist in structural (mineral) form to the extent of 5000-25,000 mg kg^{-1}, non-exchangeable (fixed or difficultly available) 50-750 mg kg^{-1}, exchangeable 40- 600 mg kg^{-1} and water-soluble forms 1-10 mg kg^{-1} (Ravichandran and Sriramachandrasekharan, 2011). Havlin *et al.* (2006) reported that 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 growth of meristamatic tissues and adjustment of stomatal movement and water relation.

The optimum ranges of K content in rice at tillering, flowering and maturity is 1.8-2.6, 1.4- 2.0 and 1.5- 2.0% respectively. The critical level of deficiency of K at tillering stage is <0.15 %. To produce the maximum number of spikelets per panicle, the K content of mature leaves should be > 2% at booting stage. The critical level for K in straw at harvest is between 1.0% and 1.5% but, yields > 7 t ha^{-1} require > 1.2% K in the straw at harvest and > 1.2% K in the flag leaf at flowering (Ravichandran and Sriramachandrasekharan, 2011).

Rao *et al.* (2010) observed that 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). The nutrient uptake, grain and straw yields increased with increased levels of N and K (Arivazhagan and Ravichandran, 2005). The addition of 50 kg K_2O ha^{-1} recorded highest LAI, chlorophyll content, grain (5621 kg ha^{-1}) and straw yield (9077 kg ha^{-1}) in rabi season (Muthukumararaja *et al.*, 2009). 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).

Potassium has been found to influence the use efficiency of other nutrients (John *et al.*, 2004). The ill effects of Fe can be reduced by K fertilization. Higher level of K is reported to decrease Fe uptake and helps to maintain favourable K/Fe ratio in plants. Higher rate of K application increased efficiency of N, P and Zn in laterite soils of Kerala (Bridgit, 1999: Mathew, 2002 and Deepa, 2002).

2.5.4 Calcium

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^+. Ca makes upto about 3.64 % of earth's crust (Mengel and Kirkby, 1987). Large amount of Ca is present in soil as exchangeable Ca on silicate minerals in soils having pH 6 or above.

Exchangeable Ca in soils can range from < 25mg kg^{-1} to more than 5000 mg kg^{-1} and that in soil solution may range from 68-778 mg kg^{-1} (Prasad and Power, 1997). The concentration of Ca in soil solution tends to increase after flooding because of the displacement of exchangeable Ca^{+2} by Fe^{+2} (Dobermann and Fairhurst, 2000). Verma and Tripati (1987) reported that the application of lime under flooded condition increased the rice yield, Mn content and decreased the Fe content.

Ca in the exchange complex in acid soils is replaced by H^+ ions. Depletion of exchangeable Ca occurs due to heavy leaching and run off. Weathering or continuous application of acid forming fertilizers also lead to the depletion of exchangeable Ca from soil. Soil acidity affects the availability of not only Ca but almost all plant nutrients and therefore the effects of Ca deficiency due to acidity are compounded with the deficiency and toxicity of other nutrients (Havlin *et al.*, 2006). Also as the soil acidity increases the proportion of exchangeable Al increases and Al toxicity is probably the major limiting factor to plant growth and crop production in strongly acidic soils (Foy, 1992). Liming of acidic red and laterite 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). Calcium is absorbed as Ca^{+2} from the soil. Percentage content of calcium in rice ranges from 0.2 – 1.0% (Samui and Mandal, 2003). The Critical level of Ca at tillering stage of rice is <0.15% (Dobermann and Fairhurst, 2000).

Ca is necessary for cell division and cell elongation and is present as calcium pectate in middle lamella of cell wall which maintain cell wall integrity. It is an enzyme activator and is required for osmoregulation. Ca is an immobile nutrient, and hence deficiency symptoms first appear in young leaves and parts of the plants. The first symptom of Ca deficiency in rice is the bleaching, rolling and curling of tip of the youngest leaves. Necrotic tissues may develop along the lateral margin of the leaves, and old leaves eventually turn brown and die. Calcium deficiency also result in impaired root function, and may predispose rice plant to Fe toxicity (Jakobsen, 1993).

Chang and Sung (2004) observed 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. Increased grain yield, decreased straw weight and markedly increased grain: straw ratio by the application of Ca (Krasaesindhu and Sims, 1972).

2.5.5 Magnesium

The Mg content in earth's crust is about 2.07 % (Mengel and Kirkby, 1987). The exchangeable form of Mg is about 4-20% 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 <1.0 c mol (p^+) kg^{-1}. A Ca: Mg ratio in soil solution greater than 7:1 is considered undesirable (Dobermann and Fairhurst, 2000).

Lynch and 'Clair (2004) reported that high soil pH, base imbalances, aluminum and manganese toxicity decreases the availability of Mg. The introduction of high yielding varieties and the increased use of nitrogen, phosphorus and potassium fertilizers also induced magnesium deficiency (Ding *et al.*, 2006). Mg is fairly mobile in plants and highly reactive. Deficiency of magnesium in rice is a widespread problem, affecting productivity and quality of rice (Hermans *et al.*, 2004).

The first symptom of Mg deficiency in rice is the development of orange- yellow interveinal chlorosis on older leaves. Later on chlorosis leads to yellowing and finally necrosis in older leaves. Mg deficient leaves are wavy and droopy due to an expansion in angle between leaf sheath and leaf blade. Deficiency also causes reduced number of spikelets, thousand grain weight, grain yield and quality (Dobermann and Fairhurst, 2000). 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 (Ding *et al.*, 2006).

Magnesium is absorbed as Mg^{+2} by plants. The Mg level in rice plants was in the order leaf > stem > panicle > root. Mg uptake is peak at tillering and panicle development stages (Yan and Chu, 1996). Mg content in the above ground portion of most grain crops is 0.1- 0.4%. Mg uptake in cereal is about 3 kg Mg^{-1} of grain (Shrotriya, 2007). A rice crop yielding 6 Mg ha^{-1} takes up approximately 21 kg ha^{-1} of Mg, of which 60% remains in straw at maturity (Dobermann and Fairhurst, 2000). The critical and adequate values of Mg for a 100 days old rice plant is 0.12-0.17% and 0.17-0.30% respectively (Fageria, 1976).

Magnesium is required for grana stacking and formation of light-harvesting chlorophyll a/b complexes (Obatolu, 1999). Depending upon the nutritional status, a range of 6- 35% of the total Mg is bound to chlorophyll (Scott and Robson, 1990). It is involved in CO_2 assimilation and protein synthesis. It also regulates cellular pH and cation- anion balance. Mg is essential for the functioning of many enzymes, including ribonucleic acid (RNA) polymerases, adenosine triphosphate- (ATP)- ases, protein kinases, phosphatases, glutathione synthase, and carboxylases such as Rubisco (Shaul, 2002).

Magnesium fertilization significantly increases fertilizer N uptake and recovery % of fertilizer N (Choudhury and Khanif, 2001). Singh and Singh (2005) reported that the application of $MgSO_4$ @ 10 kg ha^{-1} promoted the absorption and translocation of Zn, Ca, P, K and that of Mg itself whereas Na accumulation was inhibited. Choudhury and Khanif (2002) reported that grain yield of rice increased significantly due to the application of 20 kg ha^{-1}. Mg application signifcantly increased total Mg uptake both at10 and 20 kg ha^{-1}.

For Mg deficient soils, application of 15 kg Mg ha^{-1} as calcium magnesium phosphate or magnesium sulphate was recommended (Yan and Chu, 1996). The application of Ca and Mg alone or together had a non-significant effect on grain and straw yields. The harvest index of rice decreased due to the applications of Mg as magnesium carbonate at 50 kg ha^{-1}. Application of P alone or in combination with Ca and Mg significantly increased the grain and straw yields. The application of Mg generally improved the plant status with regard to N, Ca, Mg and Fe (Sahrawat *et al.*, 1999).

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 (Padmaja and Verghese, 1966). Mg is involved in the protection of rice plants against grain discolouration and its application increased grain yield by an average of 34% (Yamauchi and Winslow, 1989). Kobayashi *et al.* (2005) found that in rice, the excess Mg treatment increased the Mg content of shoots and roots, and the potassium and chloride contents of roots, but slightly decreased the Ca and K contents of shoots.

2.5.6 Sulphur

Sulphur is regarded as the 4th major nutrient next to N, P and K. Sulphur nutrition to crops has not been fully realized during the past mainly because S deficiency was not a serious problem (Pandian, 2011). Katyal *et al.* (1997) reported that adsorption of sulphate due to anion adsorption is a typical phenomenon of acid soils which significantly influences S status of soil. The available sulphur status of Kerala soil is sub optimal due to its geographical position in the humid tropical tract. The losses due to leaching and erosion might be serious in the high rainfall area. Sulphur deficient soils are found in all the districts of Kerala ranging from 20-55%

(Tandon, 1991). Sheela *et al.* (2006) reported that the three levels of sulphur application (15,30,45 kg ha^{-1}) were on par and superior to control, which indicated that application of S at the rate of 15 kg ha^{-1} is sufficient for realizing higher yield in rice.

The major sources of S in soils are sulphides, sulphates and organic combinations with C and N. Sulphur in soils can be broadly grouped in to four forms *viz.*, total S, organic S, non- sulphate S and available S (Katyal *et al.*, 1997). Water soluble, adsorbed on soil exchange complex and organic matter held S occur in a state of dynamic equilibrium. These together constitute the labile pool from which plants absorbs S for their growth and development. In submerged soils sulphide is the dominant form of S (Katyal and Rattan, 2003). The mean S content in lateritic soil is 350 mg kg^{-1} (Ankineedu *et al.*, 1985). Samui and Mandal (2003) found that critical level of deficiency of S in rice soil is < 9 mg kg^{-1} of soil.

Sulphur is required for the synthesis of amino acids such as cysteine, cystine and methionine, promotes activity of proteolytic enzymes. It is responsible for the formation of chlorophyll, biotine and thiamine and for the metabolism of carbohydrates, proteins and fats (Jeena *et al.*, 2013). Critical level of deficiency of S in rice plant at tillering stage is < 0.16% (Tandon, 1991). The S removal by rice varies from 7-35 kg ha^{-1} (Sarkar *et al.*, 2000). Sulphur is less mobile in plant and therefore deficiency symptom is mainly observed in younger leaves. In rice, the deficiency causes interveinal yellowing of younger leaves, while older leaves remain in green (Tiwari and Gupta, 2006). The other symptoms include reduced plant height, tiller and spikelet per panicle.

Singh *et al.* (1993) reported that the application of S upto 60 kg ha^{-1} increased the growth attributes and the yield of rice. In field condition, sulphur is found to be absorbed by the rice crop in amounts equal to phosphorus and is considered essential for the attainment of 90% of optimum yield (Sheela *et al.*, 2006). The application of 45 kg S ha^{-1} significantly increased the grain and straw yield of rice to the tune of

4490 and 6490 kg ha^{-1} respectively in laterite soil, while control treatment recorded 3820 and 5420 kg ha^{-1} respectively (John *et al.*, 2004). It also improves the sulphur uptake by crop and highest crop uptake was noticed at 45 kg S ha^{-1} (15.92 kg ha^{-1}) compared to control (7.58 kg ha^{-1}). The residual effect increases with increasing level of sulphur (John *et al.*, 2006). Rathish (2010) reported that combined application of nitrogen and sulphur increase the grain yield of rice. Maximum yield is obtained by the combined application of nitrogen at 90 kg and sulphur at 30 kg ha^{-1}(6557 kg ha^{-1}). Chandrapala *et al.* (2010) reported that the application of S along with NPK significantly increased the uptake of S by rice (7.23 kg ha^{-1}) compared to NPK alone (5.11 kg ha^{-1}). It also increased the available S status of soil (19.29 kg ha^{-1}) compared to NPK alone (9.52 kg ha^{-1}).

2.5.7 Iron

Hassan (1977) has reported that iron content range in laterite soils are in the order of 4 to 7 per cent. Singh (2009) reported that iron content in Indian soils is high, ranging from 4000-273000 mg kg^{-1} and that of available iron 0.36- 174 mg kg^{-1} soil. Iron containing primary minerals are olivine, augite, hematite *etc.* (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 reduced rice yields in wetlands by 12–100% depending on the intensity of toxicity and tolerance of the rice cultivar. Tanaka *et al.* (1968) reported that excess Fe in the soil solution readily entered the shoot of rice plant causing Fe toxicity. It is mainly experienced in rice which is grown on acid sulfate soils, ultisols and sandy soils with a low CEC, moderate to high acidity, active Fe, and low to moderately high in organic matter (Benckiser *et al.*, 1984). The iron toxicity inducing factors are 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 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, 1966).

Santos and Oliveira (2007) reported that flooding of red and laterite soils cause reduction of Fe^{3+} to Fe^{2+} and ferrous form is maintained for long period of time . It creates a high concentration of plant available Fe^{2+} in soil solution and leads to iron toxicity (Singh *et al.*, 2003; Fageria *et al.*, 2011). Flooding increases the availability of Fe from 0.1 to 50-100 mg kg^{-1} soil (Ponnamperuma, 1978). Iron is fairly mobile in soil profile. The critical level of toxicity of DTPA extractable Fe in rice is >300 mg kg^{-1} (Samui and Mandal, 2003).

Iron toxicity in rice can be expressed in two ways, ie. direct and indirect toxicity (Fageria *et al.*, 2008). The toxicity symptom in the plant caused by high concentration of Fe without any apparent deficiency of other essential nutrients known as direct or true Fe toxicity. The toxicity of Fe associated with inhibition of uptake and utilization of essential nutrients like P, K, Ca, Mg, and Zn by rice leading to their deficiency known as indirect or pseudo Fe toxicity (Sahrawat, 2004, Tanaka *et al.*, 1966). There is an antagonistic interaction between iron and manganese in rice plants (Olsen and Watanabe, 1979). Panda *et al.* (2012) reported that when the level of Fe increases concentration of Cu and Mn decreases.

Critical level of toxicity of Fe in rice at tillering stage is 300-500 mg kg^{-1} (Samui and Mandal, 2003). Fe is not very mobile in plants. Fe toxicity symptoms are generally manifested as tiny brown spots starting from the tips and spreading towards the bases of the lower leaves. Excessive Fe uptake results in increased polyphenol oxidase activity, leading to the production of oxidized polyphenols, which cause leaf bronzing (Dobermann and Fairhurst, 2000). With increased Fe toxicity, the entire leaf looks purplish brown followed by drying of the leaves. The roots of the plants become scanty, coarse, short and blunted, and dark brown in colour

(Sahrawat, 2004). The other effects include stunted plant growth, decreased tillering and high spikelet sterility (Mohapatra, 2011).

Cultural practices such as planting date, ridge planting, water management, and pre submergence of soil can be manipulated to reduce Fe toxicity in rice (Abu *et al.*, 1989). Effective measures to ameliorate Fe^{2+} toxicity include periodic surface drainage to oxidize reduced Fe^{2+}, liming of acid soils, use of adequate amounts of essential nutrients and planting of iron toxicity tolerent cultivars or genotypes. The 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 (Panda *et al.*, 2012).

2.5.8 Manganese

Mn toxicity is an important factor limiting plant growth in acid and poorly drained soil (Horst, 1988). Singh *et al.*, (1995) reported that Mn in Indian soil is varying from 37-11500 mg kg^{-1} and available status is 0.6-164 mg kg^{-1} to support optimum crop growth. The critical limit of deficiency and toxicity of Mn in rice plants are 20 and 2500 ppm, respectively (De Datta, 1981). The critical level for the occurance of Mn toxicity in rice at tillering stage is >800-2500 mg kg^{-1}. Mn toxicity rarely occurs in low land rice because rice is comparatively tolerant to large Mn concentrations (Dobermann and Fairhurst, 2000).

Rice normally accumulates more manganese under waterlogged than under well-drained conditions. Manganese toxicity apparently has seldom been observed in flooded rice for the following reasons: (i) although submergence of an acid soil causes an initial increase in available Mn due to reduction of Mn^{4+} to Mn^{2+}, the subsequent increase in pH (6.5–7.0) causes the concentration of Mn to decrease (ii) oxidation in the rhizosphere of rice roots may decrease the concentrations of Mn in the soil solution adjacent to the roots or (iii) the rice plant is able to tolerate a high concentration of Mn in its tissues (Ponnamperuma, 1965).

Excess Mn in the growth medium can interfere with the absorption, translocation, and utilization of other mineral elements such as Ca, Mg, Fe, and P. The toxicity lead to the development of yellowish brown spots in interveinal area and leaf sheaths, drying of leaf, stunting, reduced tillering, root browning and sterility resulting in reduced grain yield (Dobermann and Fairhurst, 2000).

High Mn in the nutrient solution reduced shoot and root dry matter. Poor shoot growth with high Mn may be due to the combined effects of Mn toxicity and Mn-induced Fe deficiency. Brown spots on leaves decrease the area of active photosynthesis, thereby reducing dry matter accumulation (Alam *et al.*, 2003).

2.5.9 Zinc

Zn deficiency is a serious nutritional problem limiting rice quality and productivity in most of the area (Pirzadeh *et al.*, 2010). Zinc deficiency is seen in rice growing in waterlogged condition due to precipitation and complexation of Zn with soil constituents (Alloway, 2008). Under waterlogged conditions, strongly reducing conditions can also result in a rise in pH, high concentrations of bicarbonate ions and the formation of insoluble zinc sulphide (Kirk, 2004). High amounts of organic matter can also contribute to the low availability of Zn through complexation (Rose *et al.*, 2012).

Soil chemical properties *i.e.* pH, redox potential, organic matter, pedogenic oxide and soil sulphur contents have strong influence on the adsorption-desorption reactions of Zn and play a critical role in regulating Zn solubility. The forms of Zn include soluble Zn present in soil solution (water soluble), adsorbed on exchange sites (exchangeable), associated with organic matter, co-precipitated as secondary minerals or associated with sesquioxides and as structural part of primary minerals (Alloway, 2003; Rehman *et al.*, 2012).

The critical level in soil for occurrence of Zn deficiency is 2 mg kg^{-1} of 0.1 N HCl extractable Zn. The critical level for deficiency of Zn is <20 mg kg^{-1} in younger leaves of rice at tillering stage (Dobermann and Fairhurst, 2000). Deficiency of Zn may either be primary due to low total content of Zn or secondary caused by soil factors reducing its availability to plants (Patel, 2011).

In rice, visual symptoms of zinc deficiency appear about 2-3 weeks after transplanting. Reddish brown specks are formed on the margins of fully grown third or fourth leaf from the top of the plants. These specks enlarge, coalesce and become necrotic. The deficient plant develop a rusty appearance known as Khaira disease and remain dwarf and less vigorous (Ponnusamy, 2006). Zinc deficiency not only reduces yield, but also delays crop maturity. During flooded condition, rice plant is unable to support root system respiration due to zinc deficiency (Slanton *et al.*, 2001).

2.5.10 Boron

Boron is a nonmetal micronutrient. It is amongst the important micronutrients required for rice from start till physiological maturity. Being mobile in soils, it can be leached down the soil profile with excess moisture. The range of B deficiency and toxicity is narrow. Deficiency occurs at <0.5 mg kg^{-1} hot water soluble B while toxicity could occur at >5.0 mg kg^{-1} (Rashid *et al.*, 2004). Critical level of deficiency of B in rice at tillering to panicle initiation is <5 mg kg^{-1} (Dobermann and Fairhurst, 2000). Debnath and Ghosh, (2012) reported that the critical limit of B in third leaf of rice plant is 12 mg kg^{-1}.

Rice, 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 become limiting and leads to reduced productivity and poor rice yields (Rao *et al.*, 2013).

The main functions of B in plant relate to sugar transport, flower production, retention, pollen tube elongation and germination, 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).

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). Soil application of boron leads to fixation and unavailability (Rao *et al.*, 2013).

Boron is immobile in plant. Deficiency symptoms of B in rice begin with a whitish discoloration and twisting of new leaves. 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).

General soil application rate of B is 1–1.5 kg B ha^{-1} as borax.B application at very low rate substantially improved seedling emergence, tillering, chlorophyll, water relations and yield related traits resulting in better yield and grain B contents. 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 sterility. The dry matter yield decreases 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).

2.5.11Copper

Copper is an essential micronutrient for plant growth and various biochemical processes. Slightly higher concentration of Cu from the optimal level induces toxicity to the plant. Copper is more strongly bound by clays and humus than other cations, and high aluminum content in soil, as low as 0.1 mg kg^{-1} markedly reduces total copper uptake by plants. The acidity of the soil has no effect on copper absorption by plants (Herawati *et al.*, 1998).

A gradual decrease in shoot and root elongation was observed with the increase in Cu concentration from 10 to 100 μM (Thounaojam *et al.*, 2012). Critical level for deficiency of Cu at tillering stage in rice is <5 mg kg^{-1}. The critical soil level for the occurance of Cu deficiency is 0.1 mg 0.05 N HCl extracted Cu kg^{-1} (Dobermann and Fairhurst, 2000).

2.5.12 Aluminium

Poor crop growth in acid soils was due to Al saturation of the soils and that pH had no effect in plant growth except at values below 4.2 (Black, 1973). Cate and Sukhi (1964) found that young seedlings of rice suffered from 0.5 to 2 ppm dissolved Al while 3 to 4 weeks old plants suffered from >25 ppm Al. Thawornwong and Diest (1974) observed that the concentration of 2 ppm Al was lethal only to young rice seedlings and the plants which had passed seedlings stage were not affected.

Amma *et al.* (1979) found that 1N KCl exchangeable Al in rice soils of Kerala ranged from 85 to 3700 ppm and water soluble Al from 1 to 16 ppm. Ota (1968) found that poor development of lateral roots and root hairs and the development of lion tail roots are often observed in plants grown under iron toxic conditions. He also noted that bronzing of paddy was due to high Al content and Ca deficiency.

MATERIALS AND METHODS

III. MATERIALS AND METHODS

The present study entitled "Relative efficiency of ameliorants on rice productivity in lateritic soils of Kerala" was conducted at the rice field of Department of Agronomy, College of Horticulture, Vellanikkara during January to May, 2013. The materials used and the methodology adopted for the study are described in this chapter.

3.1 General details

3.1.1 Location

The experiment was conducted in the Kotteppadam rice fields attached to the Department of Agronomy, College of Horticulture, Vellanikkara. Geographically, the area is situated at 10° 31'N latitude and 76°13'E longitude at an altitude of 40.3 m above mean sea level.

3.1.2 Weather and Climate

The area enjoys tropical humid climate. The temperature of the district varies from 20°C to 40°C. The maximum and minimum temperature during the cropping period was 35.2°C and 21.3°C respectively. The mean monthly averages of important meteorological parameters observed during the experimental period are presented in Appendix I.

3.1.3 Soil

The texture of the soil was sandy loam. The physico - chemical characteristics of the soil of the experimental fields are presented in Table 3.1.

3.1.4 Crop and Variety

The rice variety Jyothi (PTB 39), a red kernelled, short duration variety was used for the experiment.

3.1.5 Cropping history of the experimental site

The experimental area belongs to a typical double cropped wet land. The field was under bulk cropping of rice in the previous season.

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

Properties	Value
a. Physical properties	
Particle size composition	
Sand (%)	68.83
Silt (%)	16.07
Clay (%)	14.90
Texture	Sandy loam
b. Chemical properties	
Soil reaction (pH)	5.31
Electrical conductivity (dS m^{-1})	0.08
Organic carbon (%)	0.98
Available N (kg ha^{-1})	299.00
Available P (kg ha^{-1})	34.66
Available K (kg ha^{-1})	105.06
Available Ca (mg kg^{-1})	599.00
Available Mg (mg kg^{-1})	23.00
Available S (mg kg^{-1})	7.08
Available Fe (mg kg^{-1})	1413.00
Available Mn (mg kg^{-1})	75.40
Available Zn (mg kg^{-1})	2.24
Available B (mg kg^{-1})	0.13
Available Cu (mg kg^{-1})	2.50
Available Al (mg kg^{-1})	2571.31

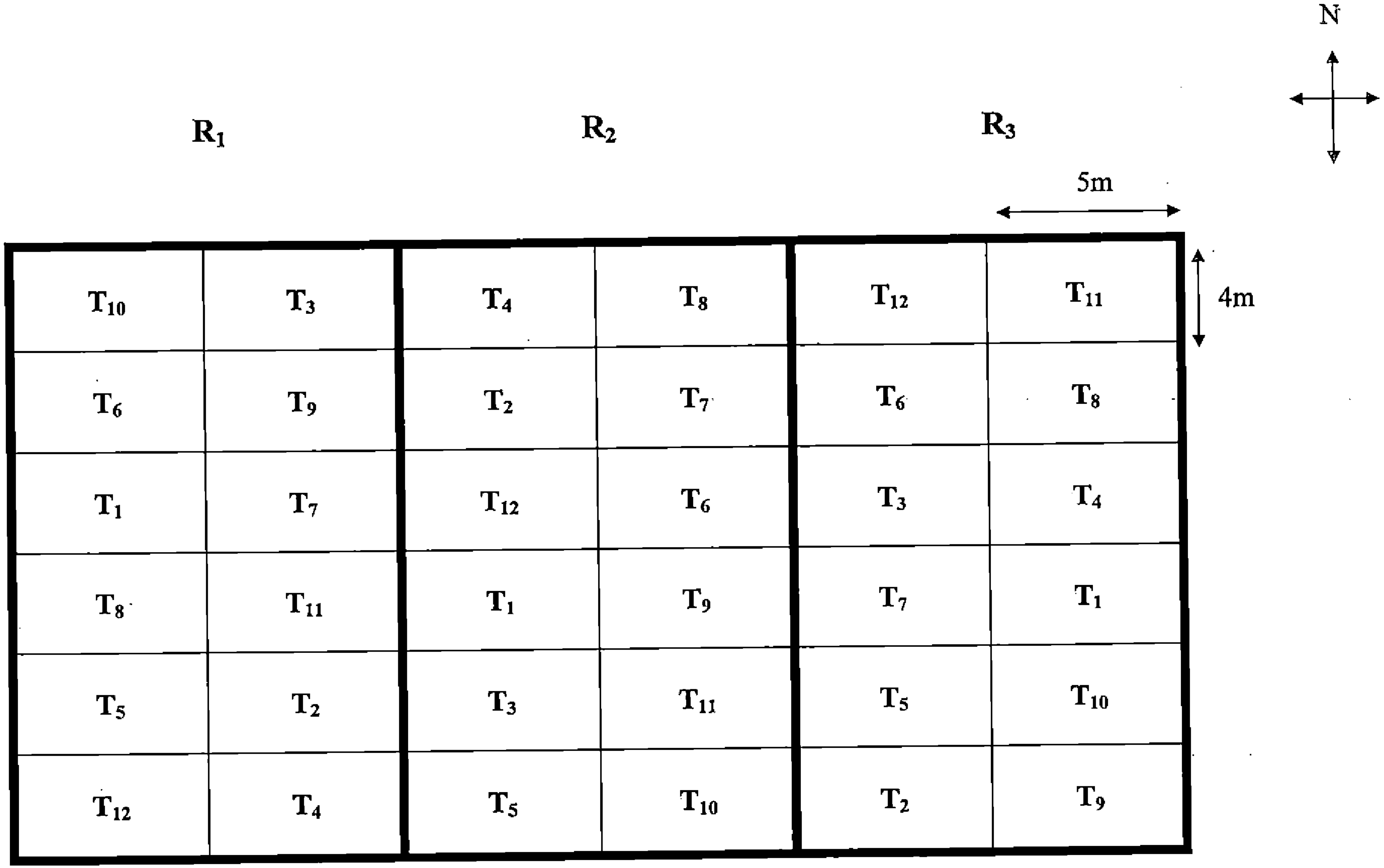
3.2 Experimental methods

A field experiment was conducted at the rice field of Department of Agronomy, College of Horticulture, Vellanikkara during January to May, 2013 to analyze the response of rice grown in laterite soil to various ameliorants. The experiment consisted of 12 treatments and 3 replications and laid out in Randomized Block Design. Transplanted Jyothi rice was grown at 15 cm x 10 cm in 5.0 m x 4.0 m plots. 1.0 m X 4.0 m along with 4.0 m side of the plots was demarcated as destructive sampling area. The layout of the experiment is depicted in Fig 3.1. The treatment details are given in the Table 3.2.

3.2.1 Treatment details

Table 3.2 Details of the treatments included in this experiment.

Treatments	
T_1	CaO 377 kg ha^{-1} + NPK
T_2	Dolomite 676 kg ha^{-1} + NPK
T_3	'Mangala setright' 774 kg ha^{-1} + NPK
T_4	CaO 377 kg ha^{-1}
T_5	Dolomite 676 kg ha^{-1}
T_6	'Mangala setright' 774 kg ha^{-1}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK
T_8	'Mangala setright' 375 kg ha^{-1} + NPK
T_9	'Mangala setright' 500 kg ha^{-1} + NPK
T_{10}	NPK only
T_{11}	FYM 5t ha^{-1} + CaO 377 kg ha^{-1} + NPK
T_{12}	Control



R_1		R_2		R_3	
T_{10}	T_3	T_4	T_8	T_{12}	T_{11}
T_6	T_9	T_2	T_7	T_6	T_8
T_1	T_7	T_{12}	T_6	T_3	T_4
T_8	T_{11}	T_1	T_9	T_7	T_1
T_5	T_2	T_3	T_{11}	T_5	T_{10}
T_{12}	T_4	T_5	T_{10}	T_2	T_9

Fig.3.1 **Lay out of the experimental plot**

T_1- CaO 377 Kg ha^{-1} + NPK , T_2 – Dolomite 676 Kg ha^{-1} + NPK, T_3 –'Mangala setright' 774 Kg ha^{-1} + NPK , T_4 – CaO 377 Kg ha^{-1}, T_5- Dolomite 676 Kg ha^{-1}, T_6- 'Mangala setright' 774 Kg ha^{-1}, T_7- 'Mangala setright' 250 Kg ha^{-1} + NPK, T_8- 'Mangala setright' 375 Kg ha^{-1} + NPK, T_9- 'Mangala setright' 500 Kg ha^{-1} + NPK, T_{10}- NPK only, T_{11}- FYM 5 t ha^{-1} + CaO 377 Kg ha $^{-1}$ + NPK, T_{12}- Control

For treatments T_1 to T_6 and T_{11} the quantity of ameliorants were fixed as the equivalent to 600 kg ha^{-1} of $CaCO_3$, which is the recommendation for liming acid soils in Kerala. The percentage $CaCO_3$ equivalence of CaO, dolomite, 'Mangala setright' were 159%, 88.5%, 77.5%, respectively.

3.2.1.1. Ameliorants and fertilizers

CaO, dolomite and 'Mangala setright' were used as the ameliorants. 'Mangala setright' is a commercial ameliorant produced by Mangalore Chemicals and Fertilizers Ltd. Urea, rajphos and muriate of potash were used as the sources for different nutrients. The nutrient content of the fertilizer or ameliorant is given in Table 3.3.

Table 3.3 Sources of nutrients

Nutrients	**Fertilizer/Ameliorant**	**Nutrient content (%)**
Nitrogen	Urea	46
Phosphorus	Rajphos	18
Potassium	Muriate of potash	60
Calcium	CaO	71.4
	Dolimite	21.7
	'Mangala setright'	20
Magnesium	Dolimite	13
	'Mangala setright'	6.8
Sulphur	'Mangala setright'	6.4

3.3 Crop culture

3.3.1 Land preparation, sowing and fertilizer application

The cultural operations were carried out as per the Package of Practices Recommendations of the Kerala Agricultural University (KAU, 2011). Seeds of the variety jyothi was obtained from Regional Agricultural Research Station, Pattambi.

Twenty three days old seedlings were transplanted from the nursery in to a well puddled and levelled field at a spacing of 15 cm x 10 cm @ 2-3 seedlings/ hill. Date of nursery sowing, transplanting and harvesting are given in table 3.4.

Table 3.4 Sowing and harvesting dates of crop

Particulars	**Date**
Sowing (nursery)	26- 01- 2013
Transplanting	18- 02- 2013
Harvesting	21- 05- 2013

Ameliorants were applied at 2/3 and 1/3 split doses, basal and before first top dressing of fertilizers, respectively. Supply of nutrients was based on the existing package of practices recommendations for rice (POP) ie. 90:45:45 kg N, P_2O_5, & K_2O kg ha^{-1}. Nitrogen and potassium were applied in three equal split doses, first as basal dressing, second at tillering stage and the third at panicle initiation stage. The full dose of phosphorus was applied as basal dressing.

3.3.2 After cultivation and plant protection

The fields were kept weed free by hand weeding. Plant protection measures were taken up against case worm (Quinalphos 25 EC 1000 ml per ha) and brown leaf spot (Carbendazim 50 WP 200 g per ha).

3.3.3 Harvesting

The crop was harvested at maturity. Plants in the two border rows on three sides of each plot and along the destructive sampling area were harvested first and removed. Net plots were harvested by cutting at the base. Threshing was done manually and weight of grain and straw were recorded. The weight of grain is expressed at 14 % 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 ten plants was measured in cm from ground level to the tip of the longest leaf at 30 DAT, 60 DAT and at harvest.

3.4.1.2 Tiller count and tiller decline

The number of tillers per hill was counted from ten different plants randomly selected and the mean was worked out at 30 DAT, 60 DAT and at harvest. Tiller decline from 60 DAT to harvest was calculated and expressed as a percentage.

3.4.1.3 Dry matter production

Ten plants in the destructive sampling area were taken for dry matter production. They were cleaned, air dried and then oven dried at 70^0C, till a constant weight is obtained and dry weight was recorded in kg ha^{-1} at 30 days, 60 days and at harvest.

3.4.1.4 Root weight and Root spread

Ten plants in destructive sampling area were used to determine the root weight and root spread. Root nail board technique was used to measure the root spread.

