EFFICIENCY OF FOLIAR AND SOIL APPLIED NUTRIENTS IN IRRIGATED RICE

By

SREEDHU P. PREMAN

(2013-11-139)

Department of Agronomy

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

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THESIS

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2015

DECLARATION

I hereby declare that the thesis entitled **"Efficiency of foliar and soil applied nutrients in irrigated rice"** 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.

Vellanikkara **Sreedhu P. Preman**

Date: **(2013-11-139)**

CERTIFICATE

Certified that thesis entitled **"Efficiency of foliar and soil applied nutrients in irrigated rice"** is a bonafide record of research work done independently by **Sreedhu P. Preman (2013-11-139)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

Vellanikkara

Date:

Dr. P. S. John
Chairman (Advisory Committee)
Professor, Department of Agronomy
College of Horticulture, Vellanikkara

CERTIFICATE

We, the undersigned members of the advisory committee of **Sreedhu P. Preman (2013-11-139)**, a candidate for the degree of **Master of Science in Agriculture**, with major field in **Agronomy**, agree that the thesis entitled **“Efficiency of foliar and soil applied nutrients in irrigated rice”** may be submitted by **Sreedhu P. Preman (2013-11-139)**, in partial fulfillment of the requirement for the degree.

Dr. P. S. John
(Chairman, Advisory committee)
Professor
Department of Agronomy
College of Horticulture, Vellanikkara

Dr. P. Sreedevi
(Member, Advisory committee)
Professor and Head
Department of Agronomy
College of Horticulture, Vellanikkara

Dr. Mercy George
(Member, Advisory committee)
Professor
Department of Agronomy
Banana Research Station, Kannara

Dr. P. Sureshkumar
(Member, Advisory committee)
Professor and Head
Radio Tracer Laboratory
Department of SSAC
College of Horticulture, Vellanikkara

EXTERNAL EXAMINER

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DEDICATED TO MY FAMILY

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INTRODUCTION

I. INTRODUCTION

Rice forms the staple food of the people of Kerala and contributes a major share towards its economy. It is grown in a vast array of ecological niches, ranging from fields situated one to three meters below mean sea level as in Kuttanadu to an altitude of 1400 m as in the high ranges. It can grow in three to four m depth of water as well as in purely rain fed uplands with no standing water. The area under rice cultivation shows a decreasing trend especially from 1994 to 1995. At present, rice is grown in a gross area of 1.99 lakh ha with a productivity of 2577 kg (GOK, 2013).

Kerala is a deficient state in rice production. While the estimated requirement of rice for the state is 35-40 lakhs t per year, it produces less than one-fifth of its requirement. The deficit in rice production is increasing year after year due to reduction in rice area and stagnant productivity of rice. Inadequate and unbalanced nutrient input coupled with very limited use of organic manures lead to the incidence and expansion of multi-nutrient deficiencies in the soils are considered to be major reasons for declined productivity associated with fertilizer use (Singh *et al*., 2009).

Soils of Kerala are deficient in secondary nutrients viz., Ca, Mg and S and micronutrients such as Zn, B and Cu. Extensive fertility surveys carried out in Kerala have shown that majority of soils of Kerala are highly acidic and are deficient in Mg (Varughese and Jose, 1993). Deficiency of Zn ranges 2-40% in Kerala (Ponnusamy, 2006). Boron stands next to zinc. Use of high analysis NPK fertilizers devoid of secondary and micronutrients, intensive cultivation with high yielding crop varieties, loss of top soil by erosion, loss of micro nutrients through leaching, limited liming of acid soils, reduced use of organic manures and restricted recycling of crop residues accelerated the exhaustion of secondary and micronutrients from the soil (Ray, 2011).

The availability of secondary and micronutrients are influenced by soil factors such as pH, redox potential, CEC, clay content and nutrient balance. The electrochemical changes occur during submergence of soil in paddy fields significantly influence the availability of nutrients in such conditions. Soils of Kerala are generally lateritic and acidic with low CEC and high AEC. The high concentrations of Fe and Mn in lowland condition result in the toxicity of these nutrients (Samui and Mandal, 2003).

Low yield due to decline in soil productivity can be enhanced by the implementation of fertilizer best management practices. Balanced fertilization inclusive of secondary and micronutrients with 4 R (Right type, dose, time and method of application) are key components of best fertilizer management practices. The use efficiency of macro and micronutrients are very low and it is hardly 2 to 4% for the latter (Yadav, 2012). The fertilizer use efficiency can be increased and losses can be reduced by matching supply with crop demand, optimizing split application, correct method of application, and site specific and soil test based nutrient management. Soil and foliar application, seed treatment, and seedling dip are the different methods of fertilizer application. Among these soil and foliar application are the most widely used methods.

Sometimes soil application of nutrient may not all be equally effective in correcting the deficiency because of the negative effects of pH, nutrient interactions and nutrient losses. Continuous soil application of micronutrients many lead to accumulation of those in soils. Foliar application has been found to be favourable where the soil applied fertilizer may not become fully available before maturity of crop (Ganapathy *et al*., 2008). Soluble inorganic salts are generally as effective as synthetic chelates in foliar sprays and inorganic salts are usually chosen because of lower costs. $MgSO_4$, $ZnSO_4$ and sodium borate at 3 to 10, 1.5 to 2.5 and 0.25 to 0.5 kg, respectively in 500 litres is used for foliar application (Fageria and Baligar, 1997).

Rice farming is a labour-intensive activity and demands skilled and unskilled labour. Labour scarcity in agriculture, especially in rice farming, is reported to be an important reason behind declining paddy area in Kerala (Devi, 2012). Even though farm mechanization reduces the need for labourers for transplanting and harvesting in rice, fertilizer application still depends on them. Individual application of each of the macro and micro nutrient fertilizers either soil or foliar applied is difficult, time consuming, labour intensive and increases the cost of production. Combined application of nutrients either as soil application or as foliar application seems to be an alternative.

Combined soil application of Zn and B at the rate 150g $ZnSO_4$ and 17g boric acid resulted in higher paddy yield and nutritional qualities of the grain (Abbas *et al.,* 2013). Paddy yield was significantly higher with the application of micronutrients (Zn, B and Mo) alone or in combination with each other (Hossain, *et al*., 2001).