3.4.1.5 Leaf Area Index (LAI)

Leaf area index is the ratio of leaf area to ground area. Ten plants collected for drymatter production at 60 DAT from the destructive sampling area was used to determine the leaf area. Leaf area was found by using Leaf Area Meter (CI-202 Area Meter). The leaf samples are put back to determine the dry weight.

$$\text{Leaf area index (LAI)} = \frac{\text{Leaf area}}{\text{Land area}}$$

3.4.1.6 Number of panicles per hill

The number of panicles per hill was counted from ten different hills randomly selected and the mean was worked out.

3.4.1.7 Number of spikelets per panicle

The number of spikelets per panicle was counted from panicles collected from ten different hills randomly selected and mean was worked out.

3.4.1.8 Percentage of filled grain

Grains collected from randomly selected ten hills at harvest were separated in to filled grains and chaff. The percentage of filled grains was then worked out.

3.4.1.9 Thousand grain weight

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

3.4.1.10 Yield

The crop harvested from each net plot area were threshed, winnowed and weight of grain and straw was recorded separately and expressed in t ha^{-1} at 14 % moisture content.

3.4.1.11 Harvest index

Harvest index was calculated as the ratio of economical yield to biological yield.

3.4.2. Physiological characters

3.4.2.1 Chlorophyll content

The top most fully opened leaves were selected from four hills for chlorophyll estimation. For analysis, 0.2 gm of finely cut sample were taken in a beaker and 10 ml DMSO (Dimethyl Sulphoxide) solution was added. This was kept in dark place overnight and the next day, after filtering content is made up to 25 ml in a volumetric flask. The chlorophyll content was estimated colorimetrically (Yoshida *et al.*, 1972) in a spectronic- 20 spectrophotometer at two wave lengths ie, 663 and 645 nm. Using the equation given below, cholorophyll a, cholorophyll b and total cholorophyll contents were computed at 60 DAT.

Chlorophyll a = 12.7x OD @ 663nm- 2.69xOD@ 645nm xVxW/1000

Chlorophyll b = 22.9x OD @ 645nm- 4.63xOD@ 663nm xVxW/1000

Total chlorophyll = 8.02x OD @ 663nm + 20.2xOD@ 645nm xVxW/1000

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

3.4.3. Chemical analysis

3.4.3.1 Soil analysis

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

3.4.3.2 Plant analysis

For plant analysis six hills were selected at random from each plot. Plant samples were collected at 30 DAT, 60 DAT and at harvest. After cleaning the samples, leaf blades and sheath were separated, dried in a hot air oven at 70°C, powdered well and analyzed for different nutrients. The methods used for the analysis of different nutrients are given in Table 3.5.

3.4 Statistical analysis

Statistical packages such as MSTAT - C and 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 3.5 Methods used for soil and plant analysis

Particulars	Method
Soil	
Particle size analysis	International Pipette Method (Robinson, 1922)
Soil reaction (pH)	Soil water suspension of 1:2.5 and read in pH meter (Jackson,1958)
Electrical conductivity	Soil water suspension of 1:2.5 and read in pH meter (Jackson,1958)
Organic carbon	Walkley and Black method (Walkley and Black, 1934)
Available N	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P	Ascorbic acid reduced molybdophosphoric blue colour method (Bray and Kurtz, 1945; Wattanabe and Olsen, 1965)
Available K	Neutral normal ammonium acetate extract using flame photometer (Jackson, 1958)
Available Ca, Mg	Neutral normal ammonium acetate extract using flame photometer (Jackson, 1958)
Available S	$CaCl_2$ extract- turbidimetry method (Chesnin and Yien, 1951)
Available Fe, Mn, Zn, Cu & Al	HCl acid extract method using Atomic Absorption Spectrophotometer (Sims and Johnson, 1991)
Available B	Hot water extraction and Azomethine- H method using Spectrophotometer (Berger and Truog, 1945; Gupta, 1967)
Plant	
N	Microkjeldhal digestion and distillation method (Jackson, 1958)
P	Diacid digestion of leaf sample followed by filtration. Vandadomolybdate phosphoric yellow colour in nitric acid system (Piper, 1966)
K, Ca, Mg, Fe, Mn, Zn, B, Cu & Al	Diacid extract using Perkin-Elmer Atomic Absorption Spectrophotometer (Piper, 1966)
S	$CaCl_2$ extract- turbidimetry method (Chesnin and Yien, 1951)
B	By dry ashing (Gaines and Mitchell, 1979) and Azomethine-H method (Bingham, 1982)

Plate 1. Field preparation

Plate 2. Transplanting

Plate 1. Field preparation

Plate 2. Transplanting

Plate 3. Ameliorant application

Plate 4. General view of the experimental plot

RESULTS

IV. RESULTS

A field experiment to compare the relative efficiency of soil ameliorants in lateritic soils of Kerala was conducted at the rice field of Department of Agronomy, College of Horticulture, Vellanikkara during January to May, 2013. The data obtained from the experiment after statistical analysis are described here with appropriate tables.

4.1 Crop growth factors

4.1.1 Plant height

The effect of various treatments on height of plants at 30 and 60 DAT and at harvest are given in table 4.1. The height recorded by the treatments at 30 DAT ranged from 40.3 to 44.4 cm. 60 DAT and harvest it ranged from 64.1 and 78.7 cm, and from 81.3 to 100.4 cm, respectively. The treatment POPR for rice (T_{11}) produced tallest plants at harvest. Among the different ameliorants applied without the fertilizer component, CaO and 'Mangala setright' performed better than dolomite. However, when the ameliorants applied together with fertilizers the plant height was at par even though 'Mangala setright' produced the tallest plants.

4.1.2 Tiller count and Tiller decline

The data regarding the effect of treatments on tiller count of rice plants at various stages and tiller decline from 60 DAT to harvest are presented in table 4.2. The tiller count at 30 DAT was significantly higher for 'Mangala setright' applied @ 500 kg ha^{-1}(T_9). The tiller count at 60 DAT was significantly highest when 'Mangala setright' applied @ 774 kg ha^{-1} (T_3), however it was at par with the lower doses of the same and other ameliorants. The lowest was in control treatment (8.6). The tiller count increased from 30 to 60 DAT in all treatments except in control treatments. At harvest stage control treatment had the lowest productive tillers (6.7). In all other treatments the number of productive tillers ranged from 7.1 to 9.3.

The tiller decline from 60 DAT to harvest, were not statistically significantly influenced by the treatments. Percentage of tiller decline was high in treatment which received 'Mangala setright' 774 kg ha^{-1} + NPK and least was in control treatment.

Table 4.1 Effect of treatments on plant height (cm)

Treatments		**30DAT**	**60 DAT**	**Harvest**
T_1	CaO 377 kg ha^{-1} + NPK	*43.4^{abc}	73.23^{abcd}	86.7^{bcd}
T_2	Dolomite 676 kg ha^{-1} + NPK	42.5^{abc}	68.8^{abcd}	85.7^{bcd}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	44.2^{a}	76.9^{abc}	88.9^{bcd}
T_4	CaO 377 kg ha^{-1}	40.6^{bc}	72.5^{abcd}	84.8^{bcd}
T_5	Dolomite 676 kg ha^{-1}	40.4^{c}	64.1^{d}	82.3^{cd}
T_6	'Mangala setright' 774 kg ha^{-1}	41.2^{abc}	66.8^{bcd}	85.3^{bcd}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	42.7^{abc}	74.6^{abcd}	89.6^{bcd}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	43.7^{ab}	77.1^{ab}	91.5^{bc}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	41.8^{abc}	69.1^{abcd}	91.8^{b}
T_{10}	NPK only	44.3^{a}	78.7^{a}	85.9^{bcd}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	44.4^{a}	76.8^{abc}	100.4^{a}
T_{12}	Control	40.3^{c}	66.1^{cd}	81.3^{d}

* The values followed by same superscript do not differ significantly in DMRT

Table 4.2 Effect of treatments on tillers/hill and tiller decline

Treatments		**Tillers/hill**			**Tiller decline From 60 DAT-Harvest (%)**
		30 DAT	**60 DAT**	**Harvest**	
T_1	CaO 377 kg ha^{-1} + NPK	*10.6^{abcd}	14.0^{abcd}	8.3^{abc}	39.69^{a}
T_2	Dolomite 676 kg ha^{-1} + NPK	9.6^{bcd}	13.3^{abcde}	8.9^{a}	44.79^{a}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	11.5^{ab}	15.9^{a}	8.9^{a}	42.96^{a}
T_4	CaO 377 kg ha^{-1}	8.9^{d}	9.3^{de}	6.9^{cd}	25.00^{a}
T_5	Dolomite 676 kg ha^{-1}	9.5^{cd}	10.7^{bcde}	7.1^{bcd}	27.44^{a}
T_6	'Mangala setright' 774 kg ha^{-1}	8.8^{d}	10.6^{cde}	8.5^{ab}	33.70^{a}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	9.9^{abcd}	12.3^{abcde}	8.3^{abc}	26.29^{a}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	10.3^{abcd}	13.9^{abcd}	8.4^{abc}	39.27^{a}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	11.6^{a}	14.8^{abc}	9.3^{a}	37.13^{a}
T_{10}	NPK only	10.7^{abcd}	13.8^{abcd}	8.0^{abcd}	41.02^{a}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	11.1^{abc}	15.6^{ab}	9.2^{a}	40.67^{a}
T_{12}	Control	9.3^{cd}	8.6^{e}	6.7^{d}	23.81^{a}

* The values followed by same superscript do not differ significantly in DMRT

4.1.3 Leaf area index (LAI)

The data on LAI are given in table 4.3. Leaf area index was significantly lower for CaO and dolomite than 'Mangala setright' when ameliorants were given without fertilizers. However, in the presence of fertilizer all the ameliorants have resulted in almost similar LAI. However 'Mangala setright' @ 375 to 774 kg ha^{-1}

resulted significantly higher LAI than its lower dose. Treatment which received FYM 5 t ha^{-1} + CaO 377 kg ha^{-1} + NPK resulted in relatively higher LAI (5.9) and the least was in control treatment (2.7).

Table 4.3 Effect of treatments on LAI

Treatments		LAI 60DAT
T_1	CaO 377 kg ha^{-1} + NPK	*5.2^a
T_2	Dolomite 676 kg ha^{-1} + NPK	5.0^{ab}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	5.7^a
T_4	CaO 377 kg ha^{-1}	3.7^{cd}
T_5	Dolomite 676 kg ha^{-1}	3.9^{bc}
T_6	'Mangala setright' 774 kg ha^{-1}	4.9^{ab}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	4.7^{abc}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	5.2^a
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	5.6^a
T_{10}	NPK only	5.5^a
T_{11}	FYM 5 t ha^{-1} + CaO 377 kg ha^{-1} + NPK	5.9^a
T_{12}	Control	2.7^d

* The values followed by same superscript do not differ significantly in DMRT

4.1.4 Chlorophyll content

The treatment effects on chlorophyll a, chlorophyll b and total chlorophyll at 60 DAT are presented in table 4.4. Present POP for rice nutrition (T_{11}) recorded significantly higher chlorophyll a (2.62 mg kg^{-1}) and total chlorophyll (3.29 mg kg^{-1}) over most of the treatments and the least was in control treatment.

4.1.5 Dry matter production

The dry matter production are observed at 30 DAT, 60 DAT and at harvest by the application of various treatments is presented in Table 4.5. The treatment which received POP for rice nutrition (T_{11}) has resulted in the constant improvement in rice dry matter production at all growth stages, (1.31 t ha^{-1}, 8.75 t ha^{-1}, 13.18 t ha^{-1}) which was significantly highest. 'Mangala setright' at all the doses (T_3, T_7, T_8, T_9) and CaO @ 377 kg ha^{-1} with fertilizer application (T_1) have produced similar dry matter both at 60 DAT and harvest than non application of ameliorants or dolomite with fertilizer. The lowest dry matter was noted in control treatment at all the three stages.

4.1.6 Root weight and root spread

The root weight and root spread (Table 4.6) were significantly lower in the treatments where the soil was not ameliorated. Both the parameters were significantly superior in T_{11}, which received the ameliorants, organic manure and fertilizers. Application of CaO @ 377 kg ha^{-1} or 'Mangala setright' 500 to 774 kg ha^{-1} together with fertilizer application also resulted in significantly higher improvement in root weight and spread. Treatment which received 5 t ha^{-1} FYM + CaO 377 kg ha^{-1} + NPK resulted relatively higher root weight (8.30 g) and root spread (31.23 cm) the least was in control treatment (2.5 g and 23.50 cm).

Table 4.4 Effect of treatments on chlorophyll content at 60 DAT (mg kg^{-1})

Treatments		**Chl. a**	**Chl. b**	**Total chl.**
T_1	CaO 377 kg ha^{-1} + NPK	*2.36^{ab}	0.58^{a}	2.94^{ab}
T_2	Dolomite 676 kg ha^{-1} + NPK	1.95^{abcd}	0.47^{a}	2.42^{bc}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	2.31^{ab}	0.53^{a}	2.34^{bc}
T_4	CaO 377 kg ha^{-1}	1.99^{abcd}	0.45^{a}	2.44^{bc}
T_5	Dolomite 676 kg ha^{-1}	1.36^{d}	0.48^{a}	1.84^{c}
T_6	'Mangala setright' 774 kg ha^{-1}	1.75^{bcd}	0.54^{a}	2.29^{bc}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	1.86^{bcd}	0.53^{a}	1.79^{c}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	1.87^{bcd}	0.56^{a}	1.95^{c}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	2.16^{abc}	0.52^{a}	2.02^{c}
T_{10}	NPK only	1.50^{cd}	0.41^{a}	1.91^{c}
T_{11}	FYM 5 t ha^{-1} + CaO 377 kg ha^{-1} + NPK	2.62^{a}	0.68^{a}	3.29^{a}
T_{12}	Control	1.37^{d}	0.37^{a}	1.75^{c}

* The values followed by same superscript do not differ significantly in DMRT

Table 4.5 Effect of treatments on dry matter production (t ha^{-1})

Treatments		30 DAT	60 DAT	Harvest
T$_1$	CaO 377 kg ha^{-1} + NPK	*0.98^{c}	8.22^{a}	12.26^{a}
T$_2$	Dolomite 676 kg ha^{-1} + NPK	1.25^{ab}	7.71^{abc}	11.94^{b}
T$_3$	'Mangala setright' 774 kg ha^{-1} + NPK	1.03^{bc}	8.48^{a}	13.71^{a}
T$_4$	CaO 377 kg ha^{-1}	0.93^{c}	8.19^{a}	10.09^{bc}
T$_5$	Dolomite 676 kg ha^{-1}	0.89^{c}	6.51^{bc}	9.47^{c}
T$_6$	'Mangala setright' 774 kg ha^{-1}	0.88^{c}	7.79^{abc}	9.70^{bc}
T$_7$	'Mangala setright' 250 kg ha^{-1} + NPK	1.07^{abc}	8.55^{a}	12.84^{a}
T$_8$	'Mangala setright' 375 kg ha^{-1}+ NPK	1.06^{abc}	7.75^{abc}	13.01^{a}
T$_9$	'Mangala setright' 500 kg ha^{-1} + NPK	1.07^{abc}	8.03^{ab}	13.13^{a}
T$_{10}$	NPK only	1.24^{ab}	7.53^{abc}	12.06^{b}
T$_{11}$	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	1.31^{a}	8.75^{a}	13.18^{a}
T$_{12}$	Control	0.84^{c}	6.24^{c}	8.27^{c}

* The values followed by same superscript do not differ significantly in DMRT

Table 4.6 Effect of treatments on root weight and root spread at 15 days before harvest

Treatments		Root weight (g/hill)	Root spread (cm)
T_1	CaO 377 kg ha^{-1} + NPK	$*7.63^{ab}$	30.50^{a}
T_2	Dolomite 676 kg ha^{-1} + NPK	6.27^{abc}	28.93^{ab}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	7.57^{ab}	29.17^{ab}
T_4	CaO 377 kg ha^{-1}	4.53^{cd}	23.33^{cd}
T_5	Dolomite 676 kg ha^{-1}	2.77^{d}	21.37^{d}
T_6	'Mangala setright' 774 kg ha^{-1}	4.87^{cd}	23.90^{cd}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	6.27^{abc}	25.20^{cd}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	5.73^{bc}	26.47^{bc}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	5.87^{bc}	29.97^{ab}
T_{10}	NPK only	3.10^{d}	24.40^{cd}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	8.30^{a}	31.23^{a}
T_{12}	Control	2.5^{d}	23.50^{cd}

* The values followed by same superscript do not differ significantly in DMRT

4.2 Yield attributes

Rice grain yield is the product of productive tiller or panicles/hill, spikelets/panicle, fertility or filled grain percentage and the test weight of grain.

4.2.1 Panicles/hill

The effect of various treatments on panicles/hill is shown in table 4.7. The highest number of productive tillers/ hill was observed with 'Mangala setright' @ 500 kg ha^{-1} (9.30), though at par with the POP recommendation (9.23). The control treatment resulted in the lowest number of productive tillers (6.67).

4.2.2 Spikelets/panicle

The effect of various treatments on spikelets/panicle is shown in table 4.7. The number of spikelets ranged from 72.20 to 95.73. 'Mangala setright' at the highest dose of 774 kg ha^{-1} both in the absence or presence of fertilizers (T_6 and T_3) produced higher number of spikelets/panicles (92.20 and 94.50) and were statistically similar to T_{11} which received the organic manure component too (95.73). The absolute control recorded the lowest number of spikelets/panicle (72.20).

4.2.3 Filled grains/ panicle

The effects of treatments on filled grains/ panicle is given in Table 4.7. The highest percentage of filled grains was observed with T_{11} (95.90%). Ameliorants, except dolomite, irrespective of the doses improved the filled grain percentage over control. The lowest percentage of filled grains was shown by control treatment (92.86%).

4.2.4 Thousand grain weight

The data on thousand weight of grain is shown in table 4.7. The application of CaO 377 kg ha^{-1} along with recommended fertilizer recorded significantly higher thousand grain weight (28.94 g), which was on par with most of the treatments. The test weight in terms of 1000 grain weight has also significantly increased over control when either the ameliorant or fertilizer or both were applied. The control treatment resulted in the lowest thousand grain weight (27.91 g).

Table 4.7 Effect of soil ameliorants on yield attributes of rice

Treatments		Yield Attributes			
		Panicle/ hill	**Spikelets/ panicle**	**Filled grains/ panicle (%)**	**1000 grain wt.(g)**
T_1	CaO 377 kg ha^{-1} + NPK	*8.33^{abc}	90.50^{ab}	94.85^{abc}	28.94^{a}
T_2	Dolomite 676 kg ha^{-1} + NPK	8.93^{a}	88.53^{ab}	94.78^{abc}	28.80^{a}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	8.93^{a}	94.50^{a}	94.97^{abc}	28.84^{a}
T_4	CaO 377 kg ha^{-1}	6.93^{cd}	82.03^{bc}	93.53^{bcd}	28.40^{ab}
T_5	Dolomite 676 kg ha^{-1}	7.10^{bcd}	75.57^{cd}	92.27^{d}	28.56^{a}
T_6	'Mangala setright' 774 kg ha^{-1}	8.53^{ab}	92.20^{a}	94.68^{abc}	28.86^{a}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	8.27^{abc}	88.43^{ab}	93.77^{abd}	28.47^{a}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	8.40^{abc}	89.87^{ab}	95.19^{ab}	28.54^{a}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	9.30^{a}	90.27^{ab}	93.84^{abd}	28.57^{a}
T_{10}	NPK only	8.00^{abcd}	90.10^{ab}	95.16^{ab}	28.60^{a}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	9.23^{a}	95.73^{a}	95.90^{a}	28.70^{a}
T_{12}	Control	6.67^{d}	72.20^{d}	92.86^{cd}	27.91^{b}

* The values followed by same superscript do not differ significantly in DMRT

4.3 Yield

4.3.1 Grain yield

The effect of various treatments on grain yield is shown in table 4.8. The grain yield in the treatments which received the lower doses of 'Mangala setright' (T_7 to T_9) and the one which received the POP recommendation without organic manure (T_1) produced statistically similar yields in the range of 6.0 to 6.4 t ha^{-1}. But in the absence of fertilizers (T_4 to T_6) higher grain yields over control were observed though not statistically significant.

4.3.2 Straw yield

The treatment effects on straw yield is shown in table 4.8. The straw yield has showed almost similar response to the treatments as that of grain. The highest straw yield (6.99 t ha^{-1}) was obtained by the application of 'Mangala setright' 774 kg ha^{-1} along with the NPK. The control treatment gave the lowest straw yield (4.36 t ha^{-1}).

4.4 Harvest Index

The effect of various treatments on harvest index is shown in table 4.8. T_1 (CaO 377 kg ha^{-1} + NPK) and T_{11} (FYM 5 t ha^{-1} + CaO 377 kg ha^{-1} + NPK) recorded the highest harvest index (0.51). The treatment which received CaO @ 377 kg ha^{-1} without fertilizer component recorded the least harvest index (0.42).

Table 4.8 Effect of treatments on grain and straw yield (t ha^{-1}) and HI

Treatments		Yield(t ha $^{-1}$)		HI
		Grain	Straw	
T_1	CaO 377 kg ha^{-1} + NPK	*6.23^{abc}	6.03^{ab}	0.51^{a}
T_2	Dolomite 676 kg ha^{-1} + NPK	5.33^{c}	5.61^{bc}	0.48^{abc}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	6.72^{a}	6.99^{a}	0.49^{ab}
T_4	CaO 377 kg ha^{-1}	4.21^{d}	5.87^{ab}	0.42^{c}
T_5	Dolomite 676 kg ha^{-1}	4.12^{d}	5.35^{bc}	0.44^{bc}
T_6	'Mangala setright' 774 kg ha^{-1}	4.30^{d}	5.40^{bc}	0.44^{bc}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	6.00^{abc}	6.84^{ab}	0.47^{abc}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	6.42^{ab}	6.60^{ab}	0.49^{ab}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	6.25^{abc}	6.88^{ab}	0.48^{abc}
T_{10}	NPK only	5.59^{bc}	6.48^{ab}	0.46^{abc}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	6.75^{a}	6.42^{ab}	0.51^{a}
T_{12}	Control	3.90^{d}	4.36^{c}	0.47^{abc}

* The values followed by same superscript do not differ significantly in DMRT

4.5 Nutrient content

4.5.1 Nitrogen

The data pertaining to nitrogen content of rice plant at 30 DAT, 60 DAT and at harvest are shown in table 4.9. The N content varied from 2.66% in absolute control to 3.28% in treatment which received POP recommendation for rice nutrition

Table 4.9 Effect of treatments on nitrogen content (%) of rice

Treatments		**30 DAT**	**60 DAT**	**Harvest**	
				Grain	**Straw**
T_1	CaO 377 kg ha^{-1} + NPK	*3.19^{ab}	2.19^{b}	1.37^{a}	0.65^{ab}
T_2	Dolomite 676 kg ha^{-1} + NPK	3.20^{ab}	2.13^{c}	1.36^{a}	0.63^{ab}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	3.03^{abcd}	2.16^{bc}	1.39^{a}	0.66^{ab}
T_4	CaO 377 kg ha^{-1}	2.74^{cd}	2.02^{dc}	1.12^{b}	0.53^{d}
T_5	Dolomite 676 kg ha^{-1}	2.77^{cd}	1.99^{e}	1.00^{b}	0.53^{d}
T_6	'Mangala setright' 774 kg ha^{-1}	2.80^{bcd}	2.03^{de}	1.04^{b}	0.57^{cd}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	3.05^{abcd}	2.12^{c}	1.37^{a}	0.63^{ab}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	3.02^{abcd}	2.14^{bc}	1.36^{a}	0.60^{bc}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	3.13^{abc}	2.15^{bc}	1.36^{a}	0.63^{ab}
T_{10}	NPK only	3.13^{abc}	2.07^{d}	1.10^{b}	0.53^{d}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	3.28^{a}	2.26^{a}	1.40^{a}	0.67^{a}
T_{12}	Control	2.66^{d}	1.93^{f}	0.85^{c}	0.53^{d}

* The values followed by same superscript do not differ significantly in DMRT

(T_{11}) at 30 DAT. Similarly the N content of plants varied from 1.93% in absolute control to 2.26% in T_{11} at 60 DAT. N content in grain and straw varied significantly due to treatment effects. Grain N content was the highest in treatment which received 5 t ha^{-1} FYM, CaO 377 kg ha^{-1} along with recommended fertilizer application (T_{11}), which was on par with treatments which receive different soil ameliorants at varying doses along with recommended fertilizer application (T_1,T_2,T_3,T_7,T_8,T_9). The absolute control treatment resulted in the lowest grain N content of 0.85%.

4.5.2 Phosphorus

The phosphorus content of plant at 30 DAT, 60 DAT and harvest are shown in table 4.10. P content varied from 0.19% to 0.25% at 30 DAT. The highest P content at 30 DAT was observed in treatment which received POP recommendation for rice nutrition (T_{11}) and treatment which received 'Mangala setright' 774 kg ha^{-1} along with recommended fertilizer application. At 60 DAT, P content was highest in T_1 which received CaO 377 kg ha^{-1} along with NPK which was on par with T_{11}. P content in grain was significantly higher in T_{11} (FYM 5 t ha^{-1} + CaO 377 kg ha^{-1} + NPK) which was on par with T_1 (CaO 377 kg ha^{-1} + NPK) and treatments which received varying doses of 'Mangala setright' with or without fertilizer application (T_6, T_7, T_8, T_9). T_{11} recorded the highest P content in straw (0.21%). The control treatment recorded the lowest P content in straw (0.15%).

4.5.3 Potassium

The potassium content of plant at 30 DAT, 60 DAT and harvest are presented in table 4.11. The application of CaO @ 377 kg ha^{-1} along with recommended fertilizers (T_1) recorded the highest K content at 30 DAT (2.71 %). It was on par with POP recommendation with FYM (T_{11}).

At 60 DAT, T_{11} showed the highest K content (2.15%), which was on par with the application of different soil ameliorants along with NPK (T_1,T_2,T_3) whose quantity of ameliorants were fixed as the equivalent to 600 kg ha^{-1} of $CaCO_3$, which is the recommendation for liming acid soils in Kerala.

The K content in grain and straw were highest in T_{11} which received 5 t ha^{-1} FYM + CaO 377 kg ha^{-1} + NPK (0.26% and 2.11%). The lowest K content was shown by control treatment at all the stages.

Table 4.10 Effect of treatments on phosphorus content (%) of rice

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	CaO 377 kg ha^{-1} + NPK	*0.24^{a}	0.25^{a}	0.29^{a}	0.19^{abc}
T_2	Dolomite 676 kg ha^{-1} + NPK	0.24^{ab}	0.24^{ab}	0.25^{bc}	0.18^{bcd}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	0.24^{a}	0.24^{ab}	0.26^{b}	0.18^{bcd}
T_4	CaO 377 kg ha^{-1}	0.21^{c}	0.22^{cd}	0.26^{b}	0.17^{cde}
T_5	Dolomite 676 kg ha^{-1}	0.21^{c}	0.21^{d}	0.24^{cd}	0.16^{ef}
T_6	'Mangala setright' 774 kg ha^{-1}	0.21^{c}	0.22^{cd}	0.28^{a}	0.17^{cde}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	0.22^{bc}	0.22^{cd}	0.29^{a}	0.20^{ab}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	0.22^{bc}	0.23^{bc}	0.28^{a}	0.18^{bcd}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	0.23^{abc}	0.22^{cd}	0.29^{a}	0.18^{bcd}
T_{10}	NPK only	0.22^{c}	0.22^{cd}	0.22^{d}	0.17^{def}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	0.25^{a}	0.25^{a}	0.30^{a}	0.21^{a}
T_{12}	Control	0.19^{d}	0.18^{e}	0.24^{cd}	0.15^{f}

* The values followed by same superscript do not differ significantly in DMRT

4.5.4 Calcium

The effect of various treatments on Ca content in plant at 30 DAT, 60 DAT and at harvest are shown in table 4.12. The soil application of CaO @ 377 kg ha^{-1} along with recommended fertilizer application recorded significantly higher Ca content (0.44%) at 30 DAT followed by 'Mangala setright' @ 774 kg ha^{-1} along with recommended fertilizer application. The Ca content was least in treatment which received Dolomite @ 676 kg ha^{-1} without fertilizer application which was on par with absolute control and the treatment which received only the fertilizer component.

Table 4.11 Effect of treatments on potassium content (%) of rice

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	CaO 377 kg ha^{-1} + NPK	*2.71^a	2.14^a	0.22^{bc}	1.74^c
T_2	Dolomite 676 kg ha^{-1} + NPK	2.68^b	2.14^a	0.23^b	1.67^c
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	2.66^c	2.14^a	0.21^{cde}	1.74^c
T_4	CaO 377 kg ha^{-1}	2.30^h	1.83^f	0.21^{cde}	1.54^d
T_5	Dolomite 676 kg ha^{-1}	2.33^g	1.80^g	0.20^{de}	1.52^d
T_6	'Mangala setright' 774 kg ha^{-1}	2.34^g	1.84^f	0.21^{cde}	1.56^d
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	2.38^f	2.02^d	0.24^b	1.95^b
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	2.42^d	2.07^c	0.24^b	1.85^b
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	2.41^e	2.09^b	0.22^{bc}	1.93^b
T_{10}	NPK only	2.29^h	1.99^e	0.22^{bcd}	1.85^b
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	2.70^a	2.15^a	0.26^a	2.11^a
T_{12}	Control	2.22^i	1.77^h	0.19^e	1.52^d

* The values followed by same superscript do not differ significantly in DMRT

During 60 DAT, T_2 (Dolomite 676 kg ha^{-1} + NPK) recorded 0.56 % Ca content. There was a gradual increase in Ca content from 30 to 60 DAT. The lowest Ca content was in absolute control (0.41 %). Ca content in grain, the difference was not statistically significant. But in the case of straw highest Ca content was observed in T_{11} (0.44 %) and the lowest was in T_4 which receive CaO 377 kg ha^{-1} without fertilizer component (0.39 %).

Table 4.12 Effect of treatments on Ca content (%) of rice

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	CaO 377 kg ha^{-1} + NPK	*0.44^{a}	0.52^{b}	0.10^{a}	0.43^{abc}
T_2	Dolomite 676 kg ha^{-1} + NPK	0.43^{a}	0.57^{a}	0.10^{a}	0.42^{abcd}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	0.44^{a}	0.53^{b}	0.11^{a}	0.42^{abcd}
T_4	CaO 377 kg ha^{-1}	0.38^{bc}	0.43^{cde}	0.11^{a}	0.39^{d}
T_5	Dolomite 676 kg ha^{-1}	0.36^{c}	0.42^{de}	0.11^{a}	0.42^{abcd}
T_6	'Mangala setright' 774 kg ha^{-1}	0.39^{abc}	0.44^{cde}	0.09^{a}	0.41^{bcd}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	0.44^{a}	0.45^{cd}	0.11^{a}	0.42^{abcd}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	0.44^{a}	0.46^{c}	0.11^{a}	0.41^{bcd}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	0.44^{a}	0.45^{cd}	0.09^{a}	0.43^{ab}
T_{10}	NPK only	0.37^{c}	0.44^{cde}	0.10^{a}	0.42^{abcd}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	0.42^{ab}	0.51^{b}	0.10^{a}	0.44^{a}
T_{12}	Control	0.37^{c}	0.41^{e}	0.09^{a}	0.40^{cd}

* The values followed by same superscript do not differ significantly in DMRT

4.5.5 Magnesium

The data pertaining to Mg content of rice plant at 30 DAT, 60 DAT and at harvest are presented in table 4.13. The highest Mg content was noted in T_{11} (FYM 5t ha^{-1} + CaO 377 kg ha^{-1} + NPK). During 30 DAT, T_{11} recorded 0.17 % Mg content followed by 0.16 % where 'Mangala setright' 774 kg ha^{-1} + NPK (T_3) was applied. At 60 DAT, T_{11} recorded 0.12 % of Mg. Even at harvest the Mg content in the straw was 0.13 % along with 0.12 % Mg content in grain. The lowest Mg content was in control treatment in all stages.

Table 4.13 Effect of treatments on Mg content (%) of rice

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	CaO 377 kg ha^{-1} + NPK	*0.15^{c}	0.11^{d}	0.08^{c}	0.10^{c}
T_2	Dolomite 676 kg ha^{-1} + NPK	0.14^{d}	0.11^{d}	0.09^{b}	0.11^{b}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	0.16^{b}	0.11^{c}	0.11^{a}	0.13^{a}
T_4	CaO 377 kg ha^{-1}	0.11^{g}	0.09^{g}	0.06^{e}	0.08^{fg}
T_5	Dolomite 676 kg ha^{-1}	0.12^{f}	0.08^{i}	0.06^{de}	0.08^{fg}
T_6	'Mangala setright' 774 kg ha^{-1}	0.12^{f}	0.08^{h}	0.09^{b}	0.08^{ef}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	0.14^{e}	0.11^{b}	0.08^{c}	0.10^{c}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	0.14^{e}	0.11^{d}	0.06^{d}	0.09^{d}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	0.14^{e}	0.10^{e}	0.08^{c}	0.09^{de}
T_{10}	NPK only	0.12^{g}	0.09^{f}	0.06^{d}	0.07^{g}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	0.17^{a}	0.12^{a}	0.12^{a}	0.13^{a}
T_{12}	Control	0.09^{h}	0.07^{j}	0.04^{f}	0.07^{h}

* The values followed by same superscript do not differ significantly in DMRT

4.5.6 Sulphur

The effect of various treatments on S content in plant at 30 DAT, 60 DAT and at harvest are shown in table 4.14. The application of 'Mangala setright' 774 kg ha^{-1} along with recommended fertilizer application recorded significantly higher S content (1823 mg kg^{-1}) at 30 DAT. The S content was least in absolute control (851 mg kg^{-1}).

During 60 DAT, T_{11} (FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK) recorded 2865 mg kg^{-1} content S which was on par with T_9 (2778 mg kg^{-1}). The lowest S content was in absolute control (1979 mg kg^{-1}). T_{11} recorded the highest S content in grain (990 mg kg^{-1}). But in the case of straw highest S content was observed in T_2 (2969 mg kg^{-1}) and the lowest was in control treatment (1667 mg kg^{-1}).

Table 4.14 Effect of treatments on S content of rice (mg kg^{-1})

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	CaO 377 kg ha^{-1} + NPK	*1250^{bc}	2517^{ab}	729^{b}	2292^{bc}
T_2	Dolomite 676 kg ha^{-1} + NPK	1424^{ab}	2326^{ab}	747^{b}	2969^{a}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	1823^{a}	2361^{ab}	851^{ab}	2483^{abc}
T_4	CaO 377 kg ha^{-1}	1267^{bc}	2240^{ab}	747^{b}	2604^{ab}
T_5	Dolomite 676 kg ha^{-1}	1424^{ab}	2431^{ab}	660^{b}	2552^{abc}
T_6	'Mangala setright' 774 kg ha^{-1}	1476^{ab}	2361^{ab}	747^{b}	2517^{abc}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	1545^{ab}	2535^{ab}	799^{ab}	2535^{abc}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	1719^{ab}	2431^{ab}	677^{b}	2569^{ab}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	1597^{ab}	2778^{a}	712^{b}	2587^{ab}
T_{10}	NPK only	1233^{bc}	2014^{b}	469^{c}	2014^{cd}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	1597^{ab}	2865^{a}	990^{a}	2483^{abc}
T_{12}	Control	851^{c}	1979^{b}	365^{c}	1667^{d}

* The values followed by same superscript do not differ significantly in DMRT

4.5.7 Iron

The effect of various treatments on Fe content of rice plant at 30DAT, 60 DAT and at harvest are shown in table 4.15. Since rice was grown on acidic soil the content of Fe was very high in the plant at all stages. Though the Fe content varied from 812 mg kg^{-1} in T_{11} (FYM 5 t ha^{-1} + CaO 377 kg ha^{-1} + NPK) to 1331 mg kg^{-1} in absolute control at 30 DAT the difference was not statistically significant. Similarly the Fe content of plants varied from 455 mg kg^{-1} in T_{11} (FYM 5 t ha^{-1} + CaO 377 kg ha^{-1} + NPK) to 728 mg kg^{-1} in T_8 ('Mangala setright' 375 kg ha^{-1} +NPK) at 60 DAT. Fe content in grain varied significantly due to treatments and it was highest in absolute control (223 mg kg^{-1}) and the least Fe content (130 mg kg^{-1}) observed in T_4 which received Cao @ 377 kg ha^{-1} without fertilizer application.

4.5.8 Manganese

The manganese content of rice plant analyzed at 30 DAT, 60 DAT and at harvest are shown in table 4.16. The Mn content was highest in treatment which received 'Mangala setright' 774 kg ha^{-1} + NPK (T_3) which was on par with T_{11} and T_{12}. The Mn content recorded by T_{11} at 60 DAT and at harvest (grain and straw) was 292.33 mg kg^{-1}, 98 and 195.33 mg kg^{-1} respectively. The lowest Mn content was noted in control treatment at harvest with 50.73 mg kg^{-1} (grain) and 149.93 mg kg^{-1} (straw) respectively.

4.5.9 Zinc

The data on Zn content of plant at 30 DAT, 60 DAT and at harvest are shown in table 4.17. In all stages zinc content is in various treatment was not significantly different.

Table 4.15 Effect of treatments on Fe content of rice (mg kg^{-1})

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	CaO 377 kg ha^{-1} + NPK	*1268^{a}	520^{a}	137^{c}	354^{cde}
T_2	Dolomite 676 kg ha^{-1} + NPK	1203^{a}	557^{a}	213^{a}	390^{abcd}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	1114^{a}	595^{a}	200^{b}	361^{bcde}
T_4	CaO 377 kg ha^{-1}	1240^{a}	550^{a}	130^{c}	409^{abcd}
T_5	Dolomite 676 kg ha^{-1}	1219^{a}	623^{a}	139^{c}	346^{de}
T_6	'Mangala setright' 774 kg ha^{-1}	1164^{a}	594^{a}	142^{c}	380^{bcd}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	1319^{a}	607^{a}	150^{c}	386^{abcd}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	861^{a}	728^{a}	145^{c}	392^{abcd}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	1030^{a}	566^{a}	177^{c}	421^{abc}
T_{10}	NPK only	1098^{a}	705^{a}	142^{c}	453^{a}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	812^{a}	455^{a}	213^{a}	309^{e}
T_{12}	Control	1331^{a}	710^{a}	223^{a}	429^{ab}

* The values followed by same superscript do not differ significantly in DMRT

Table 4.16 Effect of treatments on Mn content of rice (mg kg^{-1})

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	CaO 377 kg ha^{-1} + NPK	*217.00^{bc}	276.33^{bc}	94.00^{ab}	185.00^{abc}
T_2	Dolomite 676 kg ha^{-1} + NPK	223.67^{bc}	267.38^{c}	92.00^{b}	183.45^{abc}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	293.00^{a}	283.00^{ab}	93.36^{ab}	192.00^{ab}
T_4	CaO 377 kg ha^{-1}	204.33b^{c}	160.00^{g}	85.62^{d}	173.97^{c}
T_5	Dolomite 676 kg ha^{-1}	193.68^{c}	161.66^{g}	83.38^{d}	171.84^{c}
T_6	'Mangala setright' 774 kg ha^{-1}	202.34^{c}	184.67^{f}	86.01^{d}	176.00^{c}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	216.69^{bc}	224.00^{d}	95.00^{ab}	157.34^{d}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	214.65^{bc}	208.35^{e}	87.33^{cd}	179.30^{bc}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	234.00^{b}	209.30^{e}	90.66^{bc}	186.25^{abc}
T_{10}	NPK only	202.36^{c}	203.65^{e}	73.70^{e}	176.00^{c}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	273.68^{a}	292.33^{a}	98.00^{a}	195.33^{a}
T_{12}	Control	276.37^{a}	161.00^{g}	50.73^{f}	149.93^{d}

* The values followed by same superscript do not differ significantly in DMRT

Table 4.17 Effect of treatments on Zn content of rice (mg kg^{-1})

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	CaO 377 kg ha^{-1} + NPK	*45.44^a	43.42^a	9.82^a	55.64^a
T_2	Dolomite 676 kg ha^{-1} + NPK	46.57^a	42.21^a	9.22^a	52.20^a
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	41.48^a	41.68^a	10.83^a	58.04^a
T_4	CaO 377 kg ha^{-1}	45.51^a	40.59^a	10.11^a	55.30^a
T_5	Dolomite 676 kg ha^{-1}	46.91^a	42.12^a	11.58^a	51.95^a
T_6	'Mangala setright' 774 kg ha^{-1}	43.65^a	32.08^a	9.33^a	51.38^a
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	41.32^a	31.16^a	9.85^a	58.09^a
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	47.03^a	42.50^a	8.10^a	58.66^a
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	48.03^a	40.49^a	8.12^a	70.60^a
T_{10}	NPK only	47.22^a	37.55^a	7.96^a	72.79^a
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	45.06^a	47.60^a	10.44^a	79.23^a
T_{12}	Control	43.85^a	41.21^a	9.93^a	59.40^a

* The values followed by same superscript do not differ significantly in DMRT

4.5.10 Boron

The data on boron content in rice plant at 30 DAT, 60 DAT and at harvest are shown in table 4.18. There was an increase in boron content from 30 to 60 DAT. The soil application of CaO along with recommended fertilizers and FYM (T_{11}) recorded significantly higher B content at 30 DAT, 60 DAT (4.80 and 7.28 mg kg^{-1}).

The soil application of 'Mangala setright' 250 kg ha^{-1} + NPK (T_7) showed significantly higher boron content in grain (6.72 mg kg^{-1}). But in the case of straw 'Mangala setright' 774 kg ha^{-1} + NPK (T_3) recorded significantly higher B content

(9.50 mg kg^{-1}). The control treatment recorded the lowest boron content in all the stages.

Table 4.18 Effect of treatments on B content of rice (mg kg^{-1})

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	CaO 377 kg ha^{-1} + NPK	*4.17^{b}	7.23^{a}	5.90^{abcd}	8.73^{bcd}
T_2	Dolomite 676 kg ha^{-1} + NPK	4.13^{b}	6.75^{b}	6.27^{ab}	9.30^{abc}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	4.50^{ab}	7.47^{a}	6.43^{ab}	9.50^{a}
T_4	CaO 377 kg ha^{-1}	3.63^{c}	6.50^{bc}	5.67^{bcd}	5.90^{g}
T_5	Dolomite 676 kg ha^{-1}	3.27^{cde}	6.33^{c}	4.13^{e}	5.87^{g}
T_6	'Mangala setright' 774 kg ha^{-1}	3.40^{cde}	6.23^{c}	4.94^{de}	5.90^{g}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	3.43^{cd}	6.24^{c}	6.72^{a}	6.67^{f}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	3.60^{c}	5.60^{d}	6.03^{abc}	7.77^{e}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	2.90^{e}	5.45^{d}	5.14^{cd}	8.33^{de}
T_{10}	NPK only	3.00d^{e}	5.79^{d}	4.94^{de}	8.67^{cd}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	4.80^{a}	7.28^{a}	6.56^{ab}	9.40^{ab}
T_{12}	Control	2.21^{f}	3.67^{e}	2.32^{f}	4.79^{h}

* The values followed by same superscript do not differ significantly in DMRT

4.5.11 Copper

The copper content at 30 DAT, 60 DAT and at harvest is presented in table 4.19. In all stages the difference was not statistically significant.

Table 4.19 Effect of treatments on Cu content of rice (mg kg^{-1})

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	CaO 377 kg ha^{-1} + NPK	*5.43^{a}	7.06^{a}	2.39^{a}	3.64^{a}
T_2	Dolomite 676 kg ha^{-1} + NPK	5.99^{a}	8.13^{a}	2.47^{a}	4.19^{a}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	5.08^{a}	7.65^{a}	2.15^{a}	4.23^{a}
T_4	CaO 377 kg ha^{-1}	4.75^{a}	6.57^{a}	2.49^{a}	3.44^{a}
T_5	Dolomite 676 kg ha^{-1}	4.13^{a}	6.24^{a}	2.30^{a}	3.74^{a}
T_6	'Mangala setright' 774 kg ha^{-1}	4.70^{a}	7.71^{a}	2.54^{a}	4.19^{a}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	4.99^{a}	6.43^{a}	2.40^{a}	4.21^{a}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	4.80^{a}	6.44^{a}	2.31^{a}	4.37^{a}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	3.54^{a}	5.60^{a}	1.91^{a}	3.47^{a}
T_{10}	NPK only	4.43^{a}	6.72^{a}	2.46^{a}	3.86^{a}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	5.42^{a}	6.19^{a}	2.40^{a}	4.65^{a}
T_{12}	Control	5.29^{a}	6.73^{a}	2.48^{a}	4.44^{a}

* The values followed by same superscript do not differ significantly in DMRT

4.5.12 Aluminium

The effect of various treatments on Al content in plant at 30 DAT, 60 DAT and at harvest are shown in table 4.20. The control treatment recorded significantly higher Al content (3173.26 mg kg^{-1}) at 30 DAT followed by Cao @ 377 kg ha^{-1} applied treatment (2620.57 mg kg^{-1}). The Al content was lowest in T_{10} which received only the recommended fertilizers (918.32 mg kg^{-1}). The Al content at 60 DAT followed a different trend. There was a gradual decrease in Al content from 30 to 60 DAT. Here T_{11} recorded the highest Al content (987.30 mg kg^{-1}) and the lowest was in T_2 which received CaO @ 377 kg ha^{-1} along with the recommended fertilizers (449.39 mg kg^{-1}).Al content in grain and straw, the difference was not statistically significant.

Table 4.20 Effect of treatments on Al content of rice (mg kg^{-1})

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	CaO 377 kg ha^{-1} + NPK	*2088.94^{bc}	449.39^{d}	108.70^{a}	515.20^{a}
T_2	Dolomite 676 kg ha^{-1} + NPK	1530.89^{cde}	480.02^{d}	82.45^{a}	1203.42^{a}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	1287.39^{de}	518.38^{cd}	107.80^{a}	327.69^{a}
T_4	CaO 377 kg ha^{-1}	2620.57^{ab}	680.28^{abcd}	121.47^{a}	765.84^{a}
T_5	Dolomite 676 kg ha^{-1}	2131.77^{bc}	759.03^{abcd}	61.49^{a}	615.99^{a}
T_6	'Mangala setright' 774 kg ha^{-1}	1317.22^{de}	832.63^{abc}	80.24^{a}	675.66^{a}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	1319.87^{de}	913.34^{ab}	72.76^{a}	570.19^{a}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	2037.42^{bcd}	670.77^{abcd}	87.25^{a}	634.47^{a}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	1044.12^{e}	804.61^{abc}	166.28^{a}	550.56^{a}
T_{10}	NPK only	918.32^{e}	764.19^{abcd}	71.35^{a}	584.36^{a}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	1219.51^{e}	987.30^{a}	136.64^{a}	605.70^{a}
T_{12}	Control	3173.26^{a}	635.06^{bcd}	164.07^{a}	486.34^{a}

* The values followed by same superscript do not differ significantly in DMRT

4.6 Nutrient uptake

4.6.1 Nitrogen

The data pertaining to nitrogen uptake by the crop at harvest is shown in table 4.21. Treatment which received 5t ha^{-1} FYM, CaO 377kg ha^{-1} along with recommended fertilizer application (T_{11}) showed significantly higher N uptake by grain (94.62 kg ha^{-1}). The lowest N uptake in grain was recorded in control treatment (33.09 kg ha^{-1}).

The highest N uptake in straw was observed in 'Mangala setright' 774 kg ha^{-1} + NPK application (45.57 kg ha^{-1}). The least N uptake by straw was noticed in control treatment (24.10 kg ha^{-1}). The N uptake in grain was 1.52 to 2 times more than straw. The total uptake of N in absolute control was 57.18 kg ha^{-1} where as it was 125.03 in the case of CaO 377 kg ha^{-1} along with recommended fertilizers and FYM.

4.6.2 Phosphorus

The effect of various treatments on P uptake by the crop is presented in table 4.22. Application of CaO 377 kg ha^{-1} along with FYM and NPK recorded significantly higher P uptake in grain (20.11 kg ha^{-1}).

P uptake by straw was highest in 'Mangala setright' 250 kg ha^{-1} + NPK (13.52 kg ha^{-1}. T_{11} which receive soil ameliorant, fertilizer and organic manure recorded significantly higher total P uptake by the rice crop (33.39 kg ha^{-1}). The total uptake of P was least in control (15.93 kg ha^{-1}). The lowest P uptake by crop was noted in control treatment.

4.6.3 Potassium

The effect of treatments on K uptake by the crop is shown in table 4.23. The K uptake by grain was significantly higher in T_{11} (17.36 kg ha^{-1}). The control treatment recorded least uptake (7.71 kg ha^{-1}) which was on par with treatment which received only the ameliorant component (T_4, T_5 and T6).

The highest K uptake by straw was noticed in 'Mangala setright' 250 kg ha^{-1} + NPK (133.12 kg ha^{-1}), which was on par with the application of 'Mangala setright' 500 kg ha^{-1} + NPK (T_9), 5t ha^{-1} FYM + CaO 377 kg ha^{-1} + NPK (T_{11}), 'Mangala setright' 375 kg ha^{-1} + NPK (T_8) and 'Mangala setright' 774 kg ha^{-1} + NPK (T_3). The lowest was noticed in absolute control (66.36 kg ha^{-1}).

Table 4.21 Effect of treatments on N uptake by rice (kg ha^{-1})

Treatments		**Grain**	**Straw**	**Total**
T_1	CaO 377 kg ha^{-1} + NPK	*85.30^{ab}	39.73^{abc}	125.03^{b}
T_2	Dolomite 676 kg ha^{-1} + NPK	72.31^{bc}	34.88^{abc}	107.19^{bc}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	93.02^{a}	45.57^{a}	138.59^{a}
T_4	CaO 377 kg ha^{-1}	46.98^{e}	32.75^{cde}	79.73^{de}
T_5	Dolomite 676 kg ha^{-1}	41.38^{e}	27.81^{de}	69.19^{e}
T_6	'Mangala setright' 774 kg ha^{-1}	44.92^{e}	28.22^{cde}	73.14^{e}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	82.29^{ab}	42.48^{ab}	124.78^{e}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	87.36^{ab}	36.42^{abc}	123.78^{b}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	84.81^{ab}	40.56^{ab}	125.37^{b}
T_{10}	NPK only	61.48^{cd}	34.03^{bcd}	95.51^{de}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	94.62^{a}	44.32^{abc}	138.93^{a}
T_{12}	Control	33.09^{f}	24.10^{e}	57.18^{f}

* The values followed by same superscript do not differ significantly in DMRT

Table 4.22 Effect of treatments on P uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	CaO 377 kg ha^{-1} + NPK	*18.15^{bc}	11.46^{abc}	29.61^{bc}
T_2	Dolomite 676 kg ha^{-1} + NPK	13.42^{cd}	10.25^{abc}	23.67^{cd}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	17.37^{bc}	12.63^{ab}	30.00^{abc}
T_4	CaO 377 kg ha^{-1}	10.83^{def}	10.21^{bcd}	21.04^{de}
T_5	Dolomite 676 kg ha^{-1}	9.78^{ef}	8.44^{de}	18.22^{ef}
T_6	'Mangala setright' 774 kg ha^{-1}	12.08^{def}	9.41^{cd}	21.49^{de}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	17.29^{ab}	13.43^{a}	30.72^{ab}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	18.14^{ab}	11.77^{abc}	29.91^{ab}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	18.08^{ab}	12.28^{ab}	30.36^{ab}
T_{10}	NPK only	12.34^{de}	10.81^{abcd}	23.15^{de}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	20.11^{a}	13.28^{ab}	33.39^{a}
T_{12}	Control	9.22^{e}	6.71^{e}	15.93^{f}

* The values followed by same superscript do not differ significantly in DMRT

The treatment which receive 'Mangala setright' 250 kg ha^{-1} + NPK (T_7) showed the highest total uptake of K (147.29 kg ha^{-1}), which was on par with 375 kg ha^{-1}, 500 Kg ha^{-1} 'Mangala setright' along with recommended fertilizer application, T_{11} which received FYM 5 t ha^{-1} + CaO 377 kg ha^{-1} + NPK, T_3 ('Mangala setright' 774 Kg ha^{-1} + NPK) and T_{10} which receive only the fertilizer component. Here also, control treatment showed least total uptake of K (74.07 kg ha^{-1}).

Table 4.23 Effect of treatments on K uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	CaO 377 kg ha^{-1} + NPK	*13.94^{c}	105.11^{abc}	119.05^{abc}
T_2	Dolomite 676 kg ha^{-1} + NPK	12.18^{c}	93.47^{abc}	105.65^{ab}
T_3	‘Mangala setright’ 774 kg ha^{-1} + NPK	13.88^{bc}	121.46^{a}	135.33^{a}
T_4	CaO 377 kg ha^{-1}	8.63^{d}	90.60^{bcd}	99.23^{bcd}
T_5	Dolomite 676 kg ha^{-1}	8.29^{d}	81.44^{cd}	89.73^{cd}
T_6	‘Mangala setright’ 774 kg ha^{-1}	8.87^{d}	84.35^{cd}	93.22^{bcd}
T_7	‘Mangala setright’ 250 kg ha^{-1} + NPK	14.16^{bc}	133.12^{a}	147.29^{a}
T_8	‘Mangala setright’ 375 kg ha^{-1}+ NPK	15.06^{ab}	122.18^{a}	137.24^{a}
T_9	‘Mangala setright’ 500 kg ha^{-1} + NPK	13.83^{bc}	132.55^{a}	146.38^{a}
T_{10}	NPK only	12.25^{c}	120.01^{a}	132.26^{a}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	17.36^{a}	135.57^{a}	152.94^{a}
T_{12}	Control	7.71^{d}	66.36^{d}	74.07^{d}

* The values followed by same superscript do not differ significantly in DMRT

4.6.4 Calcium

The data on Ca uptake by the rice crop at harvest is shown in table 4.24.The highest uptake of Ca by grain was observed in T_3 which received ‘Mangala setright’ @ 774 kg ha^{-1} + NPK (7.07 kg ha^{-1}) which were on par with 250 Kg ha^{-1}, 375 Kg ha^{-1} ‘Mangala setright’ received treatments and T_{11} which receive the three different sources of nutrients like FYM, fertilizer and CaO. The least uptake was noted in control treatment (3.57 kg ha^{-1}).

Table 4.24 Effect of treatments on Ca uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	CaO 377 kg ha^{-1} + NPK	*6.23^{a}	25.67^{ab}	31.90^{ab}
T_2	Dolomite 676 kg ha^{-1} + NPK	5.58^{abc}	23.59^{ab}	29.17^{ab}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	7.07^{a}	29.52^{a}	36.59^{a}
T_4	CaO 377 kg ha^{-1}	4.62^{abc}	23.33^{abc}	27.95^{abc}
T_5	Dolomite 676 kg ha^{-1}	4.56^{abc}	22.21^{bc}	26.76^{bc}
T_6	'Mangala setright' 774 kg ha^{-1}	3.86^{bc}	22.09^{bc}	25.94^{bc}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	6.82^{a}	28.80^{a}	35.62^{a}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	6.90^{a}	27.04^{ab}	33.95^{ab}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	5.72^{abc}	29.78^{a}	35.50^{a}
T_{10}	NPK only	5.34^{abc}	27.31^{ab}	32.65^{ab}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	6.97^{a}	28.32^{ab}	35.28^{ab}
T_{12}	Control	3.57^{c}	17.39^{c}	20.96^{c}

* The values followed by same superscript do not differ significantly in DMRT

The application of 'Mangala setright' 500 kg ha^{-1} + NPK resulted the highest uptake of Ca by straw (29.52 kg ha^{-1}), which was on par with 'Mangala setright' 774 kg ha^{-1} + NPK (T_3). The control treatment recorded least Ca uptake by straw (17.39 kg ha^{-1}).

The total Ca uptake was highest in treatment which receive 'Mangala setright' 774 kg ha^{-1} + NPK (36.59 kg ha^{-1}) which was on par with T_9 ('Mangala setright' 500 kg ha^{-1} + NPK). The control treatment showed least total uptake (20.96 kg ha^{-1}). The Ca accumulated in grain was very less compared to total uptake and the calcium left in the straw.

4.6.5 Magnesium

The magnesium uptake by the rice crop at harvest is shown in table 4.25. The application of 5 t ha^{-1} FYM + CaO 377 Kg ha^{-1} + NPK recorded significantly higher Mg uptake by grain (7.23 kg ha^{-1}), followed by the treatment which receive 'Mangala setright' 774 kg ha^{-1} + NPK (T_3). The least uptake was noted in control (1.59 kg ha^{-1}). Mg uptake by straw was significantly higher in T_3 ('Mangala setright' 774 kg ha^{-1} + NPK). Here also control treatment recorded least uptake of Mg by straw (2.82 kg ha^{-1}).

The total uptake of Mg was higher in T11 which received CaO along with FYM and recommended fertilizer application (15.51 kg ha^{-1}), followed by T_3 ('Mangala setright' 774 kg ha^{-1} + NPK), which were on par. The least Mg uptake was recorded in control treatment (4.41 kg ha^{-1}).

4.6.6 Sulphur

The effect of treatments on S uptake by the crop is shown in table 4.26. The S uptake by grain was significantly higher in T_{11} (6.68 kg ha^{-1}). The control treatment recorded least uptake (1.42 kg ha^{-1}).

The highest S uptake by straw was noticed in T_9 (17.80 kg ha^{-1}), which received 'Mangala setright' 500 kg ha^{-1} along with recommended fertilizer application. The lowest was noticed in absolute control (7.27 kg ha^{-1}). The treatment which receives 'Mangala setright' along with recommended fertilizers (T_3) showed the highest total uptake of S (23.05 kg ha^{-1}). Here also, control treatment showed least total uptake of S (8.89 kg ha^{-1}).

Table 4.25 Effect of treatments on Mg uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	CaO 377 kg ha^{-1} + NPK	*5.03^{bcd}	6.31^{bc}	11.34^{bc}
T_2	Dolomite 676 kg ha^{-1} + NPK	5.08^{bc}	6.33^{abc}	11.40^{b}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	6.98^{a}	8.78^{a}	15.76^{a}
T_4	CaO 377 kg ha^{-1}	2.40^{f}	4.54^{de}	6.94^{f}
T_5	Dolomite 676 kg ha^{-1}	2.50^{f}	4.13^{ef}	6.63^{f}
T_6	'Mangala setright' 774 kg ha^{-1}	4.06^{de}	4.50^{de}	8.56^{def}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	5.00^{b}	6.82^{bc}	11.82^{b}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	4.11^{cde}	6.02^{cde}	10.13^{cde}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	5.25^{bcd}	6.05^{cde}	11.30^{bcd}
T_{10}	NPK only	3.56^{e}	4.66^{de}	8.22^{ef}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	7.23^{a}	8.28^{ab}	15.51^{a}
T_{12}	Control	1.59^{f}	2.82^{f}	4.41^{g}

* The values followed by same superscript do not differ significantly in DMRT

Table 4.26 Effect of treatments on S uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	CaO 377 kg ha^{-1} + NPK	$*4.54^{bcd}$	13.82^{b}	18.36^{cd}
T_2	Dolomite 676 kg ha^{-1} + NPK	3.98^{bcd}	16.67^{ab}	20.65^{c}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	5.71^{b}	17.34^{ab}	23.05^{a}
T_4	CaO 377 kg ha^{-1}	3.15^{cd}	15.29^{ab}	18.44^{cd}
T_5	Dolomite 676 kg ha^{-1}	2.72^{de}	13.64^{b}	16.36^{d}
T_6	'Mangala setright' 774 kg ha^{-1}	3.21^{cd}	13.59^{b}	16.80^{d}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	4.79^{b}	17.34^{ab}	22.13^{abc}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	4.34^{bc}	16.95^{ab}	21.29^{abc}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	4.45^{bc}	17.80^{a}	22.25^{abc}
T_{10}	NPK only	2.62^{de}	13.04^{b}	15.66^{d}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	6.68^{a}	15.94^{b}	22.63^{abc}
T_{12}	Control	1.42^{e}	7.27^{c}	8.70^{e}

* The values followed by same superscript do not differ significantly in DMRT

4.6.7 Iron

The effect of various treatments on Fe uptake by the rice crop is shown in table 4.27. The Fe uptake by grain was highest in T_{11} which received CaO along with recommended fertilizers and FYM (1.44 kg ha^{-1}). The treatment which received CaO 377 kg ha^{-1} without fertilizer component showed the lowest uptake of Fe by the crop (0.55 kg ha^{-1}). In the case of straw T_{10} reported significantly highest Fe content (2.94 kg ha^{-1}) which was on par with T_9 which receives 'Mangala setright' 500 kg ha^{-1} along with NPK (2.94 kg ha^{-1}). The total uptake of Fe by the crop was highest in

Table 4.27 Effect of treatments on Fe uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	CaO 377 kg ha^{-1} + NPK	*0.86^{cde}	2.13^{ab}	2.99^{cdef}
T_2	Dolomite 676 kg ha^{-1} + NPK	1.14^{abc}	2.19^{ab}	3.33^{abcde}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	1.35^{ab}	2.53^{ab}	3.87^{ab}
T_4	CaO 377 kg ha^{-1}	0.55^{e}	2.40^{ab}	2.95^{bcdef}
T_5	Dolomite 676 kg ha^{-1}	0.58^{e}	1.85^{b}	2.43^{f}
T_6	'Mangala setright' 774 kg ha^{-1}	0.61^{de}	2.05^{b}	2.66^{ef}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	0.90^{bcde}	2.65^{ab}	3.55^{abc}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	0.93^{bcde}	2.59^{ab}	3.52^{abcd}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	1.11^{abcd}	2.90^{a}	4.00^{a}
T_{10}	NPK only	0.80^{bcde}	2.94^{a}	3.73^{abc}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	1.44^{a}	1.99^{b}	3.43^{abcde}
T_{12}	Control	0.87^{bcde}	1.87^{b}	2.75^{def}

* The values followed by same superscript do not differ significantly in DMRT

T_9 (4.12 kg ha^{-1}). The least uptake was observed in T_5 which receive dolomite without fertilizer application (2.43 kg ha^{-1}).

4.6.8 Manganese

The uptake of Mn by the application of various treatments are shown in table 4.28. The application of FYM 5 t ha^{-1} + CaO 377 kg ha^{-1} + NPK recorded the highest Mn uptake by grain with 0.66 kg ha^{-1} respectively. The control treatment showed the

Table 4.28 Effect of treatments on Mn uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	CaO 377 kg ha^{-1} + NPK	*0.58^{ab}	1.11^{abc}	1.70^{abc}
T_2	Dolomite 676 kg ha^{-1} + NPK	0.49^{cd}	1.03^{abc}	1.52^{bcd}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	0.63^{b}	1.34^{a}	1.97^{a}
T_4	CaO 377 kg ha^{-1}	0.36^{e}	1.02^{bc}	1.38^{cd}
T_5	Dolomite 676 kg ha^{-1}	0.34^{e}	0.92^{c}	1.26^{d}
T_6	'Mangala setright' 774 kg ha^{-1}	0.37^{e}	0.95^{c}	1.32^{cd}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	0.57^{bc}	1.08^{abc}	1.64^{ab}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	0.56^{bc}	1.18^{abc}	1.74^{ab}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	0.57^{bc}	1.28^{ab}	1.85^{ab}
T_{10}	NPK only	0.41^{de}	1.14^{abc}	1.55^{abc}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	0.66^{a}	1.25^{abc}	1.91^{ab}
T_{12}	Control	0.20^{f}	0.65^{d}	0.85^{e}

* The values followed by same superscript do not differ significantly in DMRT

lowest manganese uptake by grain a (0.20 kg ha^{-1}). In the case of nutrient uptake by straw T_3 which receive 'Mangala setright' 774 kg ha^{-1} + NPK showed significantly higher uptake of Mn (1.34 kg ha^{-1}).

The highest total uptake of Mn by rice crop was also observed in T_3 (1.97 kg ha^{-1}). The control recorded the lowest Mn uptake (0.85 kg ha^{-1}). The table also showed that the Mn uptake was less than Fe uptake.

4.6.9 Zinc

The effect of various treatments on the uptake of Zn by rice crop is given in table 4.29. The Zn uptake by grain varied from 0.039 to 0.073 kg ha^{-1} and it varied from 0.259 to 0.509 kg ha^{-1} in straw. The total Zn uptake was only 0.31 to 0.56 kg ha^{-1} indicating that Zn is needed only in minute quantities. The highest Zn uptake by grain (0.073 kg ha^{-1}) was obtained when 'Mangala setright' @ 774 kg ha^{-1} applied along with fertilizers (T_3). The Zn uptake by straw more in T_{11} (0.509 kg ha^{-1}) resulting in a total uptake of 0.579 kg ha^{-1}. In the case of straw and total uptake of Zn was not statistically significant.

4.6.10 Boron

The data on B uptake by the crop is presented in table 4.30. The treatment which receive different sources of nutrients like CaO, FYM and recommended fertilizers showed significantly higher B uptake by grain (0.044 kg ha^{-1}) and in the case of straw T_3 showed highest B content(0.06 kg ha^{-1}). The least uptake was noted in control treatment (0.09 kg ha^{-1} & 0.021 kg ha^{-1}). T_3 recorded significantly higher total B uptake by crop (0.110 kg ha^{-1}). The least uptake was noted in control treatment (0.030 kg ha^{-1}).

4.6.11 Copper

The uptake of Cu by rice crop due to the application of various treatments is given in table 4.31. There were no significant differences between the treatments in the case of Cu uptake by grain, straw and also in the case of total uptake of Cu. It varied from 0.009 to 0.016 kg ha^{-1} in grain and 0.019 to 0.030 kg ha^{-1}in straw. The least uptake of Cu by the crop was recorded in control treatment.