It is in this context, study on the comparative evaluation of individual and combined application of nutrients was taken up with following major objectives.

1. To assess the relative efficiency of soil and foliar applied nutrients, alone or in combination, in rice.
2. To study the uptake of nutrients in both cases and their effect on growth and yield of rice

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Seventeen nutrients are reported to be required by rice for the completion of its normal growth and life cycle. These nutrients can be grouped as macro and micronutrients. According to Havlin *et al*. (2006) macro nutrients are required by plants in concentrations exceeding 0.1%, and these include C, H, O, N, P, K, Ca, Mg and S. Among them C, H and O are absorbed by plants from air and water, while all other nutrients are absorbed from soil. Macro nutrients are further divided into primary and secondary nutrients. N, P and K are required by plants in larger quantities compared to secondary nutrients and often referred to as primary or major nutrients. These nutrients are applied in large quantities as fertilizers.

Ca, Mg and S are mainly added through other nutrients sources either as adjunct radicals or as contaminants and hence named as secondary nutrients. Fe, Zn, Cu, B, Mo, Mn and Cl are referred to as micronutrients in the sense that they are required by plants in very small amounts in comparison to major nutrients, but not in the sense of their minor importance in plant life (Bhatt, 2011). Silicon is also reported to be highly beneficial to rice. A review about the mineral nutrition of rice and its various aspects are presented in this chapter. Since the study is mainly focused on secondary and micronutrients more detailed review is given in that respect.

2.1 Primary nutrients

2.1.1 Nitrogen

Nitrogen is the nutrient element applied in the largest quantity and it is one of the most important yield limiting nutrients for rice production in the world (Huber and Thompson, 2007). According to Clark (1982) except for legumes, N must be supplied to the plants for its normal growth and it is usually added as fertilizers.

Fageria *et al.,* (2003) reported that intensive agricultural production systems have increased the use of N fertilizer to produce and sustain the yield of crops. Even with the continuing research in N management, average world wide N use efficiencies (NUE) are reported to be around 50% (Newbould, 1989; Collins *et al.,* 2007). Raun and Johnson (1999) reported that N recovery efficiency for cereal production is approximately 33%. The main reason for lower N recovery efficiency is associated with its loss by leaching, denitrification, volatilization, surface runoff and immobilization (Fageria *et al.,* 2005). De Datta (1987) reported that in tropics, 56% of the applied N fertilizers are lost from flooded rice fields. In flooded rice fields, 10 to 50% of the applied N fertilizer is subjected to volatalization losses (Fillery and Vlex, 1986; Mikkelsen, 1987).

Nitrogen has greater influence on growth and yield of crop plants than any other essential plant nutrient and plays a pivotal role in many physiological and biochemical processes in plants. Nitrogen is an essential component of proteins and nucleic acids, structural constituent of cell wall, constituent of chlorophyll and closely related to photosynthesis (Coumaravel *et al*., 2004). It promoted plant height, shoot dry matter, number of panicles per plant, spikelets per panicle, reduce spikelet sterility (Fageria et al., 2006).

In surface mineral soils, total N content ranges from 0.2 to 5.0 g kg^{-1} with average value of 1.5 g kg^{-1}. More than 90% of the N in soils is organic and mineral N accounts for more than 1-2% of the total soil N (Brady and Weil, 2002). According to Dobermann and Fairhurst (2000) the optimum range of N content in rice at tillering, flowering and maturity is 2.9 to 4.2, 2.2 to 3.0 and 0.6 to 0.8% respectively. The critical level of deficiency of nitrogen at tillering stage is $<2.5\%$. The deficiency of nitrogen led to decreased leaf area index (LAI), lower radiation use efficiency and photosynthetic activity in plants (Muchow, 1998; Sinclair and Horie, 1989; Fageria and Baligar, 2005). Symptoms of N deficiency include yellowing of older leaves and stunted growth, tillering and low grain yield.

C:N ratio of soil is an important indication of the availability of N in soil. A C:N ratio of more than 30:1 generally immobilizes N in soil-plant systems and creates the possibility of N deficiency in crop plants (Fixen, 1996). Aulakh and Malhi (2005) reported that N has positive interactions with almost all plant nutrients. Wilkinson *et al*. (2000) reported that application of N increased the uptake of P, K, S, Ca and Mg, provided that these elements are sufficiently available in the soil. According to Marschner (1995) and Baligar *et al*. (2001) the increase in root hairs, chemical changes in the rhizosphere, and physiological changes stimulated by N are responsible for the increased uptake of macronutrients with the addition of N. 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).

Murali et al. (2007) revealed that application of N and K at flowering stage improved the grain yield and yield parameters in rice. Application of 250 kg N ha^{-1} in three splits up to the beginning of grain filling stage recorded higher N uptake (154.8 kg ha^{-1})and resulted in higher grain yield (7.30 t ha^{-1}) than the recommended prctice of applying 150 kg N ha^{-1}. Application of 200 or 250 kg N ha^{-1} increased the N content; N uptake and grain yield significantly (Masthanareddy *et al.,* 2009). According to Aulakh *et al*. (2010) on sandy loam soils in India, flooded rice responded to N rates up to 120 kg N ha^{-1}. 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}. 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 (Yadav *et al.,* 2009).

2.1.2 Phosphorus

After nitrogen, phosphorus (P) has more widespread influence on both natural and agricultural ecosystem than any other essential plant nutrient element (Brady and Weil, 2002). It is an essential nutrient for both plants and animals. It is a component of the complex nucleic acid structure of plants, which regulates protein synthesis and therefore, important in cell division and development of new tissue (Brady and Weil, 2002). P is a key component of phytin that is essential to induce germination of seeds. 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). ATP and ADP are the compounds with high energy phosphate groups that drive most physiological processes in plants including photosynthesis, respiration, protein nucleic acid synthesis, and ion transport across cell membrane (Eastin and Sullivan, 1984). In cereals, P increases tillering, root development and strengthens culm which prevents lodging (Baligar *et al.,* 1998). P is mobile within the plants and promotes tillering, root development, early flowering and ripening. Fujiwara (1964) stated that heading in rice controls vegetative growth through protein biosynthesis and reproductive growth through flower initiation is actually promoted by nucleic acids. 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).