Table 4.29 Effect of treatments on Zn uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	CaO 377 kg ha^{-1} + NPK	*0.061^{abcd}	0.335^{a}	0.397^{a}
T_2	Dolomite 676 kg ha^{-1} + NPK	0.049^{cd}	0.293^{a}	0.342^{a}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	0.073^{ab}	0.405^{a}	0.478^{a}
T_4	CaO 377 kg ha^{-1}	0.043^{cd}	0.325^{a}	0.367^{a}
T_5	Dolomite 676 kg ha^{-1}	0.048^{cd}	0.278^{a}	0.325^{a}
T_6	'Mangala setright' 774 kg ha^{-1}	0.040^{d}	0.277^{a}	0.318^{a}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	0.059^{abc}	0.397^{a}	0.456^{a}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	0.052^{abcd}	0.387^{a}	0.439^{a}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	0.051^{bcd}	0.486^{a}	0.537^{a}
T_{10}	NPK only	0.044^{cd}	0.472^{a}	0.516^{a}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	0.071^{a}	0.509^{a}	0.579^{a}
T_{12}	Control	0.039^{d}	0.259^{a}	0.298^{a}

* The values followed by same superscript do not differ significantly in DMRT

Table 4.30 Effect of treatments on B uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	CaO 377 kg ha^{-1} + NPK	*0.037^{bc}	0.053^{bc}	0.089^{abc}
T_2	Dolomite 676 kg ha^{-1} + NPK	0.033^{bc}	0.052^{bc}	0.086^{abc}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	0.043^{ab}	0.066^{a}	0.110^{a}
T_4	CaO 377 kg ha^{-1}	0.024^{def}	0.035^{de}	0.059^{d}
T_5	Dolomite 676 kg ha^{-1}	0.017^{f}	0.031^{ef}	0.048^{d}
T_6	'Mangala setright' 774 kg ha^{-1}	0.021^{ef}	0.032^{ef}	0.053^{d}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	0.040^{a}	0.046^{cd}	0.086^{abc}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	0.039^{ab}	0.051^{bc}	0.090^{abc}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	0.032^{cd}	0.057^{abc}	0.089^{abc}
T_{10}	NPK only	0.028^{cde}	0.056^{abc}	0.084^{c}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	0.044^{a}	0.060^{ab}	0.105^{ab}
T_{12}	Control	0.009^{g}	0.021^{f}	0.030^{e}

* The values followed by same superscript do not differ significantly

Table 4.31 Effect of treatments on Cu uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	CaO 377 kg ha^{-1} + NPK	*0.015^a	0.022^a	0.037^a
T_2	Dolomite 676 kg ha^{-1} + NPK	0.013^a	0.024^a	0.037^a
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	0.014^a	0.030^a	0.044^a
T_4	CaO 377 kg ha^{-1}	0.010^a	0.020^a	0.031^a
T_5	Dolomite 676 kg ha^{-1}	0.009^a	0.020^a	0.029^a
T_6	'Mangala setright' 774 kg ha^{-1}	0.011^a	0.023^a	0.034^a
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	0.014^a	0.029^a	0.043^a
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	0.015^a	0.029^a	0.044^a
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	0.012^a	0.024^a	0.036^a
T_{10}	NPK only	0.014^a	0.025^a	0.039^a
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	0.016^a	0.030^a	0.046^a
T_{12}	Control	0.010^a	0.019^a	0.029^a

* The values followed by same superscript do not differ significantly in DMRT

4.6.12 Aluminium

The data on Al uptake by the crop is presented in table 4.32. There were no significant differences between the treatments in the case of Al uptake by grain, straw and also in the case of total uptake of Al. It varied from 0.25 to 1.04 kg ha^{-1} in grain and 2.12 to 4.50 kg ha^{-1}in straw.

Table 4.32 Effect of treatments on Al uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	CaO 377 kg ha^{-1} + NPK	*0.68^a	3.11^a	3.78^a
T_2	Dolomite 676 kg ha^{-1} + NPK	0.44^a	3.51^a	3.95^a
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	0.72^a	2.87^a	3.59^a
T_4	CaO 377 kg ha^{-1}	0.51^a	4.50^a	5.01^a
T_5	Dolomite 676 kg ha^{-1}	0.25^a	3.29^a	3.55^a
T_6	'Mangala setright' 774 kg ha^{-1}	0.35^a	3.65^a	3.99^a
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	0.44^a	3.90^a	4.34^a
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	0.56^a	4.19^a	4.75^a
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	1.04^a	3.79^a	4.83^a
T_{10}	NPK only	0.40^a	3.79^a	4.18^a
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	0.92^a	3.89^a	4.81^a
T_{12}	Control	0.64^a	2.12^a	2.76^a

* The values followed by same superscript do not differ significantly in DMRT

4.7 Soil characteristics

4.7.1 pH

The effect of various treatments on pH of soil is given in table 4.33. At 20 DAT, treatment which received 'Mangala setright' 500 kg ha^{-1} + NPK showed highest soil pH (6.66). CaO @ 377 kg ha^{-1} together with FYM and NPK, and 'Mangala setright' @ 375 to 774 kg ha^{-1} constantly maintained a pH of more than 6. Wherever no ameliorants were used significantly lower pH was observed at 25 DAT

(T_{12} and T_{10}). The pH of soil after harvest of rice crop was lower than the initial value (5.31) except in T_{10} and T_3 (5.45).

Table 4.33 Effect of treatments on pH

Treatments		**Soil pH**		
		20 DAT	**25 DAT**	**After Harvest**
T_1	CaO 377 kg ha^{-1} + NPK	*5.89^{bc}	6.22^{ab}	5.25^{a}
T_2	Dolomite 676 kg ha^{-1} + NPK	6.21^{abc}	5.84^{bcd}	5.25^{a}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	6.64^{a}	6.03^{bcd}	5.30^{a}
T_4	CaO 377 kg ha^{-1}	6.63^{a}	5.99^{bcd}	5.16^{a}
T_5	Dolomite 676 kg ha^{-1}	6.37^{abc}	5.73^{bcd}	5.45^{a}
T_6	'Mangala setright' 774 kg ha^{-1}	6.16^{abc}	5.99^{bcd}	5.04^{a}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	6.08^{abc}	5.68^{cd}	5.21^{a}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	6.41^{ab}	6.00^{bcd}	5.25^{a}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	6.66^{a}	6.20^{abc}	5.36^{a}
T_{10}	NPK only	6.24^{abc}	5.51^{cd}	5.35^{a}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	6.65^{a}	6.55^{a}	5.20^{a}
T_{12}	Control	5.68^{c}	5.58^{d}	5.29^{a}

* The values followed by same superscript do not differ significantly in DMRT

4.7.2 EC

The effect of various treatments on EC of soil after harvesting is shown in table 4.34. The EC of soil increased after the experiment in all the treatments compared to the initial value (0.08 dS m^{-1}). The electrical conductivity varied from

0.14 to 0.22 dS m^{-1} and it was lower in absolute control. The EC was more in treatment which receive 'Mangala setright' 774 kg ha^{-1} and 500 kg ha^{-1} + NPK which was on par with the application 'Mangala setright' 250 kg ha^{-1} and 375 kg ha^{-1} along with fertilizers. The control treatment showed the least EC (0.14 dS m^{-1}).

4.7.3 Organic carbon

The organic carbon content of soil after harvesting of rice crop is given in table 4.34. The organic carbon content of soil after harvesting of the crop varied from 0.49 to 0.71%. The organic carbon content was reduced compared to the initial value (0.98%). There were no significant differences between the treatments. The application of 'Mangala setright' 500 kg ha^{-1} along with NPK of recorded the highest organic carbon content (0.71%).

4.7.4 Available N

The data on available N in soil is shown in table 4.35. The available N status in soil after harvesting was almost steady compared to initial value (299 kg ha^{-1}). Present POP recommendation for rice nutrition (T_{11}) was recorded significantly higher available N in soil (298.7 kg ha^{-1}) which was on par with treatment which received CaO @ 377 kg ha^{-1} along with recommended fertilizer. The absolute control recorded the lowest available N in soil after harvest (224 kg ha^{-1}).

4.7.5 Available P

The data on available P in soil is shown in table 4.35. There was a decrease in P after the harvesting of the crop compared to the initial value (34.66 kg ha^{-1}). T_{11} (FYM 5 t ha^{-1} + CaO 377 kg ha^{-1} +NPK) showed higher P content in soil after harvest (17.67 kg ha^{-1}) followed by T_3 ('Mangala setright' 774 kg ha^{-1} + NPK). The absolute control recorded least available P (6.33 kg ha^{-1}) which was on par with T_5 which received dolomite @ 676 kg ha^{-1} (6.25 kg ha^{-1}).

Table 4.34 Effect of treatments on EC and OC content of soil after the experiment

Treatments		EC (dS m^{-1})	OC (%)
T_1	CaO 377 kg ha^{-1} + NPK	*0.16^{ab}	0.70^{a}
T_2	Dolomite 676 kg ha^{-1} + NPK	0.19^{ab}	0.64^{a}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	0.17^{ab}	0.59^{a}
T_4	CaO 377 kg ha^{-1}	0.19^{ab}	0.59^{a}
T_5	Dolomite 676 kg ha^{-1}	0.17^{ab}	0.67^{a}
T_6	'Mangala setright' 774 kg ha^{-1}	0.22^{a}	0.57^{a}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	0.20^{a}	0.69^{a}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	0.21^{a}	0.67^{a}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	0.22^{a}	0.71^{a}
T_{10}	NPK only	0.17^{ab}	0.67^{a}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	0.17^{ab}	0.49^{a}
T_{12}	Control	0.14^{b}	0.70^{a}

* The values followed by same superscript do not differ significantly in DMRT

Table 4.35. Effect of soil ameliorants on available N, P and K (kg ha^{-1}) of soil after the experiment

Treatments		Available N	Available P	Available K
T_1	CaO 377 kg ha^{-1} + NPK	*291.2^{a}	17.00^{ab}	108.27^{abc}
T_2	Dolomite 676 kg ha^{-1} + NPK	272.5^{b}	15.67^{b}	102.29^{cd}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	294.9^{a}	17.33^{a}	115.73^{ab}
T_4	CaO 377 kg ha^{-1}	246.4^{d}	8.67^{d}	94.08^{de}
T_5	Dolomite 676 kg ha^{-1}	250.1^{cd}	7.00^{ef}	92.96^{e}
T_6	'Mangala setright' 774 kg ha^{-1}	250.1^{d}	7.67^{def}	93.71^{de}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	265.1^{bc}	12.67^{c}	103.79^{c}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	265.1^{bc}	12.67^{c}	107.52^{bc}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	276.3^{b}	13.67^{c}	106.40^{c}
T_{10}	NPK only	242.7^{d}	8.33^{de}	94.45^{de}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	298.7^{a}	17.67^{a}	119.09^{a}
T_{12}	Control	224.0^{e}	6.33^{f}	84.37^{f}

* The values followed by same superscript do not differ significantly in DMRT

4.7.6 Available K

The effect of various treatments on available K after harvesting of rice crop is shown in table 4.35. The available K status in soil after harvesting was almost steady compared to initial value (105.06 kg ha^{-1}). T_{11} which received 5 t ha^{-1} FYM, CaO @ 377 kg ha^{-1} along with the recommended fertilizer application recorded higher K content in soil after harvest (119.09 kg ha^{-1}). The absolute control showed the least available K (84.37 kg ha^{-1}).

4.7.7 Available Ca

The available Ca content in soil after harvesting of rice crop is presented in table 4.36. The available Ca content in soil after harvesting of rice crop was increased compared to initial value (599 mg kg^{-1}). Though available Ca varied from 576.84 - 620.87 mg kg^{-1}, there were no significant difference between treatments. However T_7 ('Mangala setright' 250 kg ha^{-1} + NPK) showed comparatively higher available Ca and was lower in the application of dolomite without fertilizer component (576.84 mg kg^{-1}).

4.7.8 Available Mg

The available Mg content in soil after harvesting of rice crop is given in table 4.36. The available Mg content in soil after the experiment showed a steady value compared to the initial value (23 mg kg^{-1}). However, treatment which received CaO 377 kg ha^{-1} along with recommended fertilizers and organic manure resulted in 25.50 mg kg^{-1} available Mg whereas it was only 22.53 mg kg^{-1} in absolute control.

4.7.9 Available S

The effect of treatments on available S content of soil is shown in table 4.36. The available S content in soil after the harvesting of the crop increased compared to the initial value (7.08 mg kg^{-1}). The available S content was significantly higher in T_3 which receive 'Mangala setright' 774 kg ha^{-1} along with recommended fertilizer application (21.50 mg kg^{-1}). The control treatment noted the lowest S content (8.01 mg kg^{-1}).

Table 4.36 Effect of soil ameliorants on available Ca, Mg & S (mg kg^{-1}) of soil after the experiment

Treatments		Available Ca (mg kg^{-1})	Available Mg (mg kg^{-1})	Available S (mg kg^{-1})
T_1	CaO 377 kg ha^{-1} + NPK	*601.42^{a}	24.40^{bc}	19.60^{bc}
T_2	Dolomite 676 kg ha^{-1} + NPK	601.51^{a}	24.27^{cd}	20.83^{ab}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	600.93^{a}	25.03^{ab}	21.50^{a}
T_4	CaO 377 kg ha^{-1}	595.49^{a}	23.50^{e}	15.45^{e}
T_5	Dolomite 676 kg ha^{-1}	576.84^{a}	23.13^{ef}	9.97^{f}
T_6	'Mangala setright' 774 kg ha^{-1}	603.77^{a}	23.70^{de}	18.73^{cd}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	620.87^{a}	24.70^{bc}	20.37^{abc}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	596.25^{a}	24.57^{bc}	20.00^{abc}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	600.65^{a}	24.87^{bc}	19.97^{abc}
T_{10}	NPK only	586.02^{a}	23.47^{e}	17.39^{d}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	598.35^{a}	25.50^{a}	19.92^{abc}
T_{12}	Control	602.28^{a}	22.53^{f}	8.01^{g}

* The values followed by same superscript do not differ significantly in DMRT

4.7.10 Available Fe

The available Fe content in soil after the harvest of rice crop is presented in table 4.37. The available Fe content in soil after harvesting of rice crop was decreased compared to initial value (1413 mg kg^{-1}). Though available Fe varied from 1118 - 1328 mg kg^{-1}, there were no significant differences between the treatments.

4.7.11 Available Mn

The available Mn content in soil after the harvest of rice crop is given in table 4.37. Treatment which received 'Mangala setright' 774 kg ha^{-1} along with recommended fertilizer application showed significantly higher available Mn content in soil (86.60 mg kg^{-1}). The lowest available Mn content was observed in T_5 which receive dolomite 676 kg ha^{-1} without fertilizer application (73.00 mg kg^{-1}).

4.7.12 Available Zn

The effect of treatments on available Zn content in soil is presented in table 4.37. The available Zn in soil after the experiment increased compared to the initial value (2.24 mg kg^{-1}). Though available Zn varied from 2.20- 3.93 mg kg^{-1} there were no significant differences between the treatments. The available Zn was least in control treatment (2.20 mg kg^{-1}).

4.7.13 Available B

The effect of various treatments on soil available B is shown in table 4.38. T_{11} which receive CaO along with FYM and fertilizers recorded significantly higher available B (1.25 mg kg^{-1}). The available B was least in control treatment (0.45 mg kg^{-1}).

4.7.14 Available Cu

The effect of various treatments on soil available Cu is shown in table 4.38. The absolute control recorded higher available Cu (8.67 mg kg^{-1}) and the lowest was in T_{11}which received present POP recommendation for rice nutrition (7.65 mg kg^{-1}).

4.7.15 Available Al

The available Al content in soil after the harvest of rice crop is presented in table 4.38. The available Al content in soil after harvesting of rice crop was decreased compared to initial value (2571.31 mg kg^{-1}). Though available varied from 1813-2565 mg kg^{-1}, there were no significant differences between the treatments.

Table 4.37 Effect of soil ameliorants on available Fe, Mn & Zn (mg kg^{-1}) of soil after the experiment

Treatments		Available Fe (mg kg^{-1})	Available Mn (mg kg^{-1})	Available Zn (mg kg^{-1})
T_1	CaO 377 kg ha^{-1} + NPK	*1312^{a}	84.17^{ab}	3.37^{a}
T_2	Dolomite 676 kg ha^{-1} + NPK	1214^{a}	79.00^{c}	3.50^{a}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	1229^{a}	86.60^{a}	3.52^{a}
T_4	CaO 377 kg ha^{-1}	1328^{a}	75.00^{d}	3.00^{a}
T_5	Dolomite 676 kg ha^{-1}	1301^{a}	73.00^{d}	3.08^{a}
T_6	'Mangala setright' 774 kg ha^{-1}	1301^{a}	73.84^{d}	3.08^{a}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	1165^{a}	82.70^{b}	3.93^{a}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	1135^{a}	83.46^{ab}	3.35^{a}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	1165^{a}	74.00^{d}	3.35^{a}
T_{10}	NPK only	1198^{a}	74.90^{d}	3.87^{a}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	1118^{a}	84.40^{ab}	3.27^{a}
T_{12}	Control	1251^{a}	82.72^{b}	2.20^{a}

* The values followed by same superscript do not differ significantly in DMRT

Table 4.38 Effect of soil ameliorants on available B, Cu and Al (mg kg^{-1}) of soil after the experiment

Treatments		Available B (mg kg^{-1})	Available Cu (mg kg^{-1})	Available Al (mg kg^{-1})
T_1	CaO 377 kg ha^{-1} + NPK	*0.96^{ab}	7.73^{ef}	1968.33^{a}
T_2	Dolomite 676 kg ha^{-1} + NPK	0.95^{ab}	7.75^{ef}	2365.17^{a}
T_3	'Mangala setright' 774 kg ha^{-1} + NPK	1.02^{ab}	7.78^{ef}	1813.00^{a}
T_4	CaO 377 kg ha^{-1}	0.82^{bc}	8.07^{cde}	2142.83^{a}
T_5	Dolomite 676 kg ha^{-1}	0.96^{ab}	8.23^{bcd}	2139.67^{a}
T_6	'Mangala setright' 774 kg ha^{-1}	0.63^{bc}	8.37^{abc}	2216.00^{a}
T_7	'Mangala setright' 250 kg ha^{-1} + NPK	0.62^{bc}	8.23^{bcd}	1887.67^{a}
T_8	'Mangala setright' 375 kg ha^{-1}+ NPK	0.91^{ab}	7.93^{def}	2565.67^{a}
T_9	'Mangala setright' 500 kg ha^{-1} + NPK	0.78^{bc}	8.15^{cd}	2355.67^{a}
T_{10}	NPK only	0.76^{bc}	8.53^{ab}	2471.83^{a}
T_{11}	FYM 5 t ha^{-1}+ CaO 377 kg ha^{-1} + NPK	1.25^{a}	7.65^{f}	2391.50^{a}
T_{12}	Control	0.45^{c}	8.67^{a}	2452.67^{a}

* The values followed by same superscript do not differ significantly in DMRT

DISCUSSION

V. DISCUSSION

A field experiment to compare the relative efficiency of soil ameliorants in lateritic soils of Kerala was conducted at the rice field of Department of Agronomy, College of Horticulture, Vellanikkara during January to May, 2013. The results obtained from the experiment reported in the previous chapter are discussed based on available literature.

5.1 Crop growth characters

Soil amelioration has resulted in significantly higher plant height both at 30 DAT and harvest (Fig 5.1). The treatment POP for rice nutrition (T_{11}) produced tallest plants at harvest, possibly due to the multifunctional advantage of organic manure included in the treatment. Rajput and Singh (1995) reported that the maximum plant height was recorded under the application of FYM @ 10 t ha^{-1} as basal + full N as foliar in 3 splits. Among the different ameliorants applied without the fertilizer component, CaO and 'Mangala setright' performed better than dolomite. However when the ameliorants were applied together with fertilizers the plant height was at par even though 'Mangala setright' produced the tallest plants.

The tiller count at 30 DAT was significantly higher for 'Mangala setright' applied @ 500 kg/ha along with the fertilizers. The tiller count at 60 DAT was the highest when 'Mangala setright' was applied @ 774 kg ha^{-1}; however it was at par with the lower doses of the same and other ameliorants (Fig 5.2). The enhanced growth reflected by the increased height and tiller number is a direct effect of absorption of nitrogen and sulphur supplied either through soil ameliorants or directly through the fertilizers. 'Mangala setright' is a commercial ameliorant produced by Mangalore Chemicals and Fertilizers Ltd, which contains 20% Ca, 6.8% Mg, 6.4% S. Uddin et *al.* (2002) found that the application of S, Zn and B along with NPK fertilizers recorded the highest number of effective tillers per plant (12.5), number of

Fig. 5.1 Effect of treatments on height of plant (cm) at 30, 60 DAT & harvest

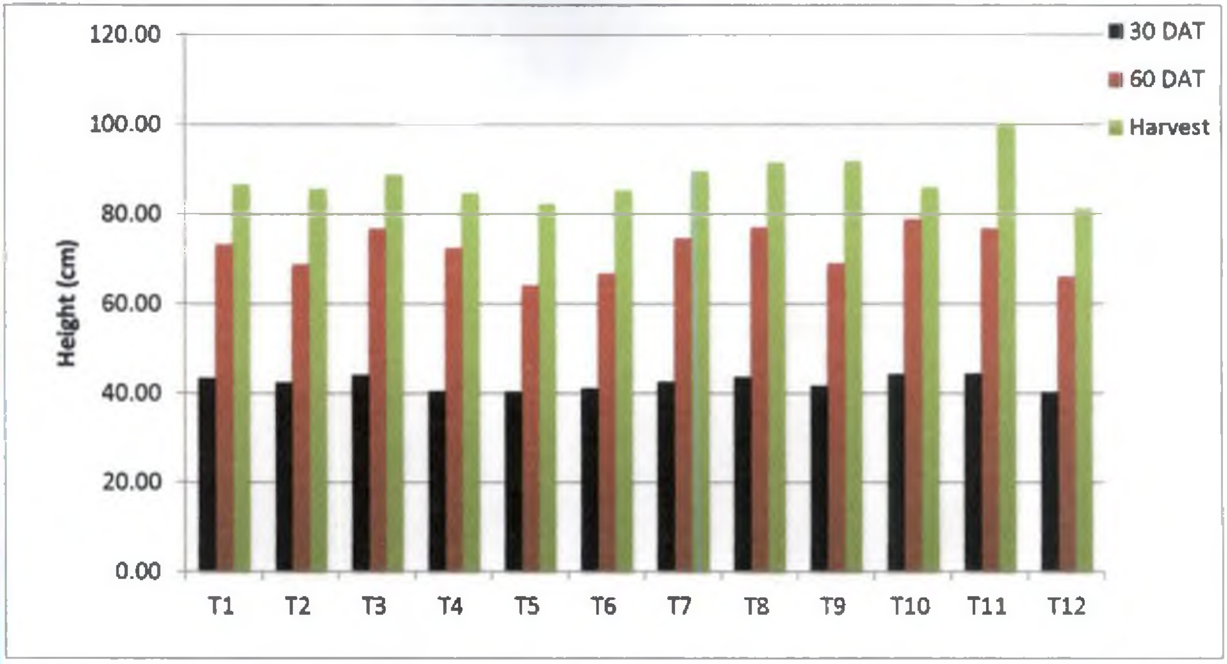
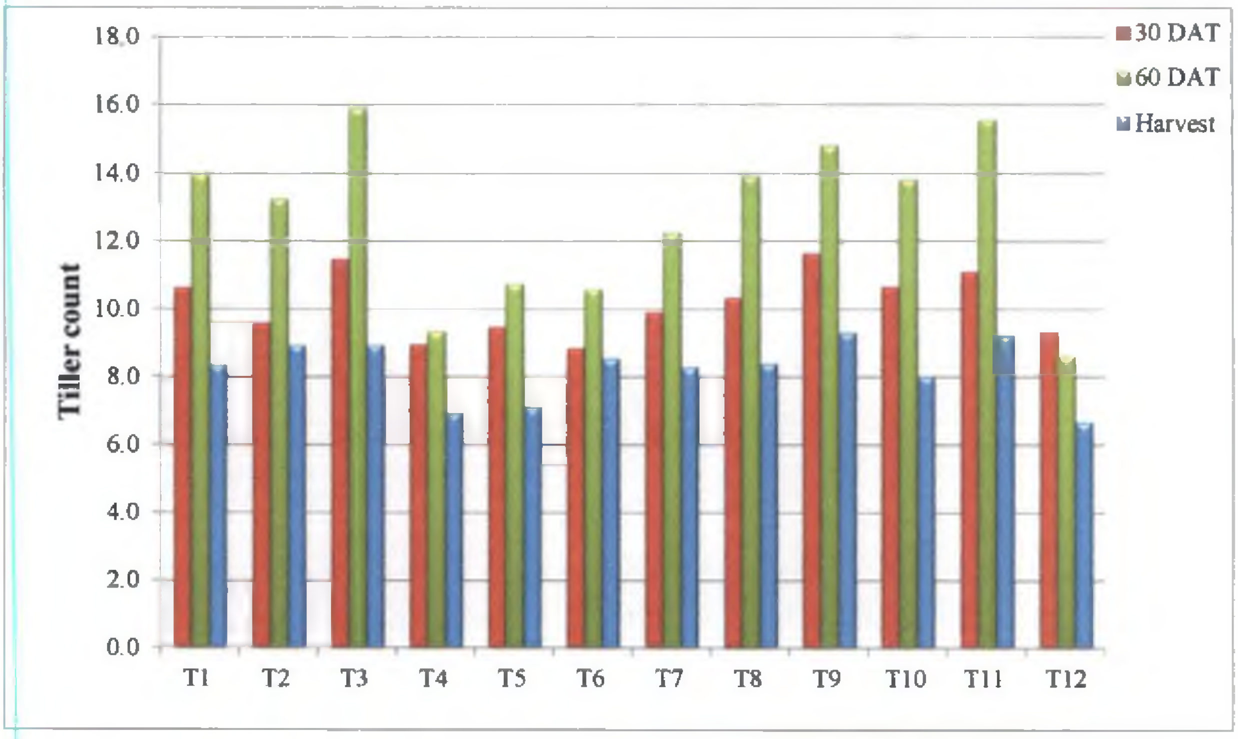


Fig. 5.2 Effect of treatments on tiller count at 30, 60 DAT & harvest



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11}-FYM +Cao + NPK, T_{12}- Con.

filled grains per panicle (99.9) and 1000 grain weight (24.4 g) and it was statistically identical with all other treatments except control.

All the vegetative tillers produced may not be productive. Only some of them will be converted to productive tiller and some may die, known as tiller decline. Tiller decline was reduced by the application of soil ameliorants with recommended fertilizers and it was very severe in control plot. The control treatment showed highest tiller decline (23.81%) due to the inadequate supply of nutrients. The availability and absorption of nutrients particularly N and S, are known to favour tiller production (Tisdale *et al.*, 1993). However an unbalanced accumulation of these elements in plant may result in an increased tiller decline and consequently low number of panicle bearing tillers and reduced yield (Vallalkannan, 2004). Higher rate of tiller decline has been reported to be a way to exclude excess of Fe in the plant though the plant has to shed other nutrients also in this process (Musthafa, 1995). Several reports reveal that disproportional concentration of Fe and Mn reduce the rice yield in lateritic alluvium (Mathew, 2002; Bridigit, 1999 and Vallalkannan, 2004).

Leaf area index was significantly lower for CaO and dolomite than 'Mangala setright' when ameliorants were given without fertilizers. However, in the presence of fertilizer all the ameliorants have resulted in almost similar LAI.

Leaf chlorophyll content is considered as a good indicator for plant growth. Present POP for rice nutrition (T_{11}) has resulted in significantly higher 'chlorophyll a' 'chlorophyll b', closely followed by the treatments receiving CaO @ 377 kg ha^{-1} (T_1) and 'Mangala setright' @ 500 and 774 kg ha^{-1} (T_3 and T_9), both applied with fertilizers. Soil amelioration with dolomite was very similar to the non - application of ameliorants, even through amelioration with CaO and 'Mangala setright' improved the 'chlorophyll a' content. Sulphur application is known to reduce plant content of iron by reducing leaf sap pH and increasing chlorophyll content (Singh, 1970 and Pillai, 1972). Grasses were treated with $CaCl_2$ (10 mM) or H_2O by foliar application

Fig. 5.3 Effect of treatments on chlorophyll content (mg kg^{-1})

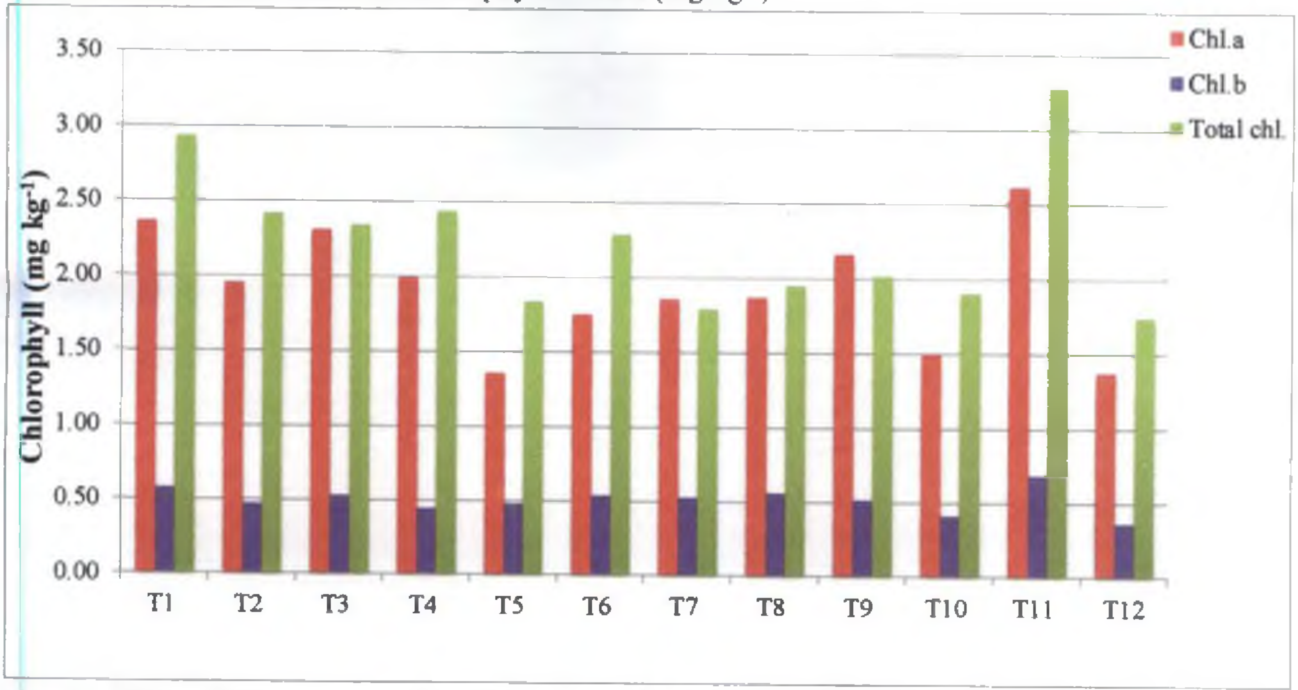
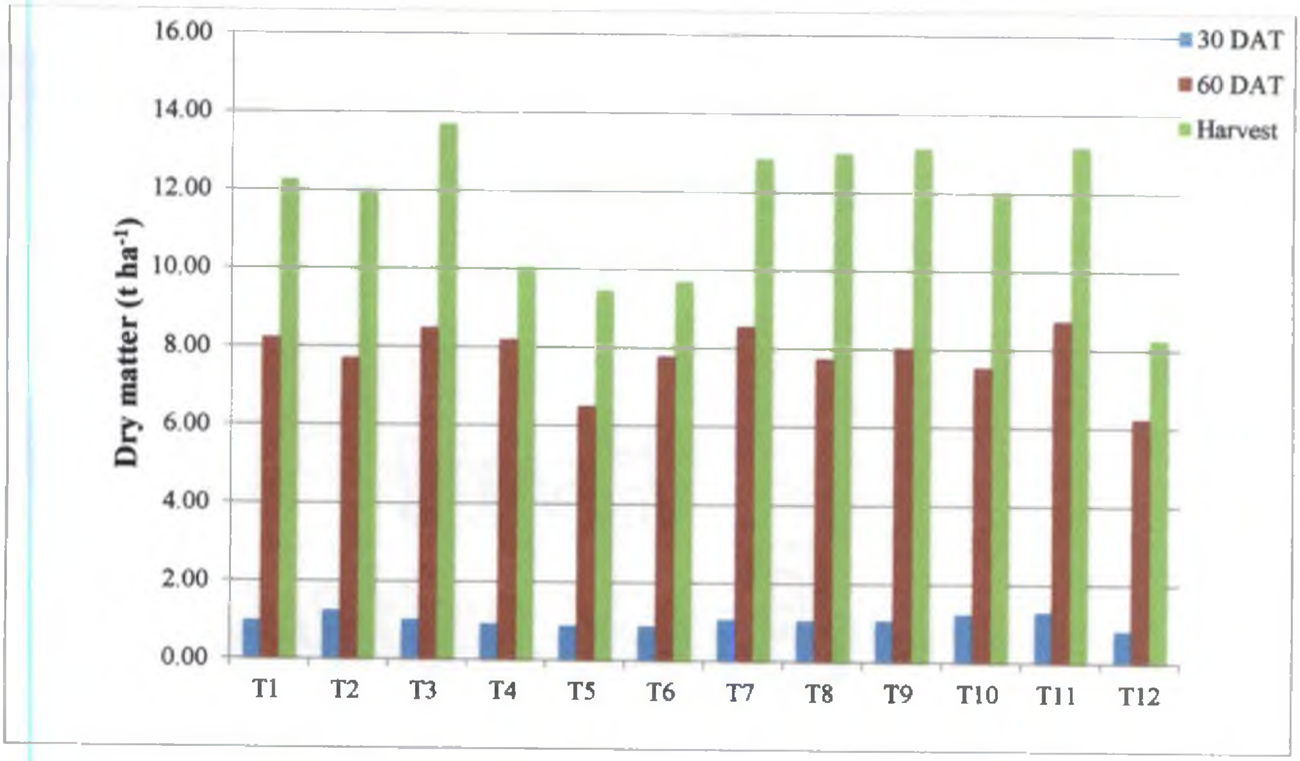


Fig. 5.4. Effect of treatments on dry matter production (t ha^{-1}) at 30, 60 DAT & harvest



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK

T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK

T_{10} - NPK only, T_{11}-FYM +Cao + NPK, T_{12}-Con.

and then exposed to heat stress (35/30 degrees C) in growth chambers. Heat stress reduced grass quality, relative water content (RWC), and chlorophyll (Chl) content of leaves in grasses tall fescue (*Festuca arundinacea* L.) and Kentucky bluegrass (*Poa pratensis* L.), but Ca^{2+} treatment increased all three factors under heat stress (Jiang and Huang, 2001).

Though 'chlorophyll a' is the precursor for production of 'chlorophyll b', significant difference as seen in the case of 'chlorophyll a' was not observed for 'chlorophyll b'. The lowest chlorophyll content was observed in the absolute control treatment, but it improved when ameliorants, alone or with fertilizers, were applied. The total chlorophyll content at 60 DAT was notably higher evidently due to the combined effect of soil amelioration, organic manure addition and fertilizer application. In the absence of soil ameliorants, the fertilizer applied and non- applied treatments resulted in statistically similar chlorophyll content bringing out the importance of soil amelioration. Among the different ameliorants, the lowest dose of 'Mangala setright' @ 250 kg ha^{-1} with fertilizers (T_7) and dolomite without fertilizer (T_5) resulted in lower chlorophyll content. Bridgit and Potty (1992) attributed the causes of disproportional reduction in chlorophyll 'b' to inhibition on concerned reactions mediated by several enzymes influenced by elemental concentrations in plant. Though the chlorophyll 'a' production increasing with S doses the increasing ratio of chlorophyll 'a' to 'b' with increasing S doses may result in partial lowering of productivity.

The treatment which received POP for rice nutrition (T_{11}) has resulted in consistently higher dry matter production at all growth stages. 'Mangala setright' at all the doses (T_3, T_7, T_8, T_9) and CaO @ 377 kg ha^{-1} with fertilizer application (T_1) also produced similar significantly higher dry matter both at 60 DAT and harvest than non - application of ameliorants or dolomite with fertilizer. Apart from the amelioration effects the presence of all the secondary nutrients viz. Ca, Mg and S also might have contributed to the better performance of 'Mangala setright'.

The enhanced dry matter production is the ultimate result of higher root growth and root spread, and leaf chlorophyll content. The volume of soil explored for nutrients is increased with the root spread increase. The increase in root weight is the result of increase in number, length and thickness of roots. Only a favourable soil environment with an optimum pH and nutrient content can result in greater nutrient uptake by crop and consequent chlorophyll development, enhanced photosynthesis and ultimately higher dry matter production.

The root weight and root spread were significantly lower in the treatments where the soil was not ameliorated; even the fertilizer application did not improve the situation. Both the parameters were significantly higher in T_{11}, which received the ameliorants, organic manure and fertilizers. The function of organic manure is not only nutritional but also physiological, since the manure contains vitamins, hormones, phenolic substances and humic acids. Kawata and Soejima (1976) showed that long-term application of compost / FYM to rice field accelerates the development of superficial roots and are helpful for more respiration and thus nutrient absorption. They also reported that the organic matter accelerated the development of active roots deep into the soil and helped to maintain their activity until late growth stage guarding the plant from early senescence

5.2 Yield and yield attributes

Rice grain yield is the product of productive tiller or panicles/hill, spikelets/panicle, fertility or filled grain percentage and the test weight of grain. The panicles per hill were significantly increased when the soil was ameliorated. Similarly it was improved when the fertilizer was applied either in the absence or in the presence of ameliorants. The highest number of panicles/ hill was observed with

'Mangala setright' @ 500 kg ha^{-1}, though at par with the POP recommendation. 'Mangala setright' at the highest dose of 774 kg ha^{-1} both in the absence or presence of fertilizers, produced higher number of panicles which were statistically similar to T_{11} which received the organic manure component too. Mondal *et al.* (1994) observed an increase in no of panicles, number of grains and thousand grain weight in rice with increased NPK rates along with FYM application. Anilakumar *et al.* (1993) obtained 7.6 percent increase in grain yield of rice by the combined application of FYM and NPK than the application of NPK alone. Singh *et al.* (1996) reported that the substitution of 25 percent of N through FYM, particularly at higher N rates, increased the rice yield.

Ameliorants, except dolomite, irrespective of the doses improved the filled grain percentage over control. The yield attributes are mainly influenced by the nutrient availability, uptake and its metabolism with in the plant mainly during and after the panicle initiation stage. The rhizosphere pH largely determine the uptake of nutrients. The ameliorant dolomite though increased the pH at the initial stage, couldn't maintain it (Table 4.33) affecting the balanced nutrient uptake and hence adversely effected the panicle characteristics.

The test weight in terms of 1000 grain weight has also significantly increased over control when either the ameliorant or fertilizer or both were applied. Nitrogen absorbed at PI stage increases spikelet number and that absorbed at maturity helps better filling of grains (De Datta, 1981). Early nitrogen absorption is known to favour tiller and panicle production (Tisdale *et al.*, 1993). Similar improvement in the percentage of filled grains and 1000 grain weight was also observed with organics and higher rate of sulphur and nitrogen. Oh (1991) observed enhanced growth and improved yield attributes due to sulphur nutrition.

'Mangala setright' at the highest dose of 774 kg ha^{-1} (T_3) and the treatment which received POP recommendation (T_{11}) produced the higher and similar yield of

Fig. 5.5 Effect of treatments on grain yield (t ha^{-1})

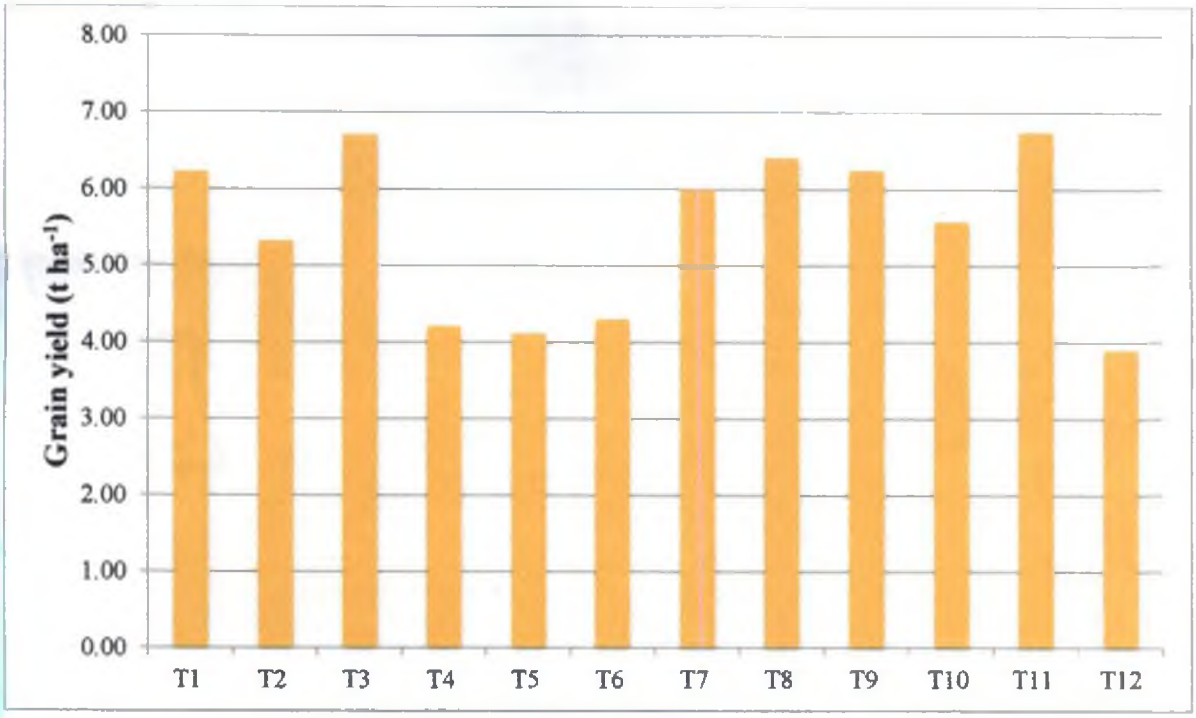
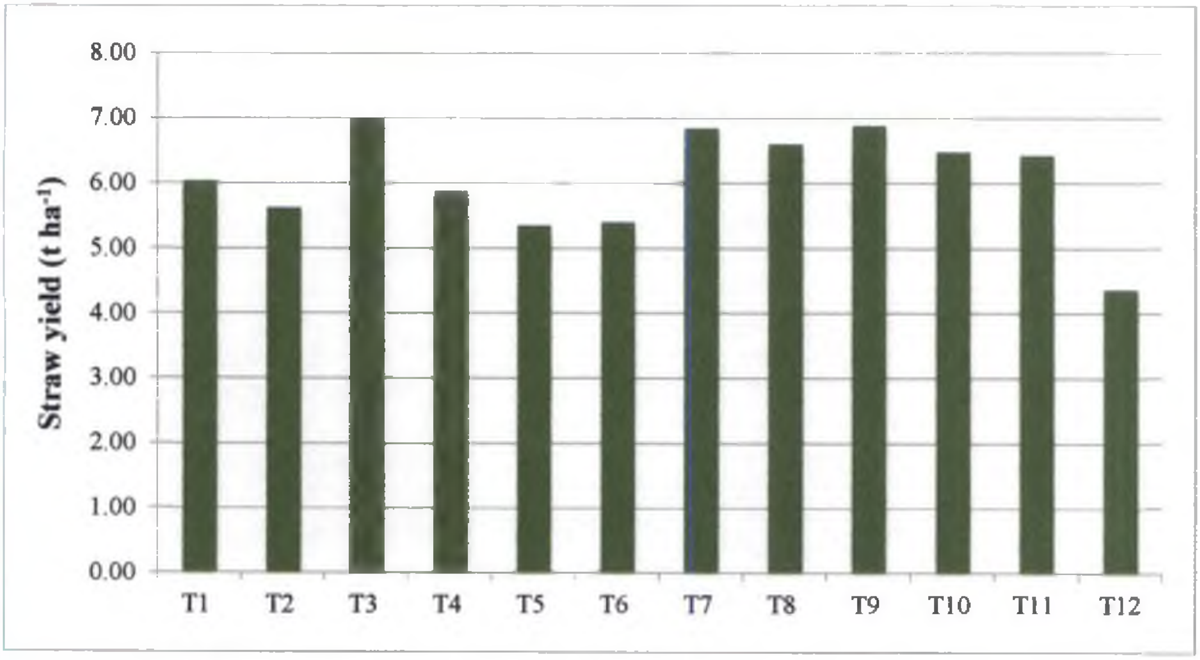


Fig. 5.6 Effect of treatments on straw yield (t ha^{-1})



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11}-FYM +Cao + NPK, T_{12}- Con.

6.7 t ha^{-1}. The grain yield in the treatments which received the lower doses of 'Mangala setright'(T_7 to T_9) and T_1 which received the POP recommendation without organic manure statistically on par and yielded in the range of 6.0 to 6.4 t ha^{-1}. In the presence of ameliorants but in the absence of fertilizers (T_4 to T_6) higher grain yields over control were observed but not statistically significant. The straw yield has showed almost similar response to the treatments as that of grain.

The results show the the positive effects of soil amelioration particularly in the presence of fertilizers. 'Mangala setright' and CaO have performed better than dolomite under the same equivalence to $CaCO_3$. The higher yield resulted by the application of higher dose of 'Mangala setright' even in the absence of organic manure could be attributed to the supplementation of secondary nutrients it contained viz., Mg and S together with the ameliorating effect and supply of Ca. Morales *et al.*, (2002) observed that liming acid soils improved soil pH, reduced P fixation and toxic accumulation of Fe, Mn and Al and created a favorable soil environment. The enhanced growth and yield characters of rice as observed in the ameliorated treatments are due to the favourable nutritional rhizosphere environment in the soil and consequent nutrient availability and uptake. While CaO did the ameliorative function, 'Mangala setright' did both soil amelioration and secondary nutrient supplementation.

5.3 Nutrient composition and uptake

The highest yield was recorded with combined application of soil ameliorants, fertilizers and FYM. Higher nutrient content of plant especially N, P and K were also noticed in the same treatment. The N content in rice plant reduced over time, due to the dilution effect. But there is a clear cut translocation of N to grains at reproductive phase which is evident from the higher N content in grains compared to straw. Nutrient uptake is a product of content of nutrients and dry matter yield. Treatment which received FYM 5 t ha^{-1}, CaO 377kg ha^{-1} along with recommended fertilizer

Fig. 5.7 Effect of treatments on nitrogen content (%) of rice at 30, 60 DAT & harvest

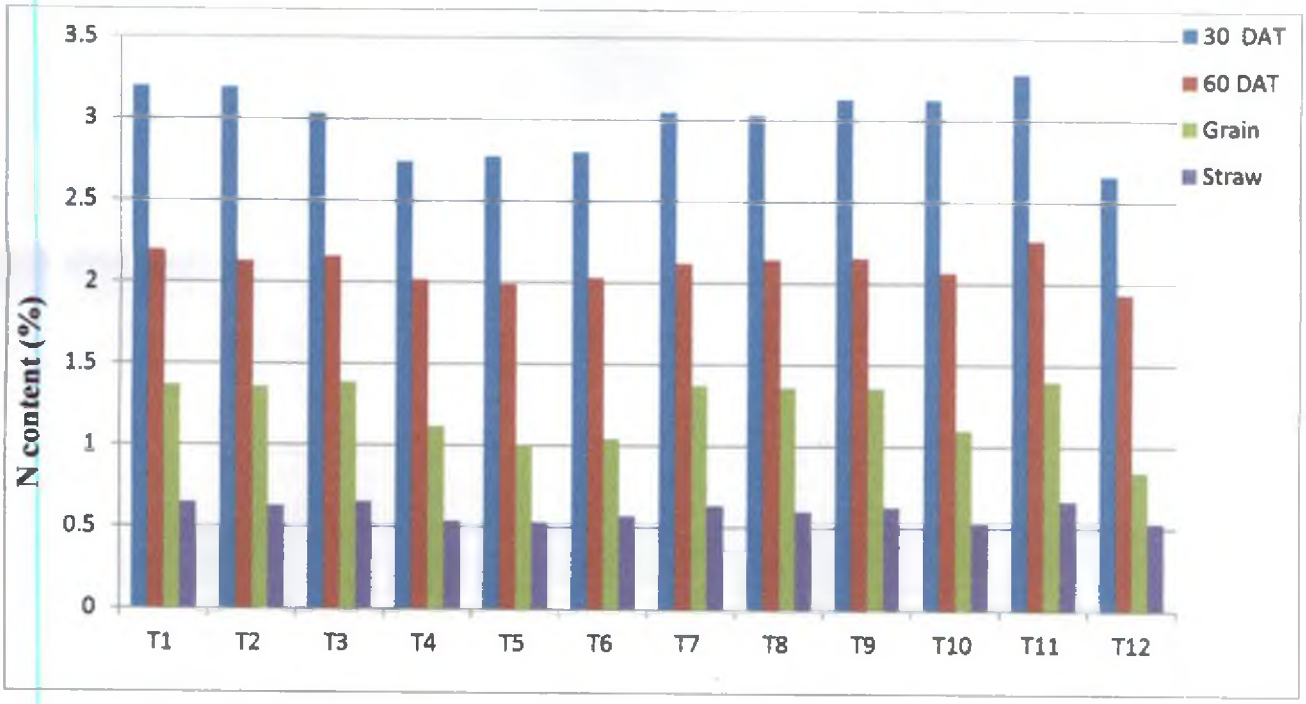
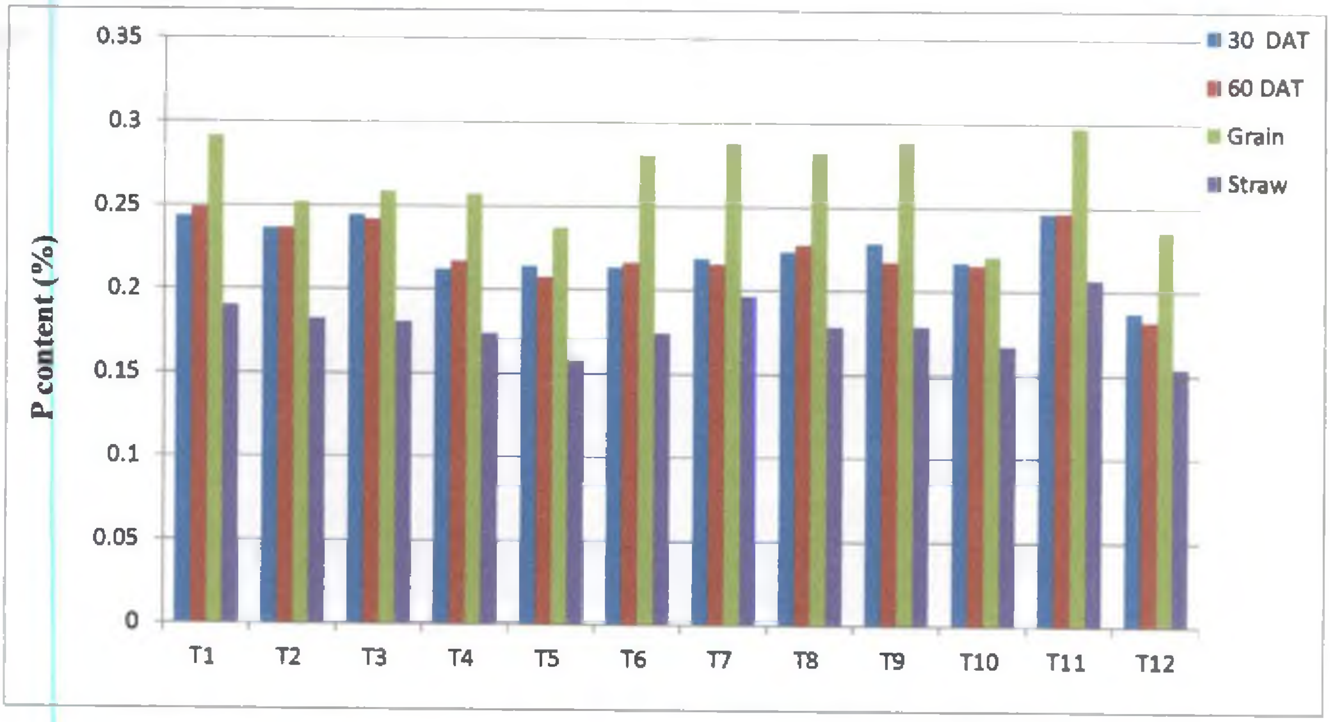


Fig. 5.8 Effect of treatments on phosphorus content (%) of rice at 30, 60 DAT & harvest



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11}.FYM +Cao + NPK, T_{12}. Con.

application (T_{11}) showed significantly higher N uptake by grain. This might be due to favourable effect of physical and chemical environment of soil with FYM application which causes continuous supply of nutrients as reported by Chandrapala *et al.* (2010) and Singh (2006) also.

All the soil ameliorated treatments showed a higher P content at different stages than the non ameliorated treatments. The availability of P increases with increase in pH of laterite soil. In the case of potassium content of rice also, a similar trend was observed and may be due to more availability of Ca in the soil solution decreased for the different ameliorants. The cationic competition between Ca and K can result in more absorption of K in plant. Deguchi and Ota (1957) reported that Ca stimulated the absorption of P and K under certain concentration ranges of ions in nutrient solutions. Application of CaO 377 kg ha^{-1} along with FYM and NPK recorded significantly higher P uptake in grain. P uptake by straw was highest in treatment which received Ca, Mg and S along with fertilizers. T_{11} which received soil ameliorant, fertilizer and organic manure recorded significantly higher total P uptake by the rice crop. Padmaja and Varghese (1972) observed an increase in phosphorus content of the grain and straw by the application of calcium.

There was a gradual reduction in potassium content according to the growth stages and the highest was at 30 DAT due to the active absorption. The application of NPK and CaO as per POP and the treatment which received the same combination along with FYM recorded the highest K content at 30 DAT (Fig. 5.9). This may be due to the integrated use of FYM with fertilizers, which determine the adsorption and release of K in soil colloids and subsequent enhanced absorption by plant. Similar results were reported by Chandrapala *et al.* (2010). Deguchi and Ota (1957) observed increase in absorption of K by the addition of Ca. Jacobson *et al.* (1961) reported that Ca stimulates absorption of K and Rb while it inhibits the absorption of Na and Li in plant roots. Erdei and Zsoldos (1977) also observed the same stimulatory effect of Ca on uptake of K. Marykutty (1986) reported that application of lime significantly

Fig. 5.9 Effect of treatments on potassium content (%) of rice at 30, 60 DAT & harvest

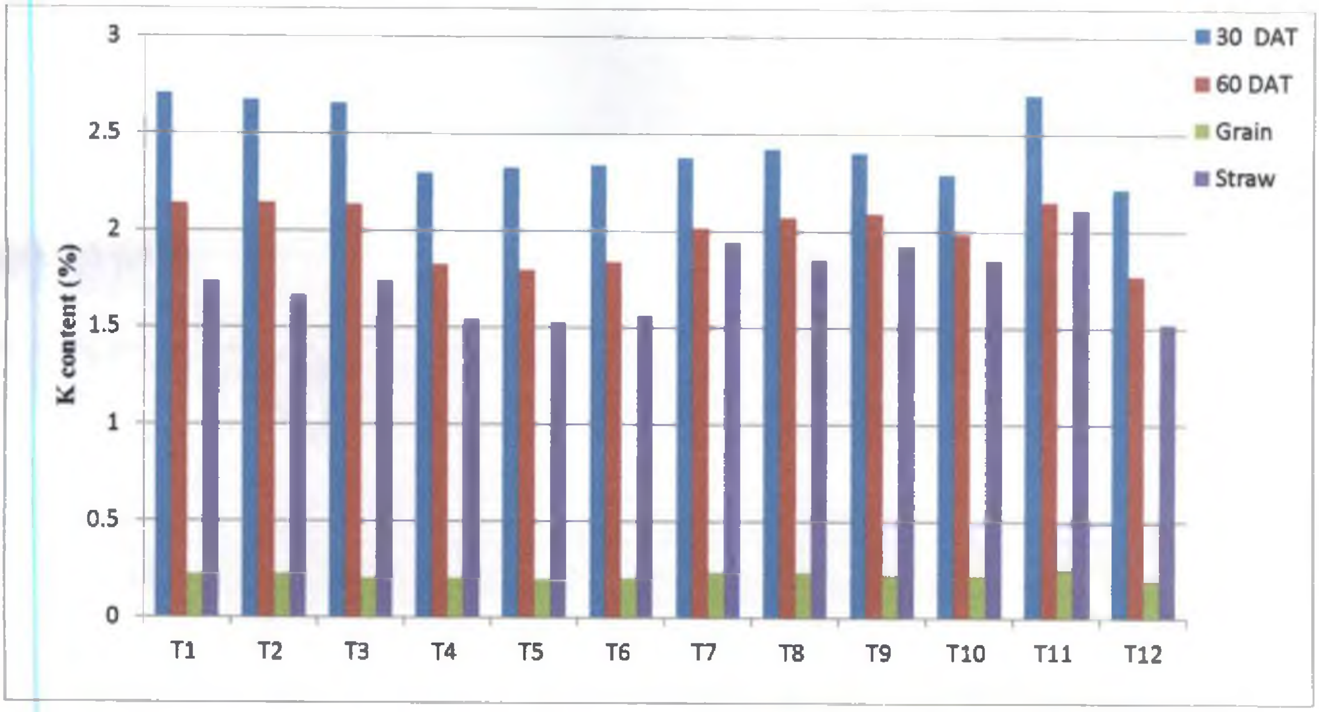
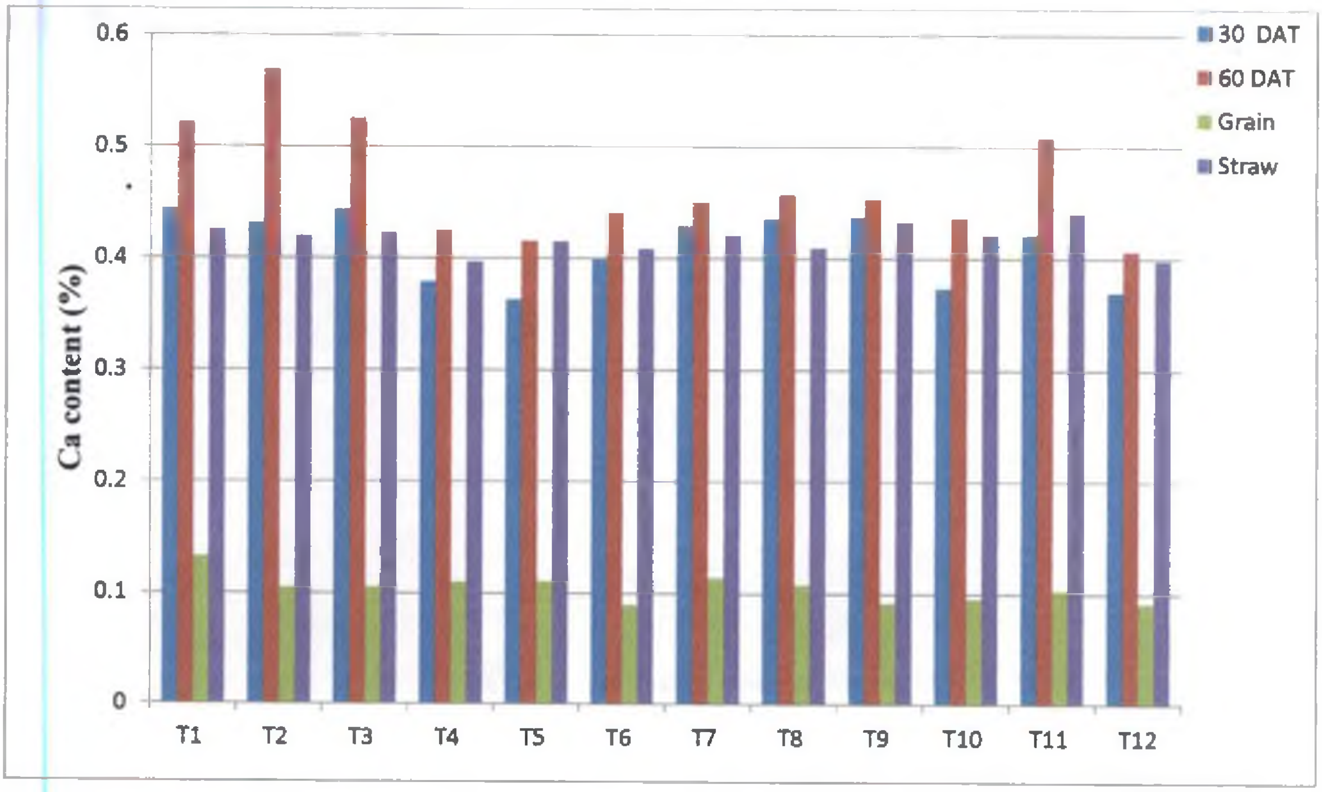


Fig. 5.10 Effect of treatments on calcium content (%) of rice at 30, 60 DAT & harvest



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11}-FYM +Cao + NPK, T_{12}-Con.

decreased available potassium status of the soil from a mean value of 85 ppm to 39.7 ppm. Sudhir *et al.* (1987) reported that absorption of K was stimulated by Ca ions at low concentrations and decreased at high concentrations. The application of CaO + NPK + FYM recorded higher K uptake by grain due to the increased supply in the soil for absorption by plants. This may lead to increased content and uptake as reported by Chandrapala *et al.* (2010). The highest K uptake by straw was noticed in treatment which received lower rate of soil ameliorant which contain Ca, Mg and S. Total uptake has also highest in the same treatment. This may be due to the Mg content of applied soil ameliorant. Singh and Singh (2005) also reported that the application of Mg also increased the accumulation of K in leaf tissues.

Application of soil ameliorants along with recommended fertilizers resulted in highest calcium content at 30 DAT. 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) and Suswanto *et al.* (2007) reported that the best yield of rice (14.15 t ha^{-1}) was obtained for treatment with 4 t/ha lime together with 120 kg N/ha + 16 kg P/ha + 120 kg K/ha. This shows that liming together with fertilizer management improves rice production. The lowest calcium content at 30 DAT was observed in the treatment which received both calcium and magnesium through dolomite. This may be due to the antagonistic effect between calcium and magnesium. This is in line with the report of Kumar *et al.* (1981).

In the case of magnesium content of rice plants, all the soil ameliorated treatments along with fertilizers showed higher magnesium content at all the growth stages. Sometimes relatively lower pH in laterite soil lead to slow dissolution and release of Mg applied in soil (Varughese and Jose, 1993). The content of Ca and Mg in flag leaves and rice yield increased with limestone surface application (Soratto *et al.*, 2007). Kobayashi *et al.* (2005) reported that in rice, the excess Mg treatment

Fig. 5.11 Effect of treatments on magnesium content (%) of rice at 30, 60 DAT & harvest

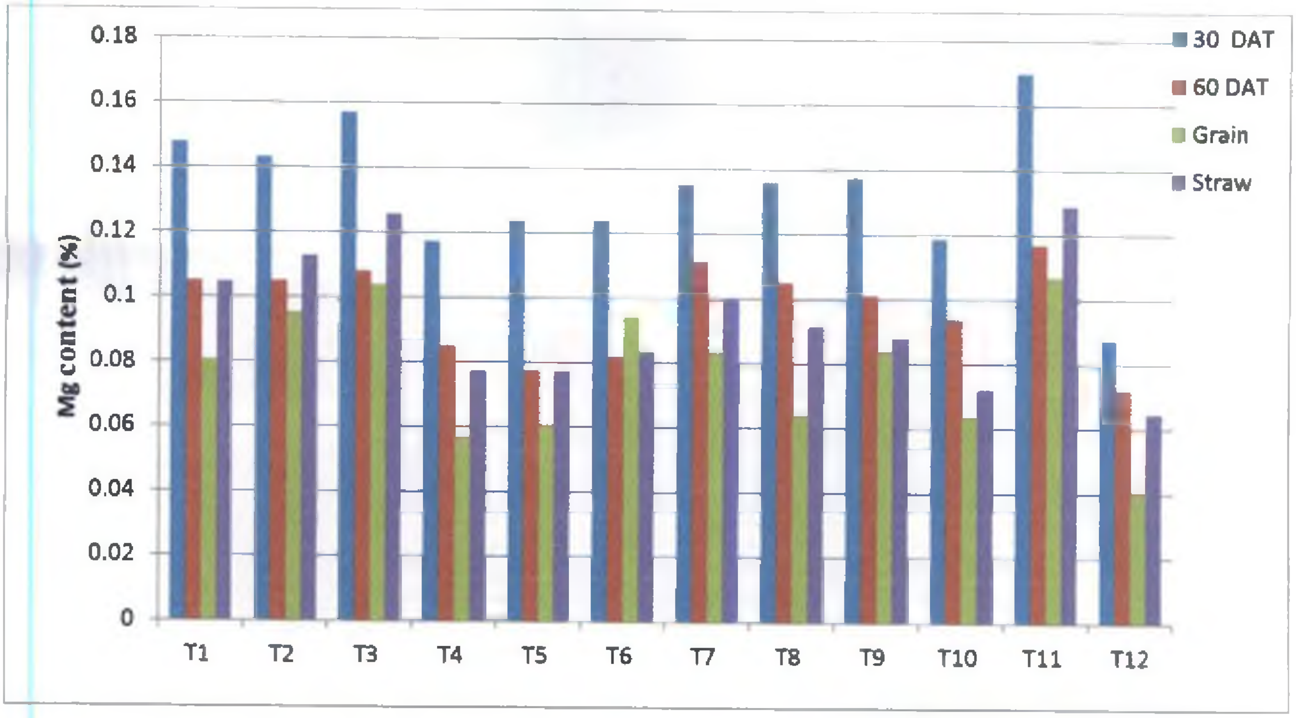
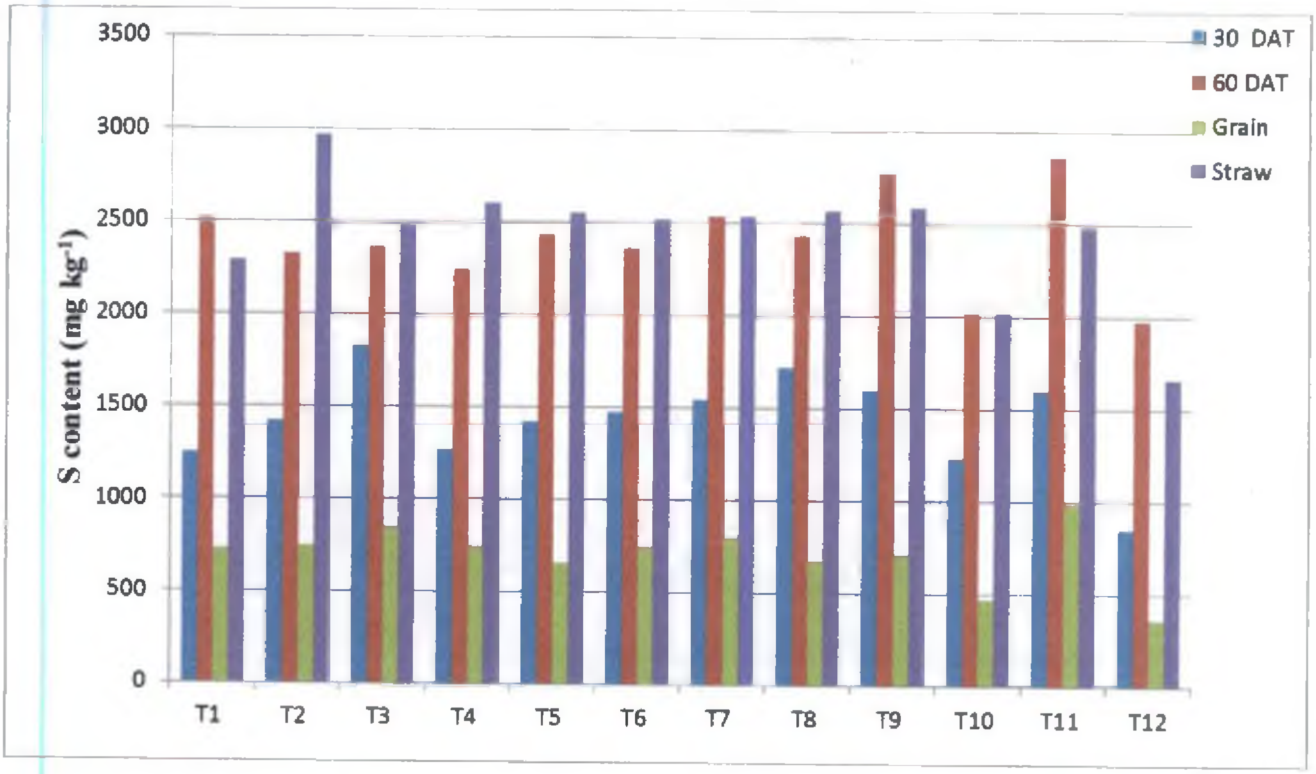


Fig. 5.12 Effect of treatments on sulphur content (mg kg^{-1}) of rice at 30, 60 DAT & harvest



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11}-FYM +Cao + NPK, T_{12}- Con increased the Mg content of shoots and roots, and the potassium and chloride contents of roots, but slightly decreased the Ca and K contents of shoots.