Tomar (2000) reported that the total P content in surface soil may vary from traces to over 3.58 mg kg^{-1}. Both organic and inorganic sources of P are found in soil-plant systems, and both are important P sources for plants. The source of organic P is inositol phosphates, nucleic acid, phospholipids *etc*. The organic fraction of P varies from soil to soil and may constitute 20 to 80% of the total P of surface soil horizons (Brady and Weil, 2002). Inorganic forms of P are mainly Ca and Fe or Al bounded compounds (Shujie, 2012).

P uptake by plants mainly occurs in the form of $H_2PO_4^-$ ion in acid soils and HPO_4^{2-} ion in basic or alkaline soils. The proportion of these two ions in the soil solution is governed by pH. At pH 5, most of P is in the form of $H_2PO_4^-$, and at pH 7, both of these ions are present more or less in equal amounts (Mengel *et al.,* 2001). The uptake of P by plants is governed by the ability of a soil to supply P to plant roots and by the desorption characteristics of the soil (Fageria *et al.,* 2003). P become immobile and unavailable to plants due to low pH and dominance of active forms of Al and Fe (Dixit, 2006). Availability of P in soil is related not only to the pH of the soil, but also the concentration of P in soil and adsorption mechanisms prevail at low P concentrations and precipitation mechanisms at high P concentrations (Lin *et al.,* 1983). Sah and Mikkelsen (1986) reported that flooding and subsequent draining of soil affect P transformations, increased amorphous Fe levels and P sorption, and induced P deficiency in flooded rice.

P deficiency in crop plants is a widespread problem in various parts of the world, especially in highly weathered acidic soils (Faye *et al.,* 2006). According to Li *et al*. (2010) application of P fertilizer is one of the most important factors 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. Application of P fertilizers lead to the adsorption of 70-90% of the P fertilizers and becomes locked in various soil P compounds of low solubility without giving any immediate contribution to crop production (Holford, 1977).

Phosphorus is a mobile nutrient in plant; hence, P deficiency symptoms first appear on older leaves. The visual symptoms of P deficiency are stunted growth, reduced yields and purple or reddish colouration on older leaves. P deficiency reduces seedling height, tiller number, stem diameter, leaf size and leaf duration in rice (Fageria *et al.,* 2003). It also reduces seed size, seed number and viability. Fageria et al. (2003) reported that rice maturity can be delayed by 10 to 12 days by P deficiency. The critical level of deficiency of P at tillering stage is <0.10 %. P deficiency also leads to reduced number of leaves, panicles and grains per panicle (Dobermann and Fairhurst, 2000).

Generally, P has positive significant interaction with N, K, and Mg. Wilkinson et al. (2000) reported that increased growth as a result of P fertilization require more nutrients to maintain tissue composition within acceptable limits; mutually synergistic effects for N and P promoted growth. Response of upland rice to P application is very common, and this generally induces Zn deficiency (Fageria, 1989).

For producing 1 t of grain, rice removes about 2 to 3 kg P. Although the rice requirement for P is much less than that for N, the continuous removal of P exploits 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 more P (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. Tandon (2004) stated that nearly 80% of Indian soils are low to medium in available P and need adequate P fertilization.

Root exudation of organic acids increases the availability of inorganic soil P (Marschner, 1995). According to Saleque and Krik (1995) rice plants growing in flooded soil were able to solubilize P and thereby increase their P uptake by including an acidification in rhizosphere. Fageria *et al*. (1997) reported that 13 mg kg^{-1} P is the critical level of P required for lowland rice. To produce one ton of rice, it requires about 2.5–3.5 kg P and 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 kgP_2O_5 ha^{-1} (Cong *et al*., 2011).

2.1.3 Potassium

Potassium (K) is an essential element for all life forms. It is abundant in nature and occurs in considerable total amounts in most soils. On an average 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).

Most of the soil K occurs in the crystal lattice structure of silicate minerals especially feldspars and micas. Silicate minerals release K slowly by means of the weathering process. Secondary clay minerals, especially the 1:1 clay minerals (kaolinite), are important sources, yielding K more easily than 2:1 clay minerals like vermiculite (De Datta and Mikkelsen, 1985).

The majority of K^+ ions moves to plant roots by diffusion. The K concentration in most soil solution is very low (0.1 – 0.2%) relative to exchangeable K^+ (1 - 2%) because of strong K^+ adsorption by many 2:1 layer silicate minerals. The nonexchangeable K is in the range of 1 – 10%, and 90 - 98% of K occurs as mineral K. Hence, nonexchangeable K and mineral K are the major K forms in soil plant system. According to Bertsch and Thomas (1985) the ability of a soil to replenish solution K is dependent on the transformations between the various labile K forms and their equilibrium with the soil solution.

According to Havlin *et al*. (2006) 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. Potassium, like N and P, is highly mobile in plant tissues. Hence, K deficiency symptoms first appear in the older leaves as scorching along leaf margins. Potassium deficient plants are stunted in growth with poorly developed root systems and weak stalks susceptible to lodging. Seeds and fruits are shriveled, and plant possesses low resistance to disease.

Dibb and Thomson (1985) reported positive interactions of K with N and P. Antagonistic interaction between K and Mg and K and Ca uptake has been widely reported (Johnson et al., 1968; Fageria, 1983; Dib and Thompson, 1985). Hill and Morrill (1975) and Gupta (1979) reported that high K rates reduced B uptake and intensified B deficiency in crop plants. Fageria (1984) reported that Fe toxicity in flooded rice reduced with the addition of adequate rate of K in soil. Potassium has been found to influence the use efficiency of other nutrients (John *et al*., 2004). Dib and Thompson (1985) reported that K improved the uptake of Mn, Cu and Zn.

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% to 1.5% but, yields more than 7 t ha^{-1} require more than 1.2% K in the straw at harvest and $>$ 1.2% K in the flag leaf at flowering (Ravichandran and Sriramachandrasekharan, 2011).