In this experiment sulphur is applied along with calcium and magnesium through soil ameliorant. High sulphur content was observed in the soil ameliorated plots than the non ameliorated treatment and control. So, the ameliorative effect of the calcium may be the reason for the higher S content in rice plant. Aulakh and Dev (1978) observed that when Ca content was increased, there was synergistic effect. Prabhakumari (1992) observed synergism between S and Ca.

Application of sulphur up to 60 kg/ha increased the growth attributes and yield of rice (Singh *et al.*, 1993 and Raju *et al.*, 1995). However Liu *et al.* (1989) reported that application of sulphur retarded organic matter accumulation in paddy soil, increased available phosphorus and sulphur and related potassium from the clay crystal lattice.

Significant reduction in Fe content of rice plant at 30 DAT, 60 DAT and in straw at harvest may be due to the combined application of nutrients through soil ameliorants along with recommended fertilizers and FYM. It indicated that low Fe absorption favoured the absorption of other nutrients which resulted in higher yield. Liming the soil decreased available Fe and Mn and increased pH, and reduced iron toxicity (Patra and Mohanty, 1994).

Fe is one of the three essential elements that causes major limitation to rice grain yield in tropical environment, the other two being nitrogen and phosphorus (Panda *et al.*, 2012). The toxicity of Fe associated with inhibition of uptake and utilization of essential nutrients like P, K, Ca, Mg and Zn by rice leading to their deficiency known as indirect or pseudo Fe toxicity (Sahrawat, 2004 and Tanaka *et al.*, 1966).

Fig. 5.13 Effect of treatments on iron content (mg kg^{-1}) of rice at 30, 60 DAT & harvest

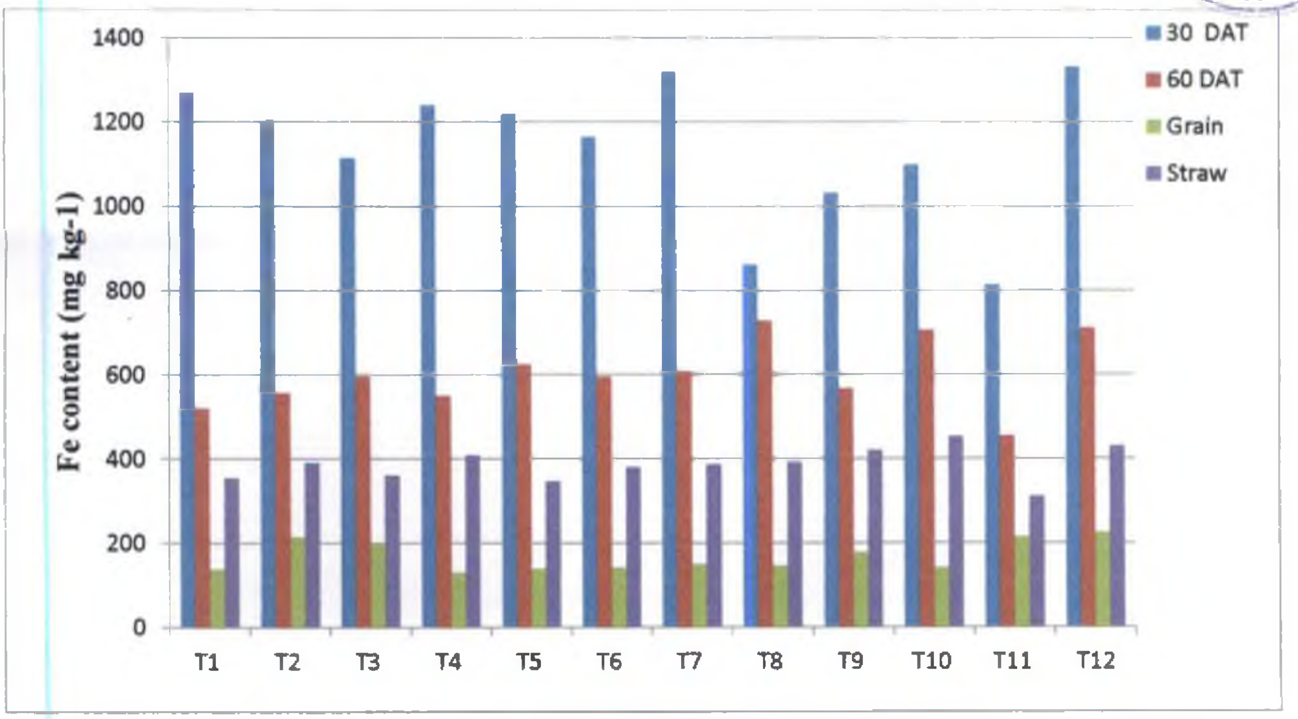
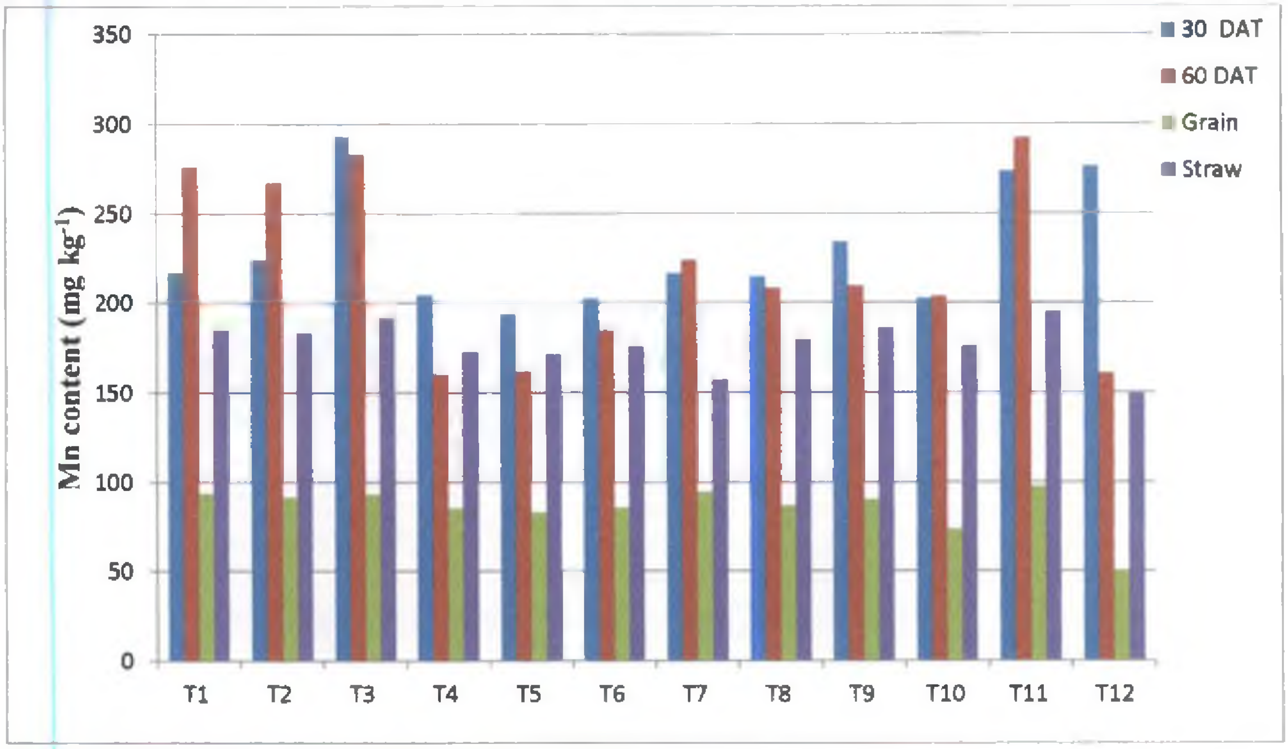


Fig. 5.14 Effect of treatments on manganese content (mg kg^{-1}) of rice at 30, 60 DAT & harvest



T$_1$, T$_2$, T$_3$- CaO, Dolo,MS respectively + NPK T$_4$, T$_5$, T$_6$ - CaO, Dolo,MS respectively - NPK

T$_7$, T$_8$, T$_9$- MS 250,375,500 kg ha^{-1} respectively + NPK T$_{10}$ - NPK only, T$_{11}$ FYM +Cao + NPK, T$_{12}$ Con

Fig. 5.15 Effect of treatments on zinc content (mg kg^{-1}) of rice at 30, 60 DAT & harvest

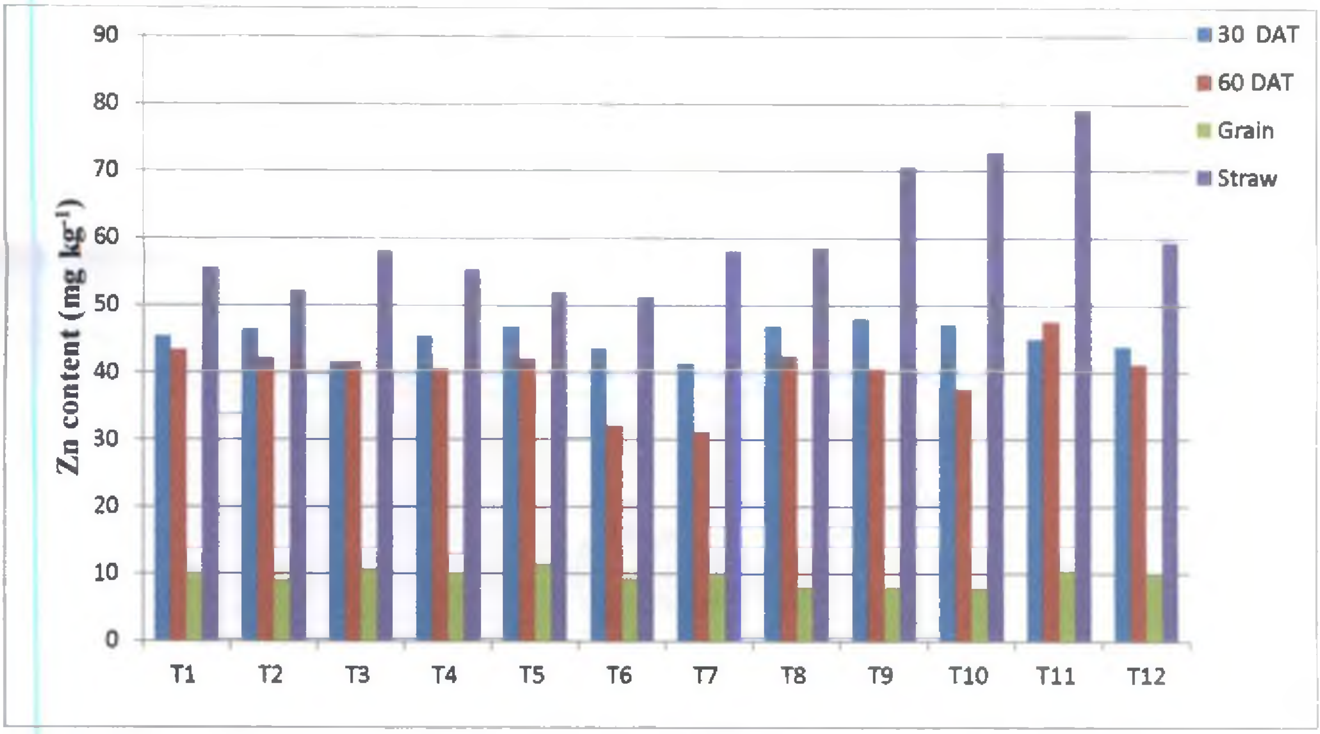
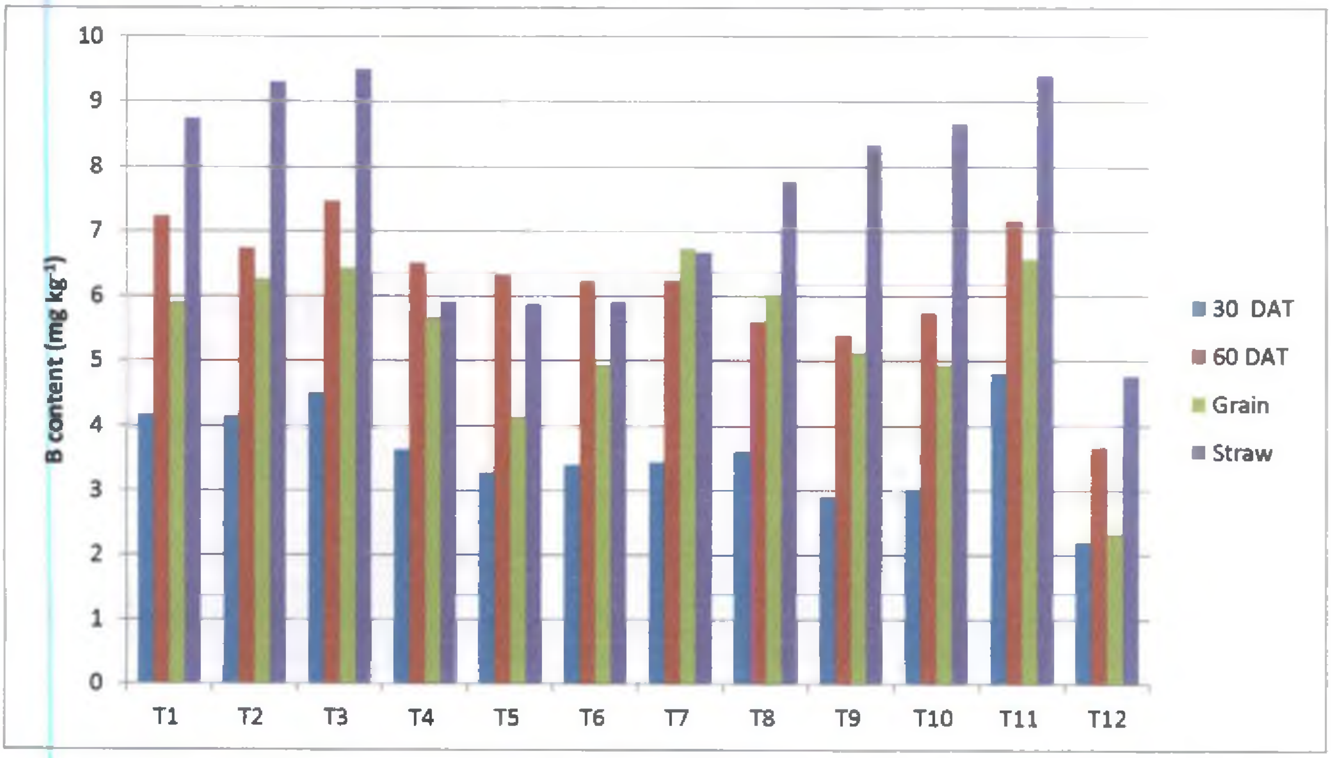


Fig. 5.16 Effect of treatments on boron content (mg kg^{-1}) of rice at 30, 60 DAT & harvest



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11}.FYM +Cao + NPK, T_{12}. Con.

Fig. 5.17 Effect of treatments on copper content (mg kg^{-1}) of rice at 30, 60 DAT & harvest

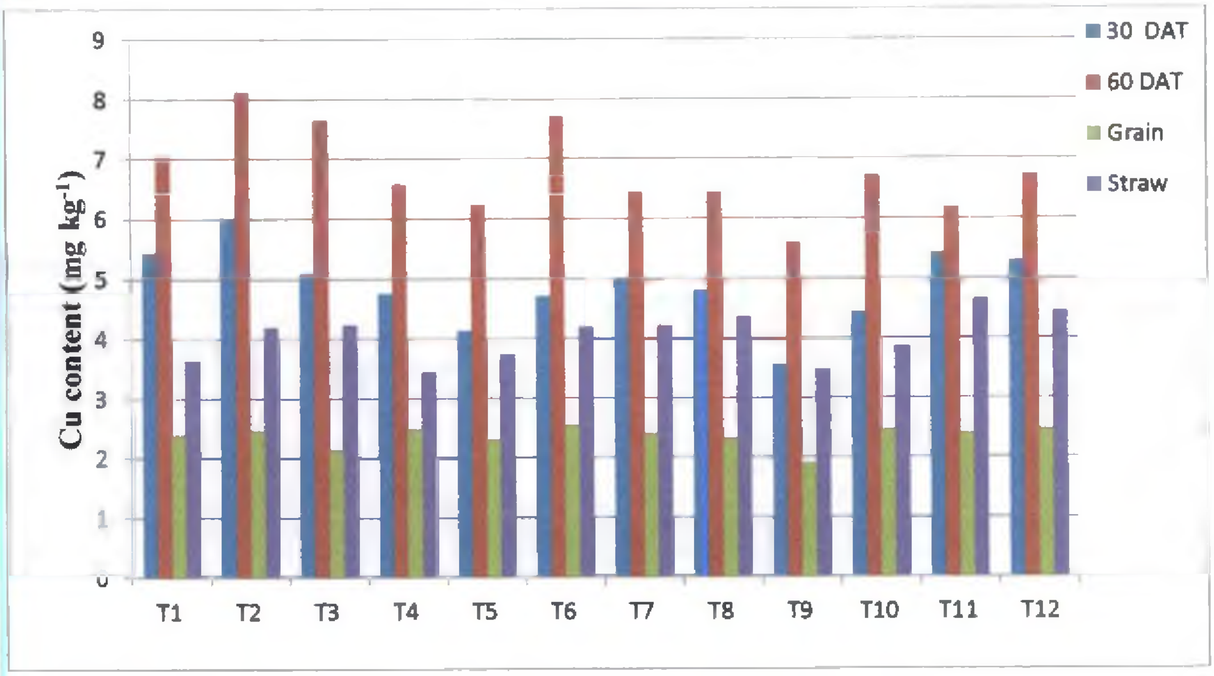
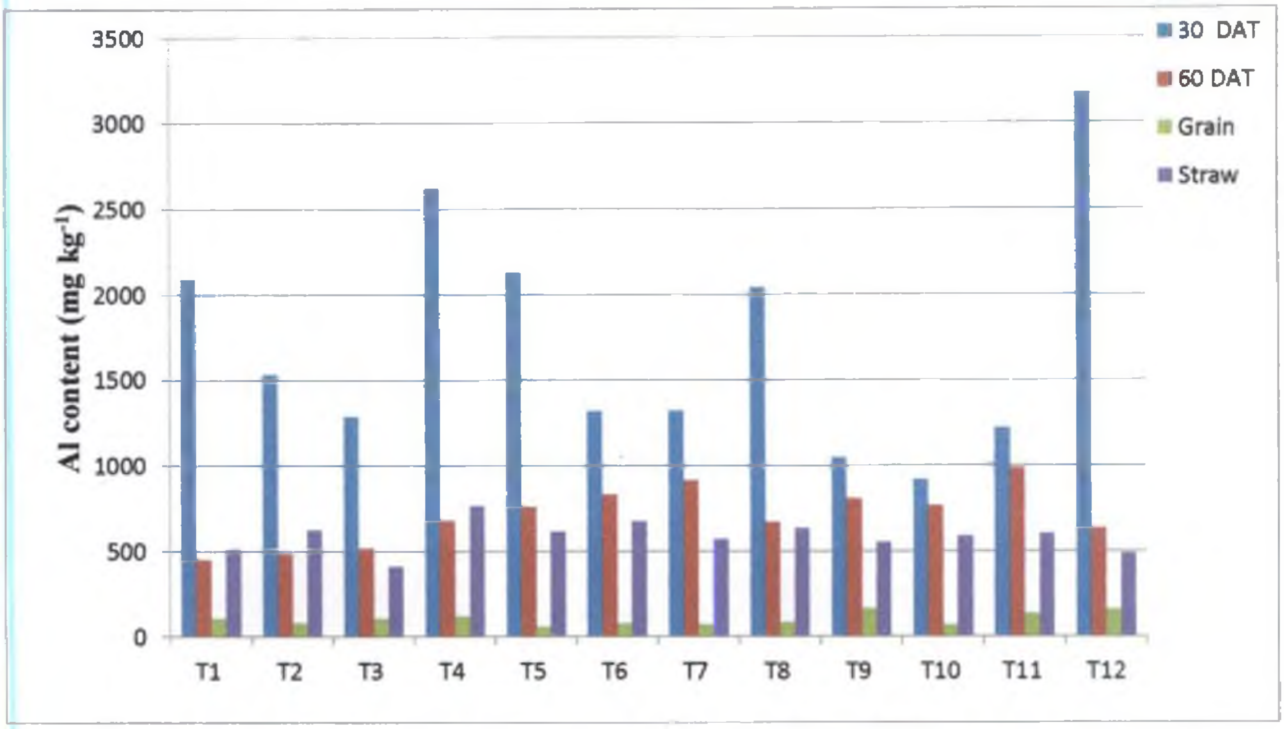


Fig. 5.18 Effect of treatments on aluminium content (mg kg^{-1}) of rice at 30, 60 DAT & harvest



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11}-FYM +Cao + NPK, T_{12}- Con

The application of POP NPK along with FYM and CaO recorded the highest Mn content at all the stages. There was decline in Mn content with the advancement of plant age as reported by Fageria (2004). One tonn of FYM may add 1.32 kg Mn depending upon its source (Kumar and Singh, 2010). So the application of FYM may lead to increased availability of Mn in soil solution for the absorption by plant which in turn increased its content in plant.

5.4 Soil characteristics

The soil pH before rice planting was 5.31, which is normally considered unsuitable for optimum rice growth. pH values on 20 and 25 DAT showed noticeable improvement in all treatments, even in control. Continuous submergence of soil as practiced in rice cultivation may bring the soil pH towards neutrality. CaO @ 377 kg/ha together with FYM and NPK, and 'Mangala setright' @ 375 to 774 kg/ha constantly maintained a pH of more than 6, which is considered good for rice. Dolomite with or without fertilizer could improve the soil pH, but could not maintain it. Wherever no ameliorants were used significantly lower pH was observed at 25 DAT. In similar results reported by Lee *et al.* (2011) liming improved soil pH and other nutrient conditions. Conclusively, CaO could be a good material to restore nutrient balance in rice soil.

The EC of soil increased after the experiment in all the treatments compared to the initial value. This may be due to the increased total soluble salts in the soil due to the application of nutrients. The organic carbon content of the soil after the experiment got reduced compared to the initial value in all the treatments. Organic matter decomposition and oxidation of carbon were expected to be higher under the increasing temperature during the summer season. Irrigation and drainage during summer season favour high oxidation rate and it enhance the harvesting period.

CaO + NPK + FYM application to rice crop recorded significantly higher quantity of available N after the harvesting of crops. Kumar and Singh (2010) reported that the application of NPK along with FYM gave significantly higher available N. This may be due to the increased addition of N from fertilizer and FYM (Chandrapala *et al.*, 2010). There was a decrease in available nitrogen content from the initial value after the harvesting of rice in all treatments. The decrease in soil N might be associated with crop uptake, immobilization of fertilizer N and its leaching under submerged condition (Yadav and Kumar, 2009). However Rathore *et al.* (1995) observed that residual soil fertility of available nutrients increased under FYM application. The continuous application of 120 kg N ha^{-1} every year failed to maintain the initial level of mineralized soil N. An increase in the available N and P content of the soils by the application of graded levels of lime was observed by Marykutty (1986).

The status of available phosphorus content after the harvesting of rice crop decreased from the initial value. This may be due to low pH and dominance of Fe in soil which leads to the fixation of phosphorus (Dixit, 2006). Slaton *et al.* (2002) reported that phosphorus is generally most available to plants when the soil pH ranged between 6.0 to 6.5. When the pH is < 6.0, the potential for P deficiency for most crops increases. Treatment which contains FYM recorded significantly higher available P after the harvest of the crop. Prasad (2007) reported that organic manure can supply 2-7 kg P_2O_5 /ton and when supplied @ 10 t/ha can meet most of the P requirements of a crop.

The content of available K in soil after the experiment remained almost steady compared to initial value. The application of nutrients did not have any effect on available K. The status of available K in soil was sufficient to supply adequate K. There is an antagonistic effect between K and Mg which resulted in reduced available K (Ananthanarayana and Rao, 1979).

Fig. 5.19 Effect of treatments on available N (kg ha^{-1}) of soil after the experiment

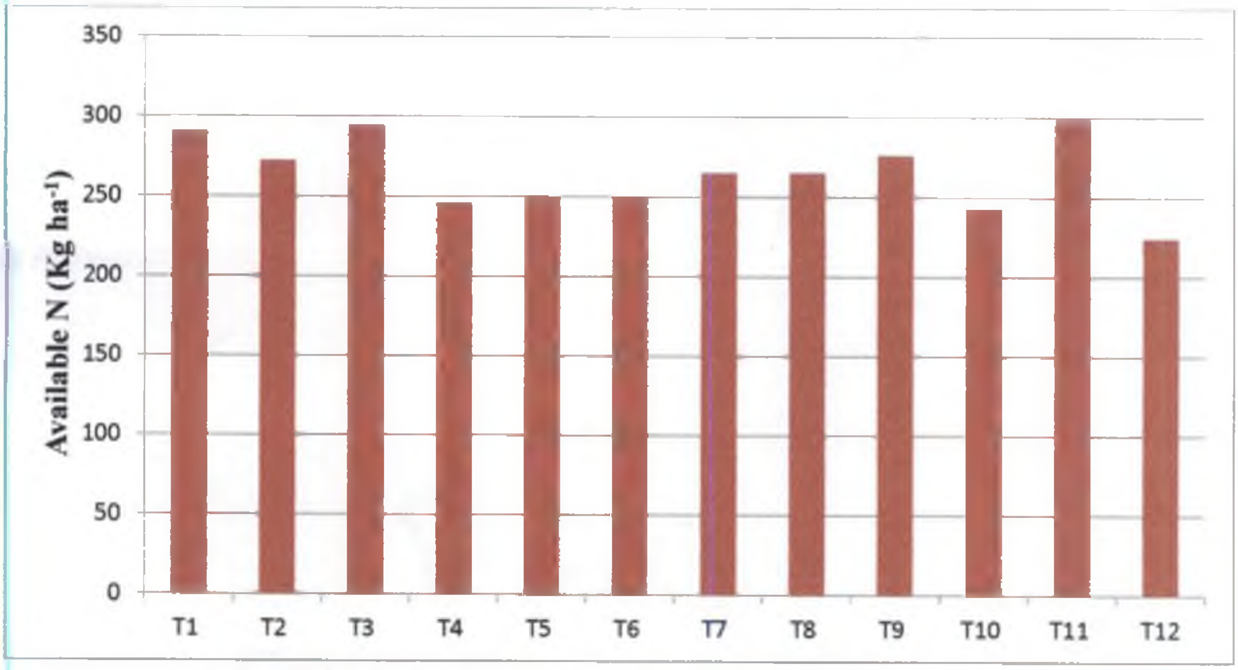
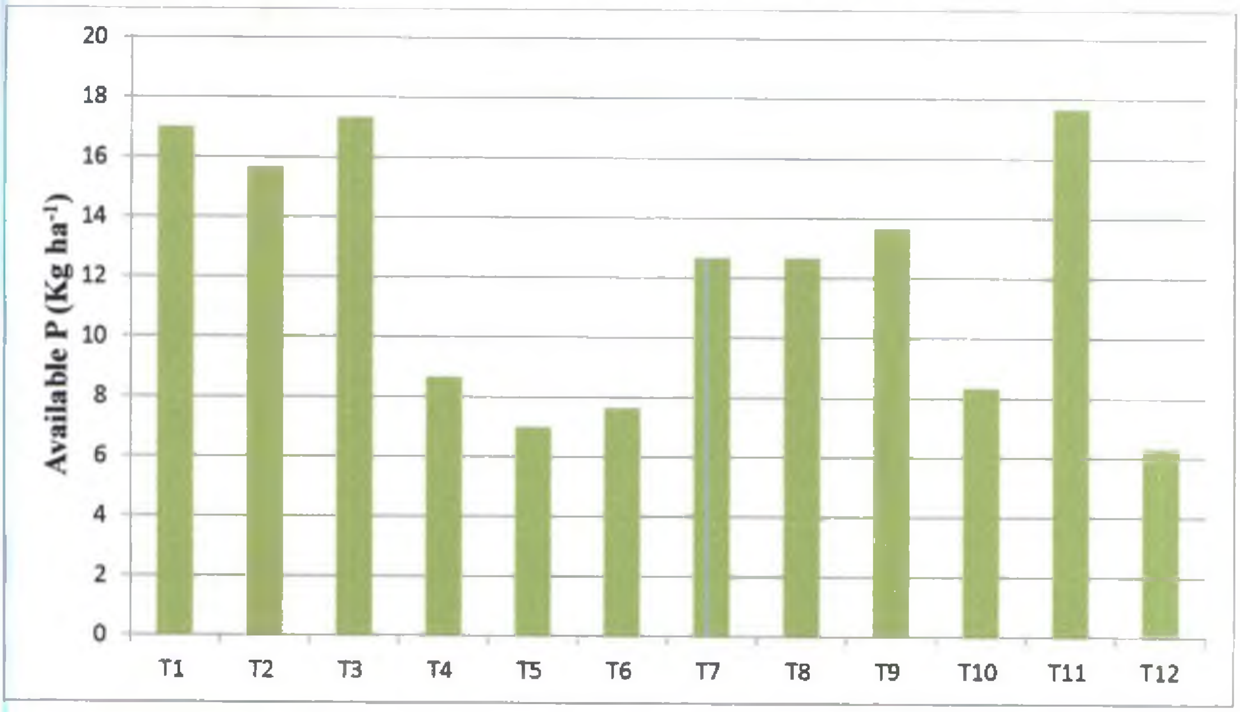


Fig. 5.20 Effect of treatments on available P (kg ha^{-1}) of soil after the experiment



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11}.FYM +Cao + NPK, T_{12}. Con.

The available Ca content in soil was decreased after the experiment compared to the initial value. Addition of Mg decreased the availability of calcium due to the calcium magnesium antagonism (Kumar *et al.*, 1981). The available Mg content in soil after the experiment showed a steady value compared to the initial value. The dissolution and release of Mg from Mg fertilizer takes place very slowly in laterite soil due to low pH (Varughese and Jose, 1993).

The available S content in soil after the harvesting of the crop increased compared to the initial value. The available S content was significantly higher in T_3 which received highest rate of soil ameliorant along with recommended fertilizer application. This ameliorant contained Ca, Mg and S. Lowest S content was observed in control treatment where it was not applied.

The available Fe content in soil after harvesting of rice crop was decreased compared to initial value. This may be due to the effects of the applied soil ameliorants. Liming the soil decreased available Fe and Mn and increased pH to the greatest extent, and reduced iron toxicity (Patra and Mohanty, 1994). Though available Fe varied from 1118-1328 mg kg^{-1}, there were no significant differences among treatments.

The available Al content in soil before the experiment was too high as soil acidity increased the portion of exchangeable Al. Al toxicity is probably the major limiting factor to plant growth and crop production in strongly acidic soils (Foy, 1992). There was no noticeable change in available Al content after the experiment which indicated that the various ameliorants had not much effect on reducing the Al content.

Fig. 5.21 Effect of treatments on available K (kg ha^{-1}) of soil after the experiment

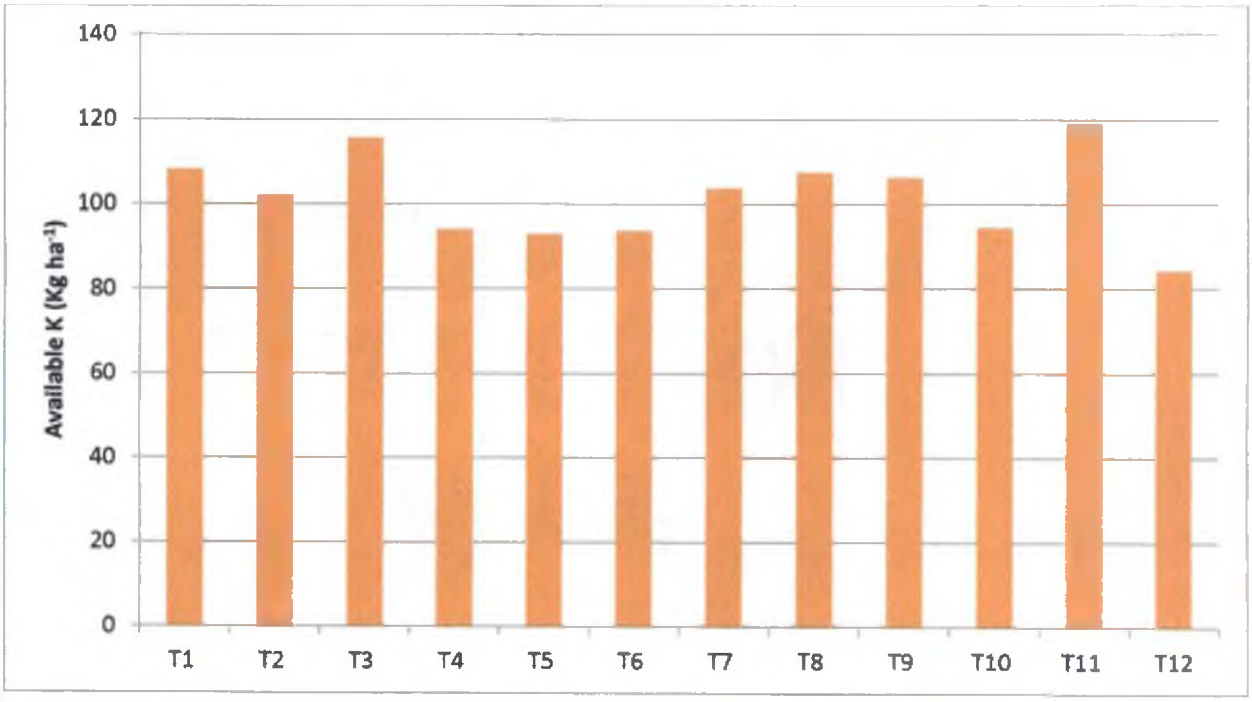
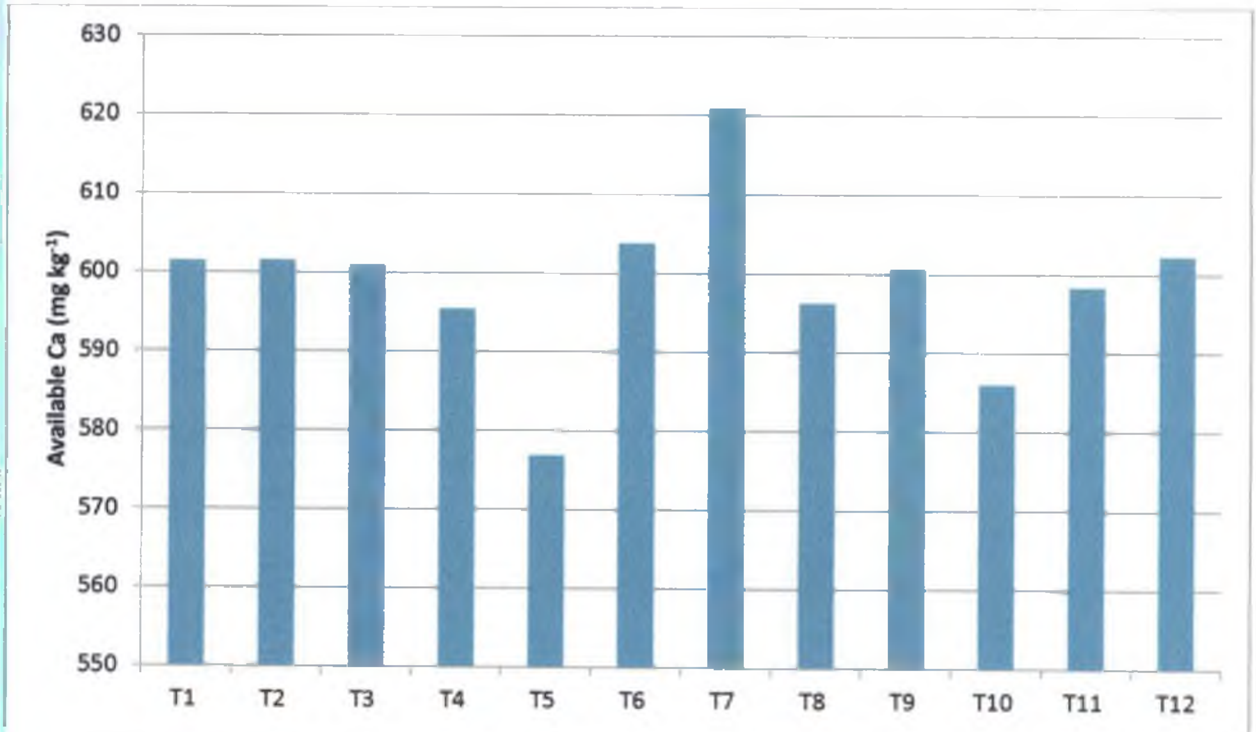


Fig. 5.22 Effect of treatments on available Ca (mg kg^{-1}) of soil after the experiment



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11}.FYM +Cao + NPK, T_{12}- Con.

Fig. 5.23 Effect of treatments on available Mg (mg kg^{-1}) of soil after the experiment

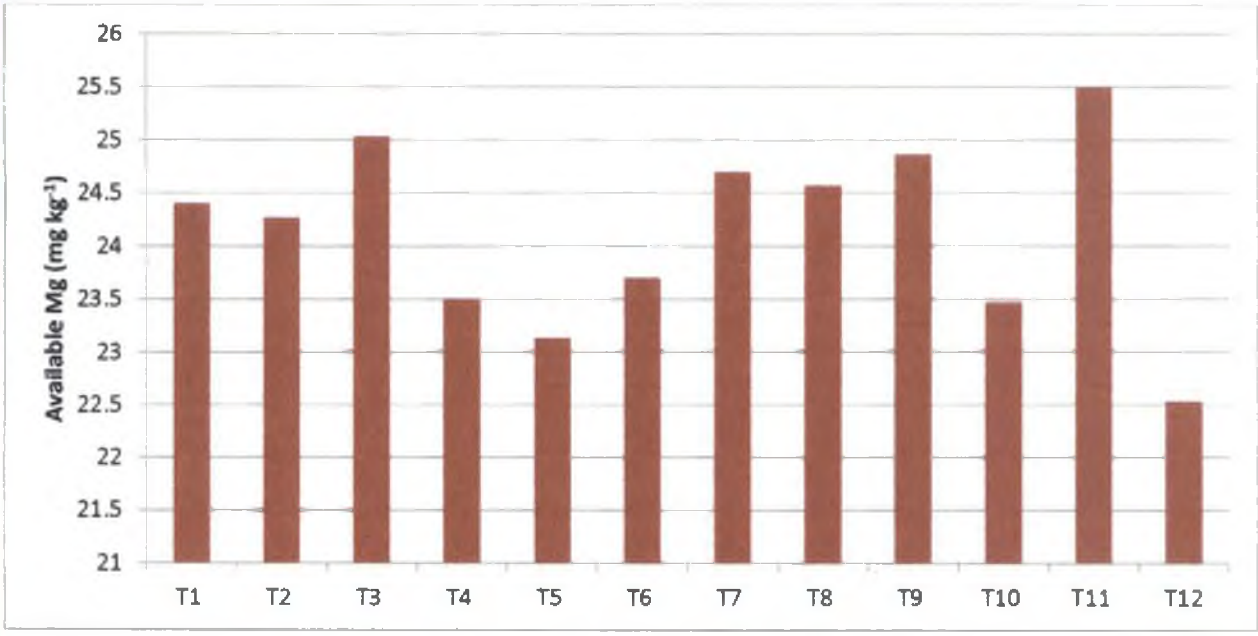
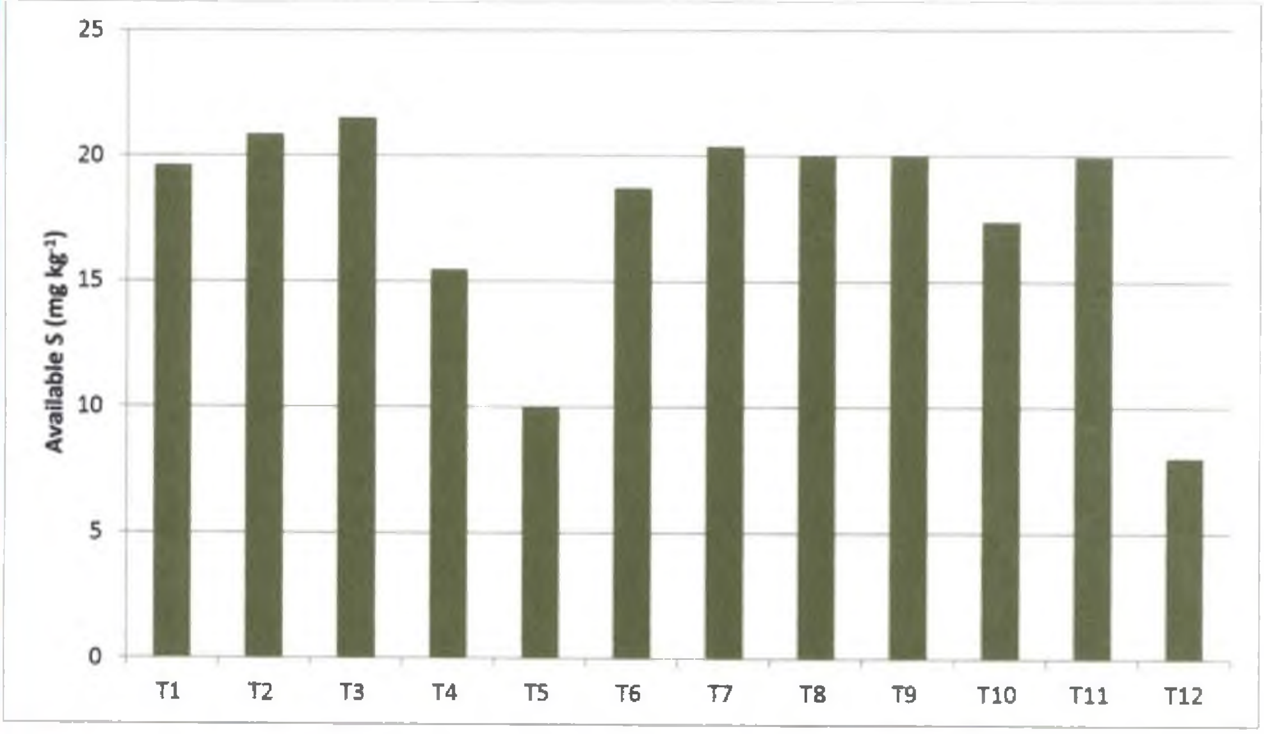


Fig. 5.24 Effect of treatments on available S (mg kg^{-1}) of soil after the experiment



T$_1$, T$_2$, T$_3$- CaO, Dolo,MS respectively + NPK

T$_4$, T$_5$, T$_6$ - CaO, Dolo,MS respectively - NPK

T$_7$, T$_8$, T$_9$- MS 250,375,500 kg ha^{-1} respectively + NPK

T$_{10}$ - NPK only, T$_{11}$-FYM +Cao + NPK, T$_{12}$- Co

Fig. 5.25 Effect of treatments on available Fe (mg kg^{-1}) of soil after the experiment

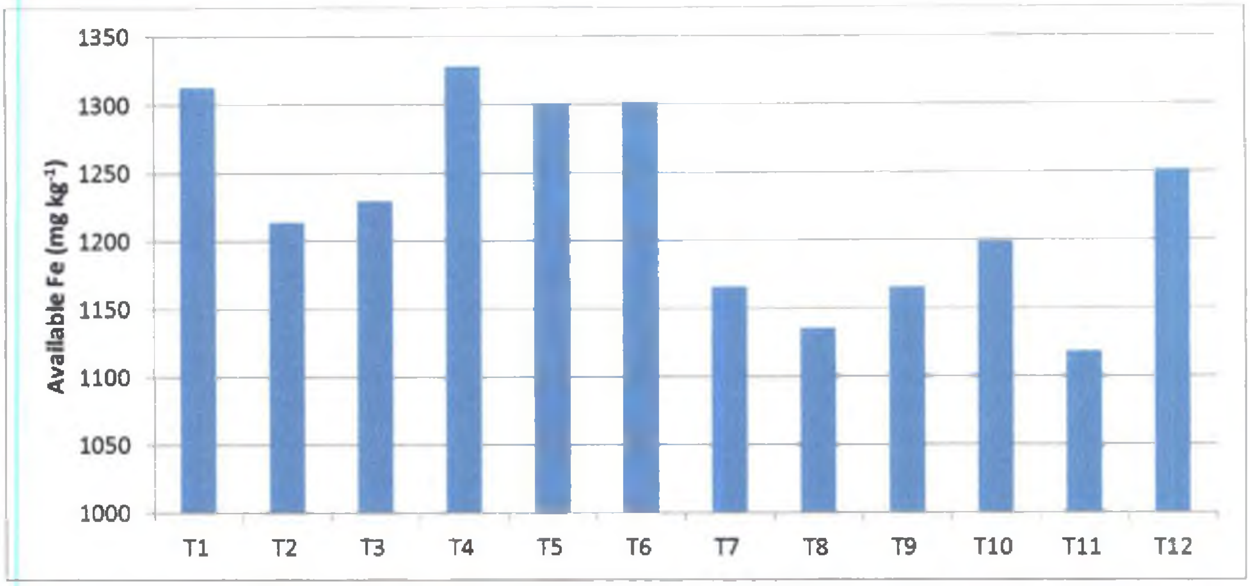
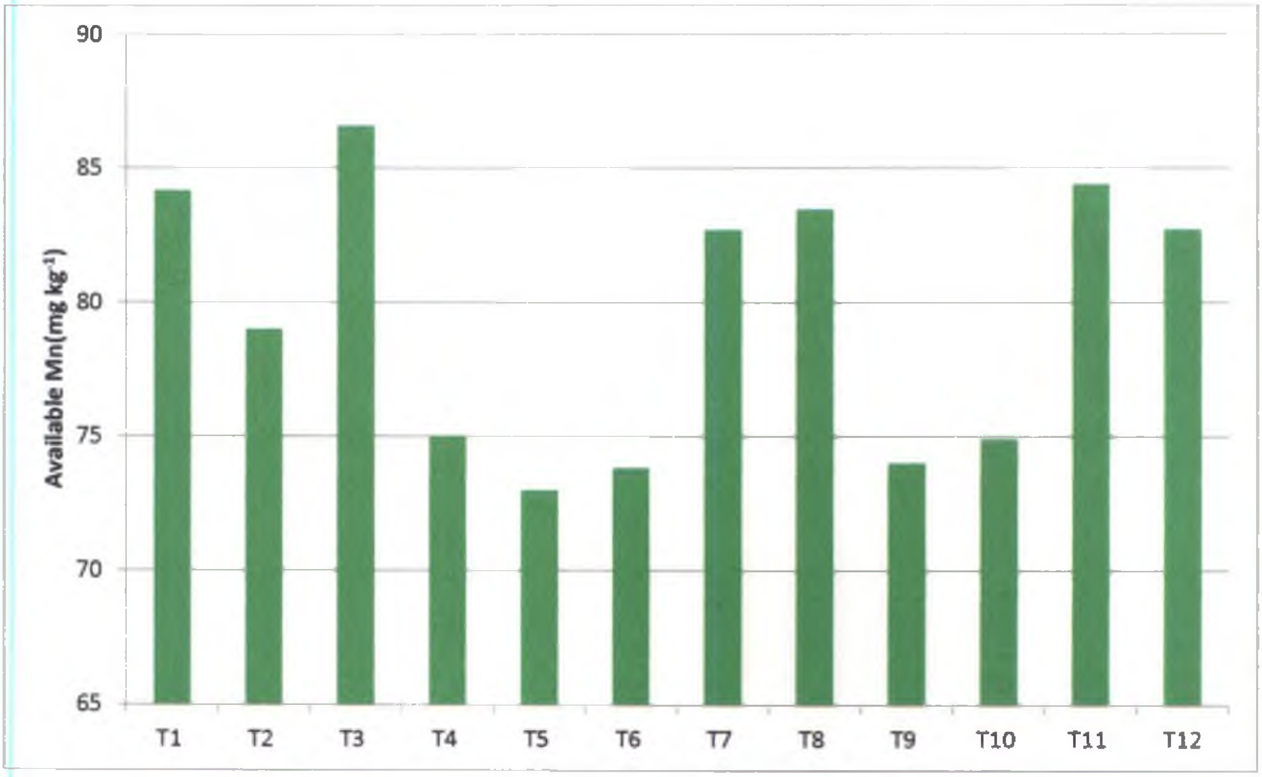


Fig. 5.26 Effect of treatments on available Mn (mg kg^{-1}) of soil after the experiment



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11}-FYM +Cao + NPK, T_{12}-Con

Fig. 5.27 Effect of treatments on available Zn (mg kg^{-1}) of soil after the experiment

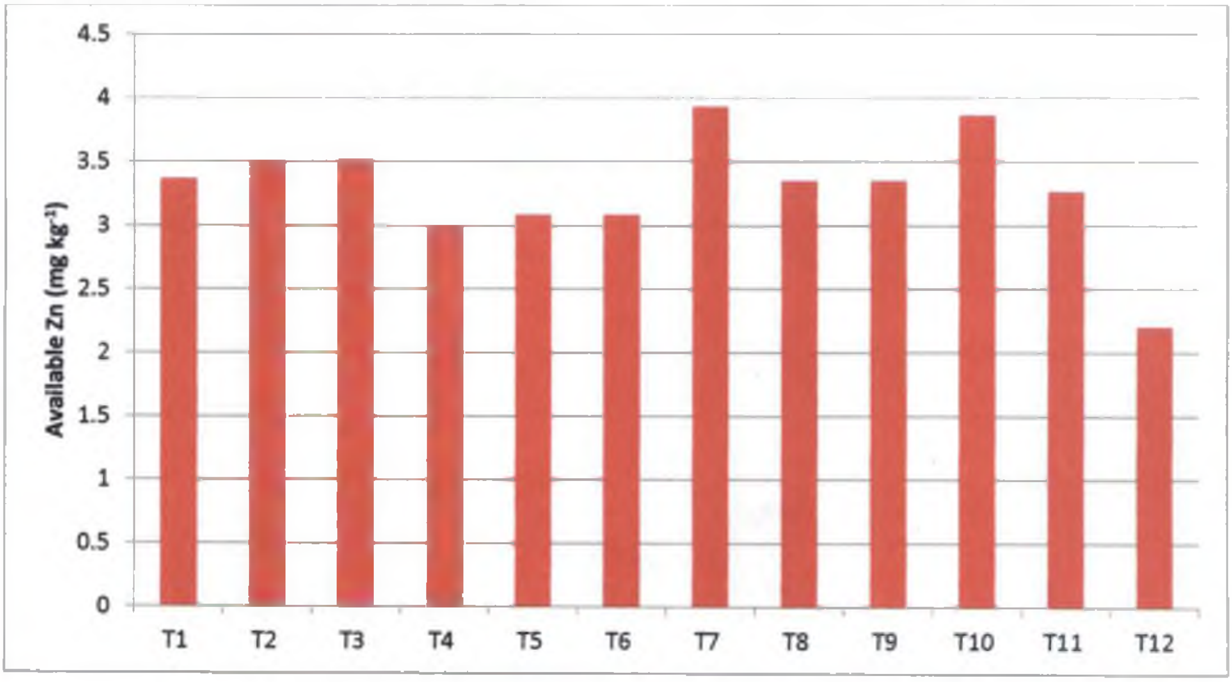
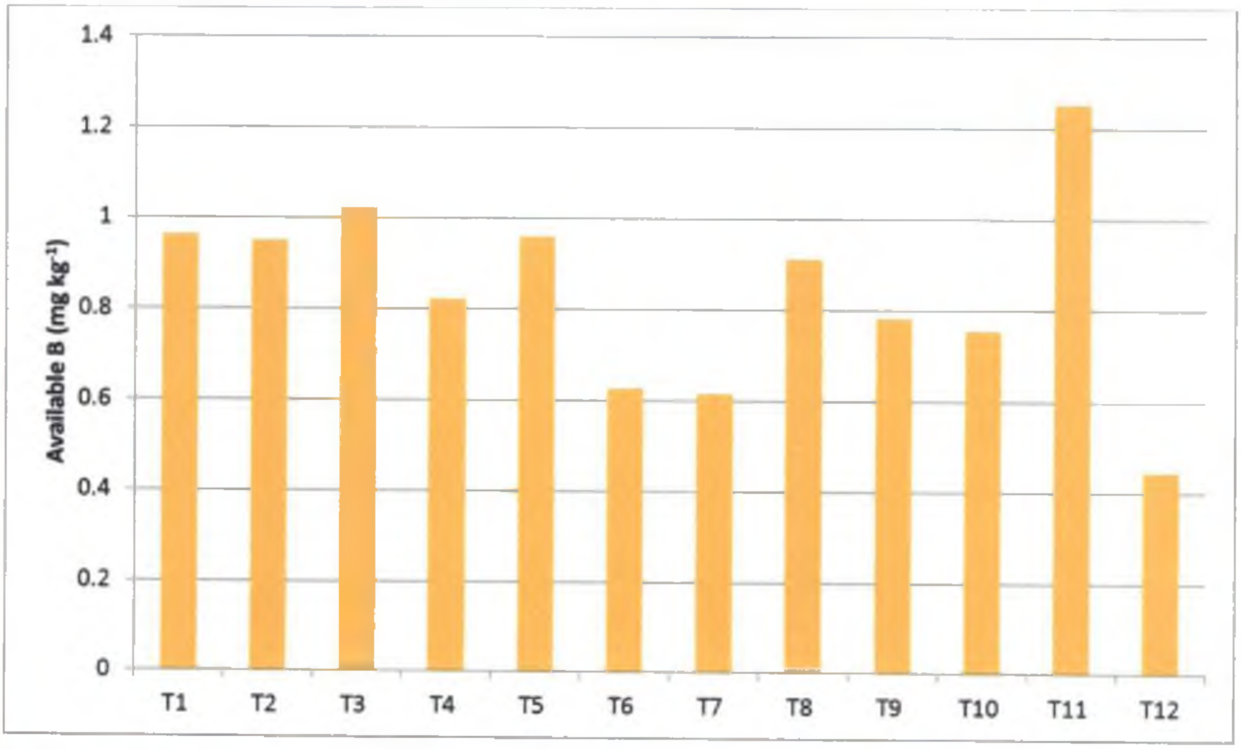


Fig. 5.28 Effect of treatments on available B (mg kg^{-1}) of soil after the experiment



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11} FYM +Cao + NPK, T_{12} Con.

Fig. 5.29 Effect of treatments on available Cu (mg kg^{-1}) of soil after the experiment

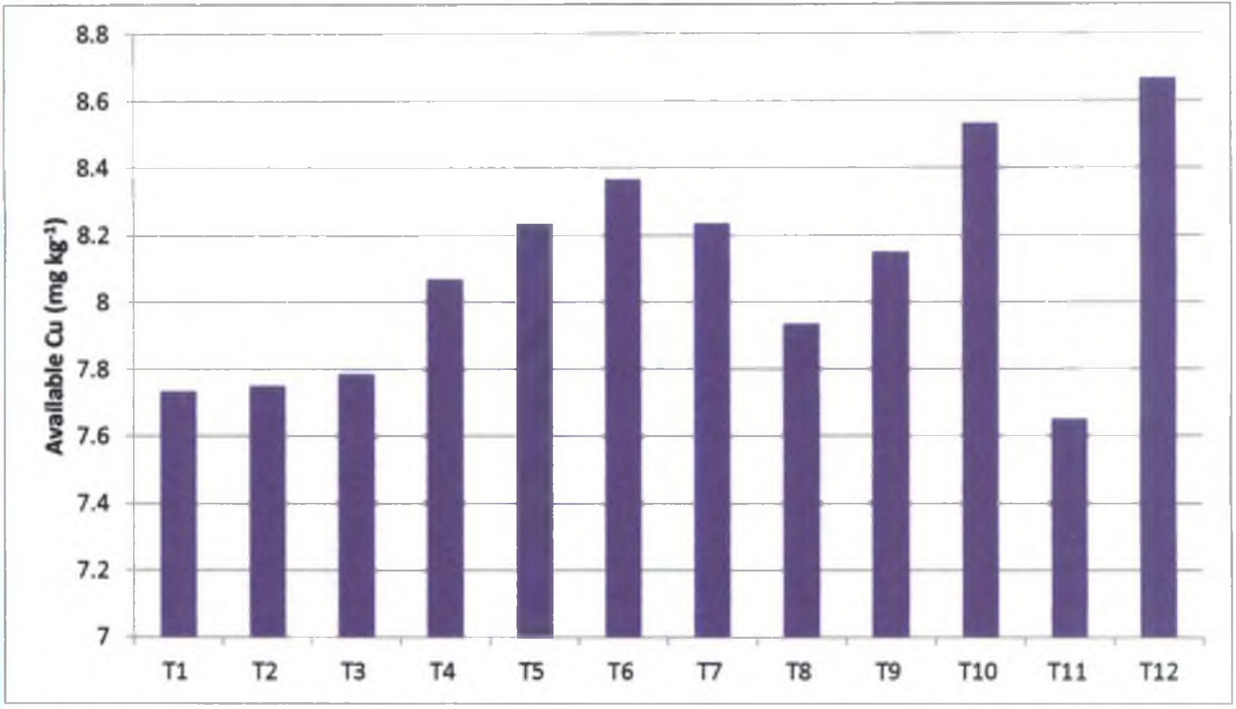
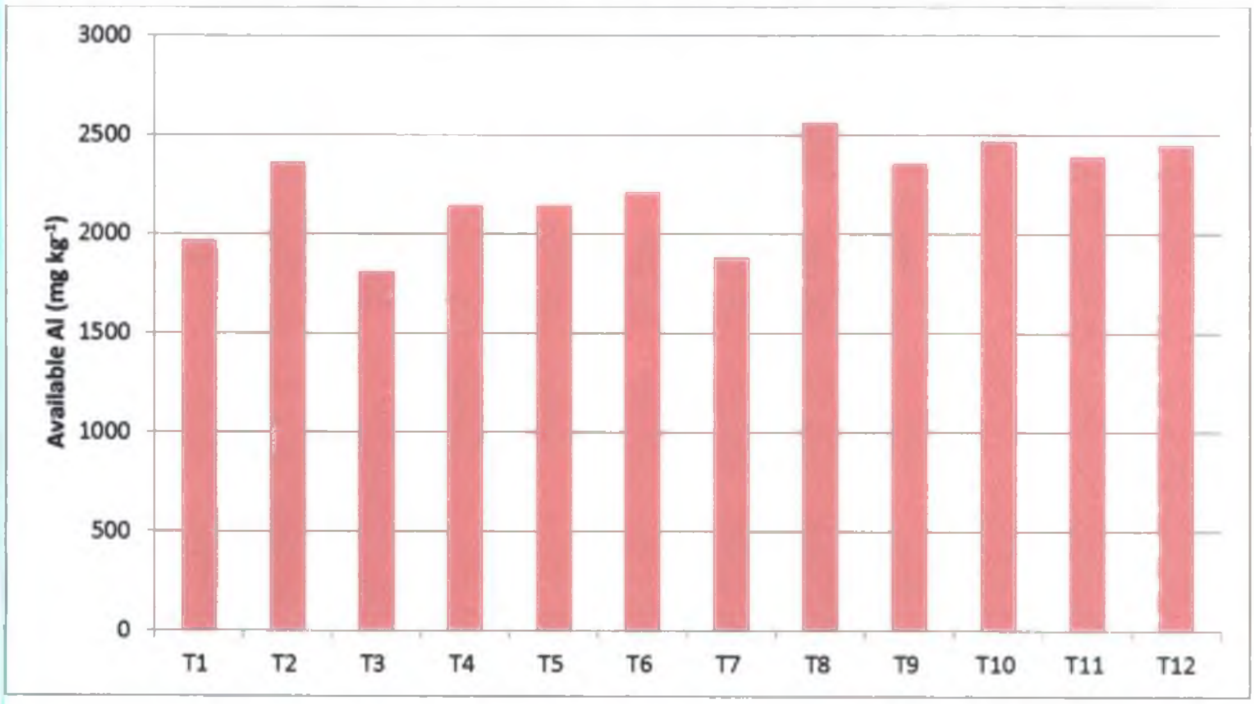


Fig. 5.30 Effect of treatments on available Al (mg kg^{-1}) of soil after the experiment



T_1, T_2, T_3- CaO, Dolo,MS respectively + NPK T_4, T_5, T_6 - CaO, Dolo,MS respectively - NPK

T_7, T_8, T_9- MS 250,375,500 kg ha^{-1} respectively + NPK T_{10} - NPK only, T_{11}-FYM +Cao + NPK, T_{12}-Con

SUMMARY

VI. SUMMARY

A field study was conducted during January to May, 2013 at the rice field of College of Horticulture, Vellanikkara to evaluate the response of soil ameliorants on growth and yield of rice. The experimental design was RBD with three replications. The soil was having an initial pH of 5.3. The treatments were amelioration of soil with different amendments such as CaO, dolomite, and 'Mangala setright', which is a commercial product. The ameliorants were applied with or without fertilizer. The package of practices (POP) for rice nutrition and non- application of soil ameliorant, organic manure and fertilizers were tried as controls.

The plant samples were drawn at 30 DAT, 60 DAT and at harvest and were analyzed for macro and micronutrients. The soil samples collected after the experiment were analyzed for pH, OC, EC and available nutrients viz. N, P, K, Ca, Mg, S, Fe, Mn, Zn, B, Cu and available Al. The results of the study are summarized and listed here.

1. Soil amelioration has resulted in significantly higher plant height both at 30 DAT and harvest. The treatment POP for rice nutrition produced tallest plants at harvest, possibly due to the multifunctional advantage of organic manure included in the treatment. Among the different ameliorants applied without the fertilizer component, CaO and 'Mangala setright' performed better than dolomite. However when the ameliorants applied together with fertilizers the plant height was at par even though 'Mangala setright' produced the tallest plants (100.4 cm).
2. The tiller count at 30 DAT was significantly higher for 'Mangala setright' applied @ 500 kg ha^{-1}. The tiller count at 60 DAT (15.9) was the highest when 'Mangala setright' was applied @ 774 kg ha^{-1}.
3. Leaf area index of 5.9 was significantly higher for the POP treatment. When ameliorants were given with and without fertilizer, 'Mangala setright'@ 774 kg ha^{-1} was better. However, in the presence of fertilizer all

the ameliorants have resulted in almost similar LAI. 'Mangala setright' @ 375 to 774 kg ha^{-1} resulted in significantly higher LAI than its lower dose.

4. The total chlorophyll content at 60 DAT was notably higher in the treatment which received the package of practices recommendations evidently due to the combined effect of soil amelioration, organic manure addition and fertilizer application. In the absence of soil ameliorants, the fertilizer applied and non- applied treatments resulted in statistically similar chlorophyll content bringing out the importance of soil amelioration. Among the different ameliorants the lowest dose of 'Mangala setright' @ 250 kg ha^{-1} with fertilizers and dolomite without fertilizer resulted in lower chlorophyll content.
5. The soil pH before rice planting was 5.31, which is normally considered unsuitable for optimum rice growth. pH values on 20 and 25 DAT showed noticeable improvement in all treatments, even in control. Continuous submergence of soil as practiced in rice cultivation may bring the soil pH towards neutrality. CaO @ 377 kg ha^{-1} together with FYM and NPK, and 'Mangala setright' @ 375 to 774 kg ha^{-1} constantly maintained a pH of more than 6, which is considered good for rice. Dolomite with or without fertilizer could improve the soil pH, but could not maintain it. Wherever no ameliorants were used, significantly lower pH was observed at 25 DAT.
6. The treatment which received POP for rice nutrition has resulted in significantly higher dry matter production at all growth stages, which was significantly highest. 'Mangala setright' at all the doses and CaO @ 377 kg ha^{-1} with fertilizer application have produced similar dry matter both at 60 DAT and harvest than non - application of ameliorants or dolomite with fertilizer. Apart from the amelioration effects the presence of all the secondary nutrients viz. Ca, Mg and S might have contributed to the better performance of 'Mangala setright'.
7. The root weight and root spread were significantly lower in the treatments where the soil was not ameliorated, even the fertilizer application did not

improve the situation. Both the parameters were significantly highest in the treatment which received all the inputs - ameliorants, organic manure and fertilizers. Application of CaO @ 377 kg ha^{-1} or 'Mangala setright' @ 500 to 774 kg ha^{-1} together with fertilizer application also resulted in significantly higher improvement in root weight and spread.

8. The panicles per hill was significantly increased when the soil was ameliorated. Similarly it was improved when the fertilizer was applied both in the absence and the presence of ameliorants. The highest number of panicles/ hill was observed with 'Mangala setright' @ 500 kg ha^{-1}, though at par with the POP recommendation. 'Mangala setright' at the highest dose of 774 kg ha^{-1} both in the absence or presence of fertilizers produced higher number of panicles which are statistically similar to the POPR treatment which received the organic manure component too.
9. Ameliorants, except dolomite, irrespective of the doses improved the filled grain percentage over control. The test weight has also significantly increased over control when either the ameliorant or fertilizer or both were applied.
10. The treatment which received 'Mangala setright' at the highest dose of 774 kg ha^{-1} and the one which received POP recommendation produced higher and similar yield of 6.7 t ha^{-1}. The grain yield in the treatments which received the lower doses of 'Mangala setright' and the one which received the POP recommendation without organic manure has produced similar yields in the range of 6.0 to 6.4 t ha^{-1}. When only ameliorants were used the yield was less but it was more than the control. The straw yield has also shown almost similar response to the treatments as that of grain.
11. Treatment which received FYM 5 t ha^{-1}, CaO 377kg ha^{-1} along with recommended fertilizer application (T_{11}) showed significantly higher N uptake by grain. This might be due to favourable effect of physical and chemical environment of soil with FYM application which causes continuous supply of nutrients.