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 increased level of N and K application increases the nutrient uptake, grain and straw yields (Arivazhagan and Ravichandran, 2005). Muthukumararaja *et al.* (2009) observed that the addition of 50 kg K_2O ha^{-1} recorded highest LAI, chlorophyll content, grain yield (5621 kg ha^{-1}) and straw yield (9077 kg ha^{-1}) in rabi season. Potassium application positively influenced yield attributes in rice. Su (1976) and Mandal and Dasmahapatra (1983) reported that potassium absorbed at the maximum tillering stage increased the number of panicles, spikelets per panicle and weight of grain.

2.2 Secondary nutrients

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

2.2.1 Calcium

Calcium is a divalent alkaline cation and plays many important roles in plant growth and development. It 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^+. Mengel and Kirkby (1987) reported that Ca makes up to about 3.64 % of earth's crust. Large amount of Ca is present in soil as exchangeable Ca on silicate minerals in soils having pH 6 or above. Adams (1984) reported that Ca concentration in soil solutions varies extensively from 1.7 – 19.4 mM.

The Ca content of soil depends on its parent material, degree of weathering, and addition of liming materials or fertilizers having calcium. Large amount of Ca in the soil is present as exchangeable Ca, which depends on the cation exchange capacity (CEC) of soil. Exchangeable Ca is more tightly held on soil colloids than either K or Mg. Solution and exchangeable Ca are the main forms that can move to plant root and be absorbed (Barber, 1995). Gypsum and calcium carbonate are soil minerals having greater solubility and higher Ca content. Low Ca content minerals are plagioclase feldspars, augite, hornblende, and epidote (Barber, 1995). Mass flow is the primary mechanism for supplying Ca to plant roots for absorption.

Prasad and Power (1997) reported that 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}. According to Dobermann and Fairhurst (2000) flooding increases the concentration of Ca in soil solution because of the displacement of exchangeable Ca^{+2} by Fe^{+2}. Verma and Tripati (1987) reported that the application of lime under flooded condition increased the rice yield, Mn content and decreased the Fe content. Moore and Patrick (1989) reported that deficiency of Ca has been a limiting factor for rice production in acid sulfate soils.

Ca is involved in cell division and cell elongation and plays a major role in the maintenance of cell membrane integrity (Fageria *et al.,* 1997). It also maintains the nutrient balance in plant tissues and ameliorates the toxicity of heavy metals. Epstein and Bloom (2005) reported that Ca protects the plasma membrane from deleterious effects of H^+ ions at lower pH and reduces harmful effects of Na^+ in salt affected soils. It also acts as a regulator ion in the translocation of carbohydrates (Bennett, 1993).

Ca is abundant in neutral and alkaline soils. However , Ca deficiency is most common in highly weathered acid soils. Ca deficient soils have low CEC and high leaching capacity. It is lost from soil plant systems by leaching, soil erosion and crop removal. At pH less than 6, Ca ion is displaced by Al and H ions from exchange complex undergoes leaching, and as the pH increases and more divalent cations become specifically adsorbed and no longer exchangeable (Chan *et al.,* 1979). Liming of acidic red and laterite soil not only ameliorate soil acidity related problem but also supply Ca and increased uptake of Ca (Fox *et al*., 1991; Samui and Mandal, 2003).

Ca is immobile in plants, and deficiency symptoms first appear on newly emerging leaves or tissues. 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. Jakobsen (1993) reported that Ca deficiency results in impaired root function, and may predispose rice plant to Fe toxicity. 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).

Amelioration of soil with lime significantly increased the yield components of rice like number of panicle per ha, grains per panicle and 1000 grain weight (Chang and Sung, 2004). Krasaesindhu and Sims (1972) reported that application of Ca increased grain yield, decreased straw weight and markedly increased grain: straw ratio in rice.

2.2.2 Magnesium

Biotite, phlogopite, hornblende, olivine and serpentine are the major mineral sources of magnesium in the earth. According to Mengel and Kirkby (1987) the earth's crust contain about 2.07 % Mg. Mengel *et al.* (2001) reprted that Mg content of most of the soils ranges between 0.5 g kg^{-1} for sandy soils and 5 g kg^{-1} for clay soils. 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}. Dobermann and Fairhurst (2000) reported that a Ca: Mg ratio in soil solution greater than 7:1 is considered undesirable.

Availability of Mg decreases with high soil pH, base imbalances, aluminum and manganese toxicity (Lynch and Clair, 2004). Most of the Mg is present in soil as primary minerals, and very little exists in the form of organic complexes. Addition of Ca increases the leaching of Mg from the soil profile. Mg content in soil organic matter is found to be less than 1% of the total soil Mg (Mengel *et al.,* 2001). Spear *et al*. (1978) reported the interaction of Mg with K and Ca. The enhanced solution Ca concentrations reduced Mg uptake rate by suppressing the Mg transport capacity of the root. Uptake of Mg by rice plants decreased by higher Ca concentration in the nutrient solution (Fageria, 1983). Continuous use of high amount of liming materials may increase Ca: Mg ratio and induce Mg deficiency. Wilkinson *et al.* (2000) reported that fertilization with NO_3^- enhances the Mg concentration in plants to meet the need for cation - anion balance. High levels of exchangeable K may reduce the Mg availability and K: Mg ratio should be 5:1 for field crops. Huang *et al*. (1990) reported that net Mg translocation from root to shoot was depressed by increasing root K concentration. Mg uptake is also affected by high levels of exchangeable Al in strongly acidic soil.

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 aids in the formation of sugars, oils, and fats. It also activates the formation of polypeptide chains from amino acids (Tisdale *et al.,* 1985). 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 is absorbed as Mg^{2+} by plants. In rice plants, the level of Mg was in the order leaf > stem > panicle > root. Yan and Chu (1996) reported that Mg uptake is peak at tillering and panicle development stages. 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).

Mg is fairly mobile in plants, and deficiency symptoms first appear in the older leaves and tissues. Symptoms of Mg deficiency includes interveinal chlorosis, brittleness, marginal curling and reddish purple colouration of leaves (Clark, 1982). Reduced root growth and dark red colouration of roots are common in Mg deficient plants. Moderate deficiency of Mg reduces the height and tiller number in cereals (Fageria and Gheyi, 1999).

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 content and net photosynthetic rate (Ding *et al*., 2006).

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

Application of Mg as calcium magnesium phosphate or magnesium sulphate at the rate of 15 kg ha^{-1} was recommended for Mg deficient soils (Yan and Chu, 1996). In rice, application of Ca and Mg alone or together had a non-significant effect on yield and the uptake of macro- and micronutrients at harvest. The harvest index of rice decreased due to the applications of Mg as magnesium carbonate at 50 kg ha^{-1}. Application of phosphorus alone or in combination with Ca and Mg significantly increased yield and agronomic and physiological P efficiencies and improved harvest index of rice. 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). Yamauchi and Winslow (1989) observed that as Mg is involved in the protection of rice plants against grain discolouration and its application increased grain yield by an average of 34%. 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.

2.2.3 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). Asher *et al.* (1983) reported that the worldwide trend towards the replacement of ammonium sulfate and single super phosphate with high analysis fertilizers such as urea, mono and di ammonium phosphates, and triple super phosphate which are low in S seems to induce S deficiency and enhanced the need for the application of S fertilizers. 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. According to the reports of Tandon (1991) S deficient soils are found in all the districts of Kerala ranging from 20-55%. 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.

S is absorbed by plants and immobilized by microorganisms and moves in soil-plant systems like N. The main S bearing mineral rocks and soils are gypsum, epsomite, mirabilite, pyrite and marcasite, sphalerite, chalcopyrite, and cobaltite

(Tisdale *et al.,* 1985). S is present in soils in both organic and inorganic forms. Inorganic form of S is usually only 5 – 10% of total S in soil (Neptune *et al*., 1975; Barber, 1995). In flooded rice, inorganic S is reduced to FeS, FeS_2, and H_2S. Organic matter contains about 50 g S kg^{-1} (Barber, 1995). Ester sulfate, C-bonded S (mainly amino acids), and residual S constitute the three fractions of soil organic S (Tabatabai, 1982). Carbon bonded fractions of S include cysteine and methionine which together comprise from 11 – 31% of the total soil organic S (Scott *et al*., 1981). Barber (1979) reported that 3% of the organic matter content of Indian soils was mineralized at the rate of 2.4% per year. Stevenson (1986) reported that mineralization of S is soil temperature and moisture dependent and optimum temperature range for the same is 20 -40^0C and optimum moisture is at 60% of maximum water holding capacity of the soil .

Adsorption of sulphate due to anion adsorption is a typical phenomenon of acid soils which significantly influences S status of soil (Katyal *et al*., 1997). Sulfate adsorption capacity of soil colloids depends on soil pH and decreases as soil pH increases. The amount of S adsorbed by soil increases with clay content. The clay minerals adsorb sulfate in the order of kaolinite > illite > bentonite (Mengel *et al*., 2001). Sulfate is weakly held in soil with anion adsorption strength in the order OH^- > $H_2PO_4^-$ > MoO_4^{2-} >SO_4^{2-} = CH_3CO_2 >NO_3^- >Cl^-. Immobilization of S in the soil plant system is controlled by the C:S ratio the organic matter or residues. Stevenson (1986) reported that soil C:S ratio of less than 200:1 will support the net gain in inorganic SO_4^{2-} and if it is more than 400:1 will lead to immobilization of S. The C:N:S ratio of the soil varies widely within any location, but the mean ratio for soils from different agro ecological regions is about 140:10:1.3 (Stevanson, 1986).

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 S on soil exchange complex and organic matter held S occurs in a state of dynamic equilibrium. These together constitute the labile pool from which plants absorb 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). S deficiemcy symptoms are similar to those of N but first appear in younger leaves because it is not easily translocated in plant. S deficienct plants lack vigor, are stunted, pale green to yellow in colour, and have elongated thin stems. S deficiency may delay the maturity in grain crops. Root development restricted, and shoots – root ratios decrease for plants grown under S deficiency (Clark, 1993). Wells *et al*. (1993) reported that the critical concentration of S in rice is about 2.5 g S kg^{-1} at tillering and 1 g kg^{-1} at heading. The critical S concentration in rice straw needed for maximum dry weight production varied from 1.6 g kg^{-1} S at tillering to 0.7 g kg^{-1} S at maturity (Yoshida, 1981). 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). In rice, the deficiency causes interveinal yellowing of younger leaves, while older leaves remain green (Tiwari and Gupta, 2006). The other symptoms include reduced plant height, tiller and spikelet per panicle. In rice, visual symptoms of recovery are usually noted within 5 days following fertilizer application (Wells *et al*., 1993). S deficiency in rice produced a high percentage of unfilled grains (Yoshida and Chaudhry, 1979).

Sulfur interaction with nitrogen is very common, and S requirement of crops are enhanced with the increase of N in growth medium. Soliman *et al*. (1992) reported that in calcareous soils, S reduces pH and improves uptake of micronutrients like Fe, Mn, and Zn. Uptake of P may also improve in calcareous soils with the application of S due to reduction of pH. Suzuki (1995) reported that excess Zn induced S deficiency in rice plants. Tanaka *et al*. (1966) reported that application of gypsum to lowland rice reduced soil pH and induced Fe toxicity. In the case of both

Mg and S, both synergistic and antagonistic effects have been reported. The antagonism between Mg and S was more when K was also applied (Tiwari, 1997).

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 (15.92 kg ha^{-1}) and highest crop uptake was noticed at 45 kg S ha^{-1} compared to control (7.58 kg ha^{-1}). The residual effect increased with increasing level of sulphur (John *et al*., 2006). Rathish (2010) reported that combined application of nitrogen and sulphur increased the grain yield of rice. Maximum yield was 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}). The application of S at normal levels less than 60 mg S kg^{-1} increased the accumulation of Fe in brown rice and stems/leaves, whereas the excessive S supply inhibited the accumulation of Fe in brown rice and stems/leaves (Wu *et al*., 2014). Aromatic rice requires 100 kg N ha^{-1} and 20 kg S ha^{-1} for increased productivity and uptake of N, P, K and S under transplanted puddle conditions (Shivay et al., 2007).

2.3 Micronutrients

The efforts to enhance the food grain production from shrinking land resources with the limited use of organic manures and unlimited use of fertilizers magnified the depletion of limited micronutrient reserves and would cause the deficiency of micronutrients in soil (Zayed *et al.*, 2011). Iron, zinc, copper, boron, manganese, chlorine and molybdenum are the essential micronutrients for field crops (Papadopoulos *et al.*, 2009). Narrow range between deficiency and toxicity limits may cause the poor use efficiency of added micronutrients (Katyal *et al.*, 2004). Micronutrient deficiencies are location specific. Among micronutrients, deficiency was found widespread in Indian soils with boron followed by zinc. The deficiencies of Cu, Fe, Mn and Mo are of lesser magnitude than Zn (Sakal, 2001). The chloride deficiency rarely occurs in nature (Ray, 2011).

2.3.1 Iron

Iron is essential for the synthesis of chlorophyll. It is involved in nitrogen fixation, photosynthesis, and electrons transfer (Bennett, 1993). It also acts as an electron carrier in the oxidation-reduction reactions. It is required in protein synthesis and is a constituent in hemoprotein. Under Fe deficiency, the activity of rubisco is reduced (Expert, 2007). Fageria (1992) reported that Fe supply at an adequate level improved the root system of rice. Fe is immobile in plants hence, deficiency symptoms first appear in younger leaves. It is exhibited as interveinal chlorosis and later leads to whitish colouration of leaves. It causes stunting, delayed flowering and maturity in crop plants.

Fe interaction with other nutrients influences its availability to the plants. Follett *et al.* (1981) reported that Fe availability is decreased with the presence of P, Zn, Co, and Mn in soil. Higher levels of Mo in soil lead to Fe chlorosis. Barber (1995) reported that increased levels of Ca inhibit the Fe uptake. The form in which N present in soil also influence the availability of Fe to the plants. NO_3^- decreases Fe availability as it increases pH and NH_4^+ increases Fe availability as it decreases pH. Deficiency of K may disrupt the movement of Fe within the plants.

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 tolerant 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).

2.3.2 Zinc

Zinc is considered as a trace element in soil. Zinc content of lithosphere is approximately 80 mg kg^{-1} and soil contains about 10 – 300 mg kg^{-1} with an average of 50 mg kg^{-1} (Lindsay, 1979). Important Zn containing minerals are sphalerite, smithsonite and hemimorphite (Tisdale *et al*., 1985; Barber, 1995). It is present in soil in divalent form. Various forms of Zn in soil are water soluble Zn, exchangeable Zn, adsorbed Zn on the surface of colloids and organic matter, and Zn substituted for Mg in crystal lattices of clay minerals (Tisdale *et al*., 1985). Soil properties such as pH, clay minerals, organic matter content, Fe and Al oxide content, and carbonate content have strong influence on the adsorption-desorption reactions of Zn and plays a critical role in regulating Zn solubility. Ionic strength and complex formation may also affect adsorption of Zn with inorganic legends in soil solution. Zn adsorption also resulted in the release of H and Mn. Increasing pH decreased Zn in water soluble and exchangeable fraction.

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).

Zn is an essential metallic component for enzymes such as dehydrogenases, oxidase, anhydrases, peroxidases *etc* (Katyal *et al*., 2004). It plays an important role in regulating the nitrogen metabolism, cell multiplication, photosynthesis and auxin concentration in plants. It is required for the synthesis of nucleic acid, cytochrome, chlorophyll and proteins and helps in utilization of phosphorus and nitrogen (Ponnusamy, 2006). Zn is immobile in plants and the deficiency symptoms first appear on the younger leaves. Plants suffering from Zn deficiency often show interveinal chlorosis. Under severe Zn deficiency, internodal length is reduced, plants are stunted, terminal growth is retarded and new leaves develop slowly (Smith *et al*., 1993). 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).

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). Under submerged situations, the concentration of water soluble Zn decreases. In acid soils, the decrease in Zn concentration may be attributed to the increase in pH following soil reduction. With calcareous soils, the pH decreases on submergence and Zn solubility supposed to increase (Ponnamperuma, 1972). In reduced soil conditions, concentration of Fe and Mn increase, which may also inhibit uptake of Zn by rice plants. Alloway (2004) reported that addition of Zn fertilizers to water logged soils increased DTPA extractable Mn but decreased the uptake and translocation of Cu, Fe and P.

Bowen (1969) and Kochain (1991) reported that Cu competitively inhibits Zn uptake. In rice seedlings, translocation of Zn from roots increases with Mn application. However, high Mn in combination with high Fe may inhibit the absorption of Zn by rice in flooded soils and enhance Zn deficiency. The absorption of B is enhanced by Zn deficiency and which enhances the P toxicity in plants due to the impaired membrane function in root (Alloway, 2004).

Source, rate, time and method of application of fertilizer influence the availability of Zn (Hedge *et al*., 2007). The sources of Zn include inorganic, synthetic chelates, natural organic complexes and inorganic complexes. The inorganic sources include sulphate, chloride, carbonate and oxides of Zn. Among synthetic chelates, Zn-EDTA is the widely used one. Natural organic complexes include Zn-humate and Zn-fulvate (Patel, 2011). Application of high water soluble Zn fertilizers is the most effective way to correct Zn deficiency (Gangloff *et al*., 2002).

Zinc sulphate is the most common and reliable fertilizer used in India (Gupta and Gupta, 2005; Gangloff *et al*., 2006). According to Sidhu and Sharma (2010) in many areas, high available Zn content in soils is reported due to the increased use of Zn sulphate by farmers in recent years. Zn deficiency is mainly corrected by soil and foliar application of Zn fertilizers, When Zn sulphate is applied to the soil, utilization by the crop seldom exceeds 5%, and most of the added Zn remains unutilized (Hedge *et al*., 2007). This may either lead to toxicity or impart residual effect.

Soil application, foliar application, dusting seed with Zn powder or soaking in Zn solution, swabbing foliage with Zn paste and seedling dip are the different methods of Zn application. The commonly recommended application rates are 25 – 50 kg $ZnSO_4.7H_2O$ ha^{-1}. Katyal et al. (2004) reported that agronomic efficiency of 11 kg Zn ha^{-1} as $ZnSO_4.7H_2O$ was similar to 22 kg Zn ha^{-1} as sparingly soluble ZnO. A soil was rated responsive to Zn fertilization if it produced > 200 kg ha^{-1} extra grain of crops. The increase in yield less than 200,200-500, 500-1000 and more than 1000 kg ha^{-1} indicating high, medium, low and very low fertile soils respectively (Sakal, 2001).

Time of fertilizer application may considerably influence crop response to fertilizers. The time of fertilizer application is influenced by a number of factors like nature of crop, its growth stages and nutrient requirements or crop needs, soil conditions, nature of fertilizers etc (Ravichandran and Sriramachandrasekharan, 2011).Prior to seedling or transplanting stages are the best time of application of Zn to most of the field crops. Zn application to rice by splitting half the dose as basal and half at tillering stage was equivalent to full basal application (Patel, 2011). Zn fertilizers can be applied in nursery, seedling stage, maximum tillering and panicle initiation.

The application of Zn as ZnO at 50 kg ha^{-1} along with NPK recorded significantly higher dry matter production/hill (47.6 g/hill), panicle/m^2 (345), grain/panicle (113), 1000 grain weight (21.8 g) and Zn uptake (122.3 g ha^{-1}) compared to NPK alone (37.4 g/ hill, 286 panicle/m^2, 89, 21.5 g and 37.2 g ha^{-1} respectively). NPK + Zn treatment also recorded higher grain yield (4.72 Mg ha^{-1}) compared to NPK (4.14 Mg ha^{-1}) alone (Chapale and Badole, 1999; Chandrapala *et al*., 2010). Growth,yield attributes, grain and straw yield as well as system productivity was increased when rice received 100% recommended dose of NPK on the basis of soil test data along with Zn at 20 kg ZnSO4 ha^{-1} (Pal *et al*., 2008).

Khanda *et al.* (1997) reported that zinc deficiency in rice soils exists since long time, hence blanket soil application of 5-20 kg ha^{-1} of ZnSO4 has been recommended to correct the deficiency and the residual response of applied $ZnSO_4$ persists for two or more years depending on soil characteristics and rate of application. Application of 10 kg Zn (5.0 + 2.5 + 2.5 kg ha^{-1}) in three splits in combination with RD of NPK (60:13:25 kg ha^{-1}) recorded significantly higher growth, yield attributes, grain (4. 25 t ha^{-1}) and straw (4.66 t ha^{-1}) yield (Mandal *et al*., 2009) . Srivastava et al. (1992) also noted that Zn applications of 20 kg zinc sulphate ha^{-1} to the soil or 500 g Zn ha^{-1} as foliar spray and chelated Zn at 1 kg ha^{-1}soil applied or 500 g Zn ha^{-1} applied as foliar spray increased the grain yields of rice.

Application of 30 kg $ZnSO_4$+ 5 kg $FeSO_4$ ha^{-1} through chelating with FYM was found to be the best combination for rice which considerably increased the growth, yield attributes and yield of rice (Kulandaivel *et al*., 2004).

$ZnSO_4$ at 45 kg ha^{-1} application recorded highest dry matter (930 g/m^2), panicle/m^2 (160), 1000 grain weight (24.26 g), harvest index (41.48%) and Zn uptake (214 g ha^{-1}) compared to the other rates such as 15 and 30 kg ha^{-1} and control. It also recorded highest grain (.4 Mg ha^{-1}) and straw (4.8 Mg ha^{-1}) yield. The soil application of $ZnSO_4$ at 45 kg ha^{-1} was superior to foliar application at 0.75%. Zn uptake by plant significantly varied with different methods and doses of $ZnSO_4$ application (Kumar and Kumar, 2009).

Soil application of 2.5 kg Zn ha^{-1} showed higher effectiveness than foliar application of 2.0 kg Zn ha^{-1} in increasing the Zn concentration in grain and straw and also the uptake of Zn by rice attributed to higher absorption and translocation of Zn applied through the foliar application (Haslett *et al*.2001) and partly to the fact that unlike a soil-applied inorganic Zn fertilizer, foliar-applied Zn is not subjected to chemical transformation in soil that could reduce solubility and availability of a soil-applied Zn (Srivastava *et al*., 2014) .

Application of N, P, K, Zn and other micronutrients based on soil test recommendations increased the yield by 23.9% in rice over recommended levels (Dev *et al*., 2011). Soil application of 50 kg $ZnSO_4$ ha^{-1} followed by foliar spray of Zn-EDTA (equivalent to 0.2% $ZnSO_4$) and seedling root dip with ZnO (equivalent to 10 kg $ZnSO_4$/l) significantly increased the grain yield (Jena *et al*., 2006).

Foliar application of Zn fertilizers represents a short term and highly effective strategy to increase grain Zn concentration. Katyal et al. (2004) reported that foliar application of Zn increased the yield of rice significantly over control. Das et al. (2004) observed that the foliar application of 0.1% of Zn as ZnSO4.7H2O at maximum tillering and panicle initiation stage recorded higher Zn uptake (77.22 g ha^{-1}) and grain yield (4.58 Mg ha^{-1}) compared to other rates such as 0.05 and 0.2%. Foliar application of 0.5% zinc sulfate ($ZnSO_4.7H_2O$) after flowering in rice increased paddy Zn concentration, with larger increases when applications were repeated. The largest increases of up to ten-fold were in the husk, and smaller increases in brown rice Zn (Boonchuay *et al.*, 2013). Zn solution sprayed at 1.1 – 2.2 kg Zn ha^{-1} generally produced yields that were comparable with yields from granular fertilizer applied at 11.2 kg Zn ha^{-1} (Slaton *et al.*, 2005). Application of 2% ZEU (Zn enriched urea) followed by 0.2% foliar spray of $ZnSO_4$ recorded highest yield, N and Zn uptake in Basmati rice (Pooniya *et al.*, 2011).

2.3.3 Boron

Boron is unique among the essential mineral nutrients because it is a nonmetal and present in soil solution as a non ionized molecule. Parent rock and derived soils are the primary sources of B in soil and the most common B mineral is tourmaline, a complex borosilicate. Tourmalines are highly resistant ot weathering and virtually insoluble. 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}.

Three B fractions recognized in soils are generally water soluble, acid soluble and total B. Soil pH, cation exchange capacity, sesquioxides, clay content, type of clay and specific surface, organic matter content, and salinity are the factors which influence the solubility and sorption of B in soil (Yermiyahu *et al.*, 2001). Availability of B is reduced with increase in the soil pH. According to Rao *et al.*

(2013) when rice 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. B does not undergo redox reactions. Hence, B concentration is not appreciably affected when soil is flooded as in the case of lowland rice (Ponnamperuma, 1985).

In most of the plant species, B requirement is much higher for reproductive growth than for vegetative growth. Hence, reproductive stage is known as sensitive period to low B stress (Uraguchi and Fujiwara, 2011). According to Rao *et al*. (2013) boron is associated with a wide range of morphological alterations, tissue differentiation, pollen germination and metabolite transfer which will greatly influence the yield and productivity. The main functions of B in plant relate to sugar transport, flower production and retention, pollen tube elongation and germination and translocation of carbohydrate and sugars to reproductive organs, which in turn improved the spikelet number and fertility that influenced the yield and productivity (Ahamad *et al*., 2009). Aslam *et al*. (2002) reported that boron is responsible for better pollination, seed setting, low spike sterility and more grain formation in different varieties of rice.

Being immobile in plant, the deficiency symptoms of B first appears in younger leaves and growing points. Characteristic symptom of B deficiency is shortening of internodes and a rosette appearance. 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). The range of optimal and toxic level of B in plants is very low. Hence, the chance of B toxicity in plants is very high. The typical visible symptom of B toxicity in plants is necrotic patches on the margins and tips of older leaves (Eraslan *et al*., 2007). Sakal *et al*. (2002) suggested that the application of boron through soil or foliar spray was found to be beneficial in simulating plant growth and increasing yield of rice.

Positive relations have been noted between B and K and N fertilizers in improving crop yields (Fageria *et al*., 2002). However, high B supplies resulted in low uptake of Zn, Fe, and Mn but increased the uptake of Cu. High rate of Ca and Mg application may reduce B uptake. Zn deficiency enhances B accumulation (Graham *et al*., 1987).

Two types of B deficiency are encountered in agricultural soils. One is natural deficiency; due to lack of B in soil forming minerals, and other is an induced deficiency as a result of over liming and other adverse environmental conditions. 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). B uptake by plants is controlled by the B level in soil solution rather than the total B content in soil (Yermiyahu *et al*., 2001). Soil application of boron leads to fixation and unavailability (Rao *et al*., 2013).

According to Dunn *et al*. (2005) rice receiving soil applied boron produced significantly greater yields than rice with foliar applied B. 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 low dry matter yield 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).

Several studies conducted have shown that application of boron to rice reduced panicle sterility and enhanced the yield (Jena *et al*., 2006; Rashid *et al*., 2004 and Hussain *et al*., 2012). Hosseini *et al*. (2005) reported that increasing levels of B up to 10 kg borax ha^{-1} significantly increased B content in grain (27.3 mg kg^{-1}) and straw (43.1 mg kg^{-1}) over control (19.3 mg kg^{-1} and 33 mg kg^{-1}). A positive interaction existed between P and B when boron was applied at higher dose (Gaur and Singh, 2010). A significant increase in straw yield was obtained by the application of boron in red loam soils of Kerala (Sreedharan and George, 1969).

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

Latheef (2013) reported that application of boron as borax 20 kg ha^{-1} along with NPK as per Package of practice and FYM increased the LAI and filled grain percentage. Santosh (2013) showed that maximum grain yield of 8.07 t ha^{-1} was recorded with 10 kg ha^{-1} borax given in two splits.

2.3.4 Manganese

Mn toxicity is an important factor limiting plant growth in acid and poorly drained soil (Horst, 1988). 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}. Dobermann and Fairhurst (2000) reported that Mn toxicity rarely occurs in low land rice because rice is comparatively tolerant to large Mn concentrations.

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).

Mn interacts negatively with a number of plant nutrients. Reduced uptake of Mn by plants has been reported by application of Fe (Baxter and Osman, 1988) and Zn (Haldar and Mandal, 1979). Bulbule and Despande (1989) reported that tolerant varieties maintained a high nutrient ratio of N/Fe, P/Fe, K/Fe, Mg/Fe and Mn/Fe. According to Maas et al. (1968) and Robson and Loneragan (1970) the uptake of Mn is inhibited by divalent cations such as Ca, Mg, and Zn. Foy (1984) reported that P additions reduces the toxicity of Mn rendering it inactive within the plant.

2.3.5 Copper

Copper is an essential micronutrient for plant growth and various biochemical processes. The average copper content of the lithosphere is reported to be 70 mg kg^{-1}, whereas soils generally range from 2 – 100 mg kg^{-1}.The average content for soils is estimated at 30 mg kg^{-1} (Lindsay, 1979). 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).

Copper is involved in photosynthesis, cell wall lignification, grain or seed formation and root development. Copper is immobile in plants and symptoms appears first in younger leaves. Leaves appear bluish green and then become chlorotic near the tip. The newly emerging leaves fail to unroll and appear needlelike. Under severe cases, the leaf tips become white and leaves are narrow and twisted.

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).

2.4 Factors affecting nutrient availability

Nutrient availability to plants is composed of several processes in the soil plant system before a nutrient is absorbed or utilized by a plant. Soil pH, soil texture, soil reaction, organic matter, calcium carbonate content, cultural and management practices, nutrient interactions and status of micronutrients in the soil are the important factors which affect availability of secondary