12. All the soil ameliorated treatments showed a higher P content at different stages than the non ameliorated treatments. The availability of P increases with increase in pH of laterite soil.
13. In the case of potassium content of rice also, a similar trend was observed and may be due to more availability of Ca in the soil solution and consequent cationic competition for the monovalent K^+ by rice roots.
14. Application of CaO 377 kg ha^{-1} along with FYM and NPK recorded significantly higher P uptake in grain. P uptake by straw was highest in treatment which received Ca, Mg and S along with fertilizers. T_{11} which received soil ameliorant, fertilizer and organic manure recorded significantly higher total P uptake by the rice crop.
15. The application of NPK and CaO as per POP and the treatment which received the same combination along with FYM recorded the highest K content at 30 DAT. This may be due to the integrated use of FYM with fertilizers, which determine the adsorption and release of K in soil colloids and subsequent enhanced absorption by plant.
16. The highest total K uptake was noticed in treatment which received lower rate of soil ameliorant 'Mangala setright' which contain Ca, Mg and S.
17. Significant reduction in Fe content of rice plant at 30 DAT, 60 DAT and in straw was observed in the treatment which received soil ameliorants along with recommended fertilizers and FYM.
18. The application of POP NPK along with FYM and CaO recorded the highest Mn content at all the stages. The application of FYM may lead to increased availability of Mn in soil solution for the absorption by plant which in turn increased its content in plant.
19. The available Al content in soil before the experiment was too high as the initial low pH of the soil increased the portion of exchangeable Al. There was no noticeable change in available Al content after the experiment.

CONCLUSION

- Amelioration of lateritic soil with liming materials has resulted in enhanced growth and yield of rice.
- The amelioration together with the application of recommended doses of organic manure and fertilizers resulted in the highest yield of rice.
- The ameliorant 'Mangala setright' and CaO have performed better than dolomite under the same equivalence to $CaCO_3$ probably due to less solubility and reactivity of dolomite.
- The higher yield resulted by the application of higher dose of 'Mangala setright' even in the absence of organic manure can be attributed to the supplementation of secondary nutrients it contain viz. Mg and S together with the ameliorating effect and supply of Ca.
- While CaO did the ameliorative function only, 'Mangala setright' did both soil amelioration and secondary nutrient supplementation.
- Combined application of nutrients through soil ameliorants along with recommended fertilizers and FYM decreased Fe and Mn in plant.
- Liming the soil decreased available Fe and Mn in the soil. The various ameliorants had not much effect on reducing the Al content in soil.

REFERENCES

REFERENCES

Abu, M. B., Tucker, E. S., Harding, S. S. and 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.

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.

Alexander, L. T. and Cady, J. G. 1962. Genesis and hardening of laterite in soils. USDA Technical Bullettin. 1282-1290.

Alloway, B. J. 2003. Zinc in soils and crop nutrition [On line]. Available at http://zinc-crops.org. [26 Feb 2013].

Alloway, B. J. 2008. *Zinc in Soils and Crop Nutrition.* International Zinc Association, IFA, France, 136p.

Amma, K., Abraham, A. and Aiyer, R. S. 1979. Extractable Al in the rice soils of Kerala. *Agric. Res. J. Kerala* 17(1):44-49.

Ananthanarayana, R. and Rao, B. V. V. 1979. Studies on dynamics of magnesium in soils and crops of Karnataka, magnesium nutrition of groundnut. *Mysore J. Agric. Sci.* **13**: 420-425.

Anetor, M. O. and Akinrinde, E. A. 2006. Lime effectiveness of some fertilizers in a tropical acid alfisol. *J. Cent. Eur. Agric.* **8**(1): 18-24.

Anilakumar, K., Johnkutty, I. and Joseph, K. 1993. Long term effect of continuous fertilization of organic and inorganic sources on rice productivity. *J. Trop. Agric.* **31**: 204-209.

Ankineedu, G., Rao, J. V. and Reddy, B.N. 1985. Advances in fertilizer management for rainfed oilseeds. *Fert. News* **28**(9): 76-79.

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.

Attanandana, T. and Vacharotayan, S. 1986. Acid sulfate soils: Their characteristics, genesis, amelioration and utilization. *Southeast Asian Studies,* **24**(2): 154-180.

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

Aulakh, M. S. and Dev, G. 1978. Interaction effect of calcium and sulphur on the growth and nutrient composition of alfalfa, (*Medicago sativa* (L.) Pers), using ^{35}S. *Plant Soil.* **50**: 125-134.

Aulakh, M., Khera, T. S., Doran, J. W., Singh, K. and Singh, B. 2010. Yield and nitrogen dynamics in a rice-wheat system using green manure and inorganic fertilizer. *Soil Sci. Soc. Am. J.* **64**: 1867-1876.

Aulakh, M. S. and Malhi, S. S. 2005. Interactions of nitrogen with other nutrients and water, its effects on crop yield, quality, nutrient use efficiency, carbon sequestration and environmental pollution. *Adv. Agron.* **86**: 341-409.

Babu, R. B. T. and Reddy, V. C. 2000. Effect of nutrient sources on growth and yield of direct seeded rice (*Oryza sativa* L.) *Crops Res.* **19**(2): 189-193.

*Barber, S. A. and Adams, F. 1984. Liming materials and practices. *Agronomy (EUA).*

Becker, M. and Asch, F. 2005. Iron toxicity in rice - conditions and management concepts. *J. Pl. Nutr. Soil Sci.* **168**(4): 558-573.

*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 Fe^{2+} formation in the rhizosphere of rice (*Oryza sativa* L.) in relation to iron toxicity. *Plant Soil* **79**: 305-316.

Benham, E. 1997. *Natural resources soil characterization and profile description data.* . Lincoln.

Bhadoria, P. B. S., Prakash, Y. S., Kar, S. and Rakshit, A. 2003. Relative efficacy of organic manures on rice production in lateritic soil. Soil Use and Management **19**: 80–82.

Bhat, J. A., Kundu, M. C., Hazra, G. C., Santra, G. H. and Mandal, B. 2010. Rehabilitating acid soils for increasing crop productivity through low-cost liming material. *Sci. Environ.* **408**(20): 4346–4353.

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

Black, C. A. 1973. *Soil plant Relationships.* Wiley Eastern Private Limited, New Delhi, pp. 273-355.

Bloom, P. R. 2000. Soil pH and pH buffering. In: Sumner ME (ed) *Handbook of Soil Science*. CRC Press, Boca Raton, FL.

Bouman, O. T., Curtin, D., Campbell, C. A., Biederbeck, V. O. and Ukrainetz, H. 1995. Soil acidification from long-term use of anhydrous ammonia and urea. *Soil Sci. Soc. Am. J.* **59**(5): 1488-1494.

*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. 1992. Chlorophyll content in rice and its significance. Proc. Fourth Kerala Science Congress, Thrissur, Kerala, pp. 229-230.

Buchanan, F. 1807. A journey from Madras through the countries of Mysore, Canada and Malabar. Chap, XII: 116. East India Company, London.

Cate, R. B. and Sukhi, A. P. 1964. A study of Al in rice soils. *Soil Sci.* **98**: 85-93.

Chandrapala, A. G., Yakadri, M., Kumar, R. M. and Raj, G. B. 2010. Productivity and economics of rice (*Oryza sativa*) – maize (*Zea mays*) as influenced by methods of crop establishment, Zn and S application in rice. *Indian J. Agron.* **55**(3): 171-176.

Chang, S. C. 1961. Response of rice to lime in Taiwan. *Chinese-American Joint Commission on Rural Reconstruction, Plant Industry Series,* 52p.

Chang, S. C. 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.

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

Choudhury, T. M. A. and Khanif, Y. M. 2001. Evaluation of effects of nitrogen and magnesium fertilization on rice yield and fertilizer nitrogen efficiency using ^{15}N tracer technique. *J. Plant Nutr.* **24**(6): 855-871.

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. *Pakist. J. Scient. Ind.l Res.* **45**(5): 345-349.

Clark, R. B., Zobel, R. W. and Zeto, S. K. 1999. Effects of mycorrhizal fungus isolates on mineral acquisition by *Panicum virgatum* in acidic soil. *Mycorrhiza,* 9(3): 167-176.

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.

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.

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

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

Ding, Y., Luo, W. and Xu, G. 2006. Characterisation of magnesium nutrition and interaction of magnesium and potassium in rice. *Ann. Appl. 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].

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

Dwivedi, B. S., Shukla, A. K., Singh, V. K. and Yadav, R. L. 2003. Improving nitrogen and phosphorus use efficiencies through inclusion of forage cowpea in the rice-wheat systems in the Indo- Gangetic plains of India. *Fld. Crops Res.* **80**: 167-193.

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

Eswaran, H., Reich, P. and Beinroth, F. (1997). Global distribution of soils with acidity. *Plant-Soil Interactions at Low pH. Brazilian Soil Science Society, Sao Paulo, Brazil*, 159–164.

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. 2004. Dry matter yield and nutrient uptake by lowland rice at different growth stages. *J. Plant Nutr.* **27**(6): 947-958.

Fageria, N. K. and Baligar, V. C. 2008. Ameliorating soil acidity of tropical oxisols by liming for sustainable crop production. *Adv. Agron.*, **99**: 345–39.

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.

Fageria, N. K., 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. and Cobucci, T. 2011. Zinc nutrition of lowland rice. *Commun. Soil Sci. Plant Anl.* **42**: 1719–1727.

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

Foy, C. D. 1992. Soil chemical factors limiting plant root growth. *Adv. soil sci. (USA)* **19**: 87-149.

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

Fujiwara, A. 1964. Specific role of N,P and K in the metabolism of the rice plant. In: Mineral Nutrition of the Rice Plant. IRRI, Oxford & IBH Publishing Co, Calcutta, pp.318-320.

Gaines, T. P. and Mitchell, G. A. 1979. Boron determination in plant tissue by the azomethine-H method. *Commun. Soil. Sci. Plant Anl.* **10**: 99-108.

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.

Hassan, M. A. 1977. Fertility investigation on the laterite soils of Kerala state. Msc. (Ag.) thesis, Kerala Agricultural University, Thrissur.

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.

Herawati, N., Rivai, I. F., Koyama, H., Suzuki, S. and Lee, Y. 1998. Copper in rice and in soils according to soil type in Japan, Indonesia, and China: a baseline study. *Bull. Environ. Contam. Toxicol.* **60**: 266-272.

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.

Horst, W. J. 1988. The physiology of manganese toxicity. *Dev. Plant Soil Sci.* **33**: 175-188.

Houqing, Z., Gan, L., Toshinori, K., Ruiping, Z., Yiyong, Z., Qirong, S. and Guohua, X. 2012. Stimulation of phosphorus uptake by ammonium nutrition involves plasma membrane H^+ ATP ase in rice roots. *Plant Soil* **357**: 205–214.

Islam, M. S. H., Bhuiya, M. S. U., Rahman, S. and Hussain, M. 2009. Evaluation of SPAD and LCC based nitrogen management in rice (*oryza sativa* L.). *Bangaladesh J,Agril,Res.* **34**(4): 661-672.

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

Jaillard, B., Plassard, C. and Hinsinger, P. 2003. Measurement of H+ fluxes and concentrations in the rhizosphere. In: Rengel Z (ed) *Handbook of soil acidity*. Marcel Dekker, Inc. New York.

Jacobson, L., Hannapel, R. J. Moore, D. P. and Schardel, M. 1961. Influence of calcium on selectivity of ion absorption process. *Pl. Physiol.* **36**: 58 – 61.

Jakobsen, S. T. 1993. Nutritional disorders between potassium, magnesium, calcium and phosphorus in soil. *Plant Soil* **154**: 21-28.

Jeena, M., George, S. and Indira, M. 2013. Effect of sulphur and boron on the nutrient release pattern in a typical entisol of Kerala. *Indian J. Fert.* **9**(2): 16-20.

Jiang, Y. and Huang, B. 2001. Effects of calcium on antioxidant activities and water relations associated with heat tolerance in two cool-season grasses. *J. Exp. Bot.* **52**(9): 341-355.

John, P. S., Mercy, G. and Jacob, R. 2001. Nutrient mining in agroclimatic zones of Kerala. *Fert. News.* **46**(8) : 45-57.

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.

John, P. S., George, M. and Jacob, D. 2006. Sulphur fertilization in rice based cropping systems in laterite soils of Kerala. In: Tewatia, R. K., Choudahary, R. S., and Kalwe, S. P. (eds.), *Sulphur in Balanced Fertilization.* Proceedings of TSI-FAI-IFA symposium- cum- workshop New Delhi, pp. 163-184.

Johnston, A. E., Goulding, K. W. T. and Poulton, P. R. 1986. Soil acidification during more than 100 years under permanent grassland and woodland at Rothamsted. *Soil use and management,* 2(1): 3-10.

Katyal, J. C., Sharma, K. L. and Srinivas, K. 1997. Sulphur in Indian agriculture. In: Biswas, B. C., Prasad, N., and Das, S. (eds.), *Sulphur in Balanced Fertilization.* Proceedings of the TSI/FAI/IFA/ symposium, New Delhi, pp. KS-2/1-12.

Katyal, J. C. and Rattan, R. K. 2003. Secondary and micronutrients research gaps and future needs. *Fert. News* 48(4): 9-20.

KAU (Kerala Agricultural University). 2011. *Package of Practices Recommendations Crops* (14th Ed.). Kerala Agricultural University, Thrissur, 360p.

Kawata, S. and Soejima, M. 1976. Effect of shading, removal of panicle and foliar application of nutrients on the formation of superficial roots of rice. *Rice Abstr. J.* p.1843.

Khan, H. R., Rahman, S., Hussain, M. S. and Adachi, T. 1994. Growth and yield response of rice to selected amendments in an acid sulfate soil. *Soil Sci. Plant Nutr.* 40(2): 231-242.

Khan, S. A., Mulvaney, R. L., Ellsworth, T. R. and Boast, C. W. 2007. The myth of nitrogen fertilization for soil carbon sequestration. *J. Environ. Qual.* **36**:1821–1832.

Kirk, G. J. D. 2004. The Biogeochemistry of Submerged Soils. John Wiley & Sons Ltd., England.

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.

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

Kumar, V., Bhatia, B. K. and Shukla, U. C. 1981. Magnesium and zinc relationship in relation to dry matter yield, the concentration and uptake of nutrients in wheat. *Soil Sci.* **131**: 151-155.

Kumar, V. and Singh, A. P. 2010. Long-term effect of green manuring and farmyard manure on yield and soil fertility status in rice-wheat cropping system. *J. Indian Soc. Soil Sci.* **58**(4): 409-412.

Lee, C. H., Hong, C.O., Kim, S.Y., Schumacher, T. and Kim, P. J. 2011. Reduction of phosphorus release by liming from temporary flooded rice rotational system in greenhouse upland soil. *Ecol. Engng,* **37**(8):1239-1243.

Li, H. G., Shen, J. B., Zhang, F. S., Marschner, P., Cawthray, G. and Rengel, Z. 2010. Phosphorus uptake and rhizosphere properties of intercropped and monocropped maize, faba bean, and white lupin in acidic soil. *Biol. Ferti. Soils* **46**: 79–91.

Liu, G. L., Li, X. H. and Qin, D. J. 1989. Effect of long term sulphate fertilizer application on rice growth and paddy yield. *Sci. Agric. Sinica.* **22**(33): 50-57.

Lynch, J. P. and Clair, S. B. 2004. Mineral stress: The missing link in understanding how global climate change will affect plants in real world soils. *Fld. Crops Res.* **90**(1): 101–115.

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

Manning, B. A. and Goldberg, S. 1996. Modeling competitive adsorption of arsenate with phosphate and molybdate on oxide minerals. *Soil Sci. Soc. of Am. J.* **60**(1): 121-121.

Marykutty, K. C. 1986. Factors governing response of rice to liming on Kerala soils. Ph.D., thesis, Kerala Agricultural University, Thrissur, India, 265p.

Marykutty, K. C. and Aiyer, R. S. 1987. Effect of liming and washing on soil characters. *Agric. Res. J. Kerala* **25**: 27-35.

Marykutty, K. C., Potty, N. N., Anilakumar, K. and Bridgit, T. K. 1992. Stress influence of nutrient ratio on rice productivity. *Proceedings of the National Seminar on Pl. Physol.* Jaipur, pp.269.

Masthanareddy, B. G., Hebbara, M., Patil, V. C. and Patil, S. G. 2009. Nitrogen use efficiency of transplanted rice as influenced by N, P and K levels. *J. Indian Soc. Soil Sci.* **57**(3): 345-351.

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.

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

Mohapatra, S. 2011. Beware of bronzing. *Rice Today* 10(3): 38-39.

Mondal, S. S., Mondal, T. K., Dandagat, S. and Sarkar, S. 1994. Effect of sulphur bearing fertilizer in conjunction with farmyard manure on the growth, productivity and nutrient uptake of rice (*Oryza sativa*). *Indian J. Agron.* 39:116-118.

Morales, L. A., Vazquez, S. and Gonzalez, A. P. 2002. Nutrient status on an acid soil as affected by lime amendments after flooding. *Commun. Soil Sci. Plant Anal.* **33**: 15-18.

Musthafa, K. 1995. Productivity of semi dry rice under simultaneous in situ green manuring. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, India. 147p.

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.

Nascimento, C. W. A., Melo, E. E. C., Nascimento, R. S. M. P. and Leite, P. V. V. 2007. Effect of liming on the plant availability and distribution of zinc and copper among soil fractions. *Commun. Soil Sci. Plant Anl.* **38**: 545–560.

Neue, H. U., Quijano, C., Senadhira, D. and Setter, T. 1998. Strategies for dealing with micronutrient disorders and salinity in lowland rice systems. *Field Crop Res.* **56**: 139-155.

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

Oh, W. 1991. Plant reponse to sulphur application. *Rice abst.* **14** (4): 203

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.

Ota, V. 1968. Mode of occurrence of Bronzing in rice plant. *Japan agric. Res. J.* **3**:1-5.

Padmaja, P. and Verghese, E. J. 1966. Effect of calcium, Magnesium and Silicon on the productive factors and yield of rice. *Agric. Res. J. Kerala* 4(1): 31-38.

Padmaja, P. and Verghese, E. J. 1972. 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.

Pandian, P. S. 2011. Effect of long term manure and fertilizer addition on sulphur forms under rice monoculture. *Madras Agric. J.* 98(7-9): 219-223.

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

Patel, K. P. 2011. Crop response to zinc cereal crops. *Indian J. Fert.* **7**(10): 84-100.

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.

Patra, B. N. and Mohanty, S. K. 1994. Effect of nutrients and liming on changes in pH, redox potential, and uptake oof iron and manganese by wetland rice in iron – toxic soil. *Biol. Fert. Soils* **17**(4): 285-288.

Patrick, W. H. Jr. 1966. Apparatus for controlling the oxidation- reduction potential of waterlogged soils. *Nature* **212**: 1278–1279.

Pillai, P. B. 1972. Inter relationship between sulphur and iron on the production of chlorosis in paddy. Ph. D. thesis, University of Udaipur, Udaipur, Rajastan, p.134.

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

Pirzadeh, M., Afyuni, M., Khoshgoftarmanesh, A. and Schulin, R. 2010. Micronutrient status of calcareous paddy soils and rice products: implication for human health. *Biol. Fert. Soils* **46**: 317–322.

Ponnamperuma, F. N. 1965. Dynamic aspect of flooded soils and the nutrition of the rice plant. International Rice Research Institute, The John Hopkins Press, Baltimore, pp. 295–328.

Ponnamperuma, F. N. 1972. The Chemistry of submerged soils. *Adv in Agron.* **24**: 29- 96.

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.

Potty, N. N. Bridgit, T. K. and Anilakumar, K. 1992. Absorption and distribution pattern of iron by rice. Proceedings of the Fourth Kerala Science Congress, Thrissur, Kerala, pp. 250-251.

Prabhakumari, P. 1992. Secondary and micronutrient interactions in continuously fertilized coconut palms. Ph. D., thesis Kerala Agricultural University, Thrissur, India, 234p.

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.

Previna, S. and Baskar, A. 2012. Lime and gypsum to mitigate soil problems in rice cultivation in the bahour commune of Union Territory of Puducherry. *Madras Agric. J.* **99**: 62-64.

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., 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.

Rathish, S. T. 2010. Productivity of rice in laterite soil in relation to nitrogen – sulphur interaction. Ph. D. (Ag.) thesis, Kerala Agricultural University, Thrissur, 273p.

Rajput, A. L. and Singh, D. P. 1995. Effect of soil and foliar application of nitrogen and zinc with farmyard manure on late – sown wheat (*Triticum aestivum*). *Indian J. Agron.* **40**(4): 598-600.

Raju, R. A., Reddy, K. A. and Reddy, M. N. 1995. Response of rice (*Oryza sativa* L.) to sulphur and zinc on coastal alluvials of Andhra Predesh. *Indian J. Agron.* **39**(4): 637-638.

Rathore, A. L., Chipde, S. J. and Pal, A. R. 1995. Direct and residual effect of bio-organic and inorganic fertilizer in rice- wheat cropping system. *Indian J. Agron.* **40**(1): 14-19.

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.

Rehman, A., 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.

Rehman, H., Aziz, T., Farooq, M., Wakeel, A. and Rengel, Z. 2012. Zinc nutrition in rice production systems: a review. *Plant Soil* **361**: 203-226.

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

Rose, M. T., Rose, T. J., Pariasca-Tanaka, J., Yoshihashi, T., Neuweger, H., Goesmann, A., Frei, M. and Wissuwa, M. 2012. Root metabolic response of rice (*Oryza sativa* L.) genotypes with contrasting tolerance to zinc deficiency and bicarbonate excess. *Planta* **236**: 959–973.

Sahrawat, K. L. 2004. Iron toxicity in wetland rice and the role of other nutrients. *J. Plant Nutr*. **27**(8): 1471–1504.

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.

Saleque, M. A. and Kirk, G. J. D. 1995. Root – induced solubilization of phosphate in the rhizosphere of lowland rice. *New physiologist.* **129**: 325-336.

Saleque, M. A., Naher, U. A., Islam, A., Pathan, A. B. M. B. U., Hossain, A. T. M. S. and Meisner, C. A. 2004. Inorganic and organic phosphorus fertilizer effects on the phosphorus fractionation in wetland rice soils. *Soil Sci. Soc. Am. J.* **68**:1635–1644.

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.

Santos, J. Q. D. 1966. Soil acidity and Ca deficiency. *Anais Inst. Sup. Agron. Univ. Tech. Lisb.* **29** : 263-269.

Santos, L. S. D. and Oliveira. A. C. D. 2007. Rice iron metabolism: from source to solution. *J. Crop Sci. Biotech.* **10**: 64–72.

Sarkar, A. K., Singh, S. and Saha, B. P. 2000. Sulphur in balanced fertilization in red and lateritic soils of Chottanagpur plateau of Bihar. In: Sarkar, M. C., Biswas, B. C. and Das, S. (eds.), *Sulphur in Balanced Fertilization.*

Proceedings of TSI/FAI/IFA workshop, The Fertilizer Association of India, New Delhi, pp. 65-72.

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.

Sehgal, J. Challa, O. Thampi, C.J. Maji, A. K. and Bhushana, N. S. R. 1998. Red and lateritic soils of India. In: Shgal, J. Blum, W. E. And Gajbhiye, K. S. (eds.), *Red and Lateritic Soils Vol II. Red and Lateritic Soils of the World.* Oxford & IBH Publishing Co. Pvt. Ltd. pp. 1-18.

Shamshuddin, J., S. Paramananthan, and Mokhtar, N. 1986. Mineralogy and Surface Charge Properties of two Acid Sulfate Soils from Peninsular Malaysia. Pertanika. 9(2): 167 -176.

Shaul, O. 2002. Magnesium transport and function in plants: The tip of the iceberg. *Biometals* **15**: 309–323.

Sheela, K. R., Geethakumari, V. L. and George, A. 2006. Sulphur in balanced fertilization. In: Tewatia, R. K., Choudahary, R. S., and Kalwe, S. P. (eds.), *Sulphur in Balanced Fertilization.* Proceedings of TSI-FAI-IFA symposium- cum- workshop New Delhi, pp. 185-208.

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.

Singh, A. L. 1970. Effect of sulphur preventing the occurrence of chlorosis in peas. *Agron. J.* 62: 708-711.

Singh, A. K., Thakur, S. K. and Singh, S. S. 1996. Effect of N with and without FYM and Zn on yield uptake and economics of rice. *J. Res. Birsa Agric. Univ.* 8:175-176.

Singh, Surendra, K. P. Singh, N. K. Rana and A. K. Sarkar. 1993. Forms of sulphur in some Ranchi soils of Chotanagpur. *J. Indian Soc. Soil Sci.* 41(3): 562- 563.

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.

Singh, H. P. and Singh, T. N. 2005. Enhancement in zinc response of rice by magnesium in alkali soil. *Indian J. Plant Physiol.* 10 (2): 158-161.

Sing, B., Sing, Y., Khind, C. S. and Cupta, R. K. 2002. Optimal Phosphorus Management in Rice-Wheat Systems Better crops international. 16(1):12-13.

Singh, M. V. 2005. Micronutrient status in Indian soils. Micro and Secondary nutrient research in India. Indian Institute of Soil Science, Bhopal 23: 148.

Singh, M. V. 2009. Micronutrient nutritional problems in soils of India and improvement for human and animal health. *Indian. J. Fert.* 5(4): 11-16.

Singh, V. 2006. Productivity and economics of rice (*Oryza sativa*) – wheat (*Triticum aestivum*) cropping system under integrated nutrient supply system in recently reclaimed sodic soil. *Indian J. Agron.* 51(2): 81-84.

Sisie, S. S. and Mirshekari, B. 2011. Effect of phosphorus fertilization and seed bio fertilization on harvest index and phoshorus use efficiency of wheat cultivars. *J. Fd. Agric. Environ.* 9(2): 388-397.

Slaton, N. A., Wilson, C. E., Ntamatungiro, S. and Norman, R. J. 2001. Evaluation of zinc seed treatments for rice. *Agron. J.* 93: 152-157.

Slaton, N. A., Wilson, C. E., Ntamatungiro, S. and Frizzell, L. D. 2002. Rice response to phosphorus fertilizer application rate and timing on alkaline soils in Arkansas. *Agron. J.* 94: 1393-1399.

Soil Survey. 2007. *Bench Mark soils of Kerala.* Soil Survey Organisation, Department of Agriculture, Kerala. 623p.

Soratto, R. P. and Crusciol, C. A. C. 2007. Dolomite and phosphogypsum surface application effects on annual crops nutrition and yield. *Agron. J.* 100 (2):261-270.

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

Sudhir, K., Ananthanarayana, R. and Deshpande, P. B. 1987. Influence of calcium, magnesium and potassium fertilization of groundnut on the yield attributes, uptake of nutrients and soil chemical characteristics. *Mysore J. Agric.Sci.* **21**: 164 -168.

Sumner, M. E., Noble, A. D. and Rengel, Z. 2003. Soil acidification: The world story. *Handbook of soil acidity,* pp. 1–28.

Sverdrup, H., Warfvinge, P. and Nihlgård, B. (1994). Assessment of soil acidification effects on forest growth in Sweden. *Water, Air, & Soil Pollution* 78(1): 1-36.

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.

Swain, D. K. and Sandip, M. S. 2010. Development of spad values of medium- and long duration rice varity for site-specific nitrogen management. *J. Agron.* 9(2): 38-44.

Tanaka, A., Loe, R. and Navasero, S.A 1966. Some mechanisms involved in the development of iron toxicity symptoms in the rice plant. *Soil Sci. Plant Nutr.***12**: 158–164.

Tanaka, A., Mulleriyawa, R. P. and Yasu, T. 1968. Some mechanisms involved in the development of iron toxicity to the rice plant. *Soil Sci. Plant Nutr.* (Tokyo), **14**: 1-6.

Tandon, H. L. S. 1991. *Sulphur Research and Agriculture Production in India* (3rded.). The Sulphur institute, Washington D. C., 140p.

Tandon, H. L. S. 2004. Fertilizers in Indian agriculture – from 20th to 21th Century, FDCC, New Delhi, 142p.

Thawornwong, N. and Diest, V. A. 1974.Influence of high acidity and aluminium on the growth of low land rice. *Plant Soil* **41**:141-145.

Thomas, G. W. and Hargrove, W. L. 1984. The chemistry of soil acidity. In 'Soil Acidity and Liming'.(Ed. F. Adams.). *Am. Soc. Agron.* pp. 3–56.

Thounaojam, T. C., Panda, P., Mazumdar, P., Kumar, D., Sharma, G. D., Sahoo, L. and Panda, S. K. 2012. Excess copper induced oxidative stress and response of antioxidants in rice. *Plant Physiol. Biochem.* **53**: 33-39.

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.

Tiwari, K. N. and Gupta, B. R. 2006. Sulphur for sustainable high yield agriculture in Uttar Predesh. *Indian J. Fert.* **1**(11): 37-52.

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

Uddin, M. K., Islam, M. R., Rahman, M. M. and Alam, S. M. K. 2002. Effects of sulphur, zinc and boron supplied from chemical fertilizers and poultry manure to wetland rice (Cv. BRRI Dhan 30). J. Biological Sci. **2**(3): 165-167.

Uexkull, H. R. and Mutert, E. 1995. Global extent, development and economic impact of acid soils. *Plant and soil* **171**(1): 1-15.

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.

Varughese, S. and Jose, A. I. 1993. Direct and residual effect of different forms and levels of magnesium on yield and magnesium uptake in rice. *J. Trop. Agric.* **31**: 34-38.

Venkataraman, S. and Krishnan, A. 1992. *Crops and Weather*. Indian Council of Agricultural Research, New Delhi, p. 293.

Verma, T. S. and Tripathi, B. R. 1987. Effect of levels of soil moisture and lime and manganese application on the growth and Fe and Mn nutrition of rice in acid alfisols of Himachal Predesh, India. *Acta Agronomica Heingarica* **36**: 29-35.

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.

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.

Xia, L., Zhiwei, S., Lei, J., Lei, H., Chenggang, R., Man, W. and Chuangen, L. 2011. High/low nitrogen adapted hybrid of rice cultivars and their physiological responses. *Afr. J. biotech.* 10(19): 3731-3738.

Yadav, D. S. and Kumar, A. 2009. Long – term effect of nutrient management on soil health and productivity of rice (*Oryza sativa*) – wheat (*Triticum aestivum*) system. *Indian J. Agron.* 54(1): 15-23.

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. IIRI, Manila, Philippines. pp. 36-37.

*Originals not seen

APPENDIX

Appendix – 1

Monthly weather data during the crop period

Month	**Temperature (^{0}C)**		**RH (%)**		**Rainfall (mm)**	**Rainy days**	**Mean evaporation (mm)**	**Sunshine hrs**
	Maximum	Minimum	Morning	Evening				
January	32.8	21.3	75	40	0.0	0.0	158.2	9.5
February	35.1	22.2	74	33	0.0	0.0	163.1	9.1
March	35.2	24.2	86	49	4.5	1.0	154.7	7.6
April	34.7	24.8	89	57	101.9	8.0	131.8	6.6
May	32.6	25.3	88	64	92.8	4.0	111.7	6.0

RELATIVE EFFICIENCY OF AMELIORANTS ON RICE PRODUCTIVITY IN LATIRITIC SOILS OF KERALA

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The correction of soil pH, reduction of toxic accumulation of native elements and supplementation of secondary nutrients may enhance the growth and productivity of rice grown in lateritic lowlands. A field study was conducted during January to May, 2013 at the rice field of College of Horticulture, Vellanikkara to evaluate the response of soil ameliorants on growth and yield of rice. The experimental design was RBD with 3 replications.Transplanted Jyothi was grown at 15 cm x 10 cm spacing in 5.0 m x 4.0 m plots. The soil was having an initial pH of 5.3. The treatments were amelioration of soil with different amendments such as CaO, dolomite, and 'Mangalasetright', which is a commercial product. The ameliorants were applied with or without fertilizer. The package of practices recommendation forlow land rice, an absolute control treatment and fertilizer only treatment were also included for effective comparison. Nitrogen and potassium were applied in three equal split doses, first as basal dressing, second at tillering stage and the third at panicle initiation stage. The full dose of phosphorus was applied as basal dressing.

CaO @ 377 kg ha^{-1} together with FYM and NPK, and 'Mangalasetright' @ 375 to 774 kg ha^{-1} constantly maintained a pH of more than 6, which is considered good for rice.Soil amelioration significantly increased the growth characters of rice such as height and tiller count in the presence or absence of fertilizers.Higher doses of 'Mangalasetright' resulted in significantly higher LAI than its lower doses.Application of CaO @ 377 kg ha^{-1} or 'Mangalasetright' @ 500 to 774 kg ha^{-1} together with fertilizer application also resulted in significantly higher improvement in root weight, root spread and leaf chlorophyll content.The leaf chlorophyll content was improved due to the combined effect of soil amelioration, organic manure addition and fertilizer application.The treatment which received the recommended POP for rice cultivation resulted in the constant improvement in rice dry matter production at all the growth stages, which was significantly highest.'Mangalasetright' at all the doses and CaO @ 377 kg ha^{-1} with fertilizer application have produced

similar dry matter at 60 DAT and harvest than non application of ameliorants.Ameliorants other than dolomite created a favorable soil environment with an optimum pH and nutrient content which resulted in greater nutrient uptake by crop and consequent development of chlorophyll, enhanced photosynthesis and ultimately higher dry matter production.

Amelioration improved all the yield attributes and consequently the yield. Among different ameliorants 'Mangalasetright performed better than CaO and the lowest effect was observed for dolomite.The highest dose of 'Mangalasetright' and the treatment which received POP recommendation resulted in the highest and similar yield of 6.7 t ha^{-1}. The superiority of 'Mangalasetright' even in the absence of organic manure addition is attributed to its Mg and S contents. The enhanced growth and yield characters of rice observed in the ameliorated treatments are due to the favorable nutritional rhizosphere environment in the soil and consequent nutrient availability and uptake. While CaO did the ameliorative function 'Mangalasetright' did both soil amelioration and secondary nutrient supplementation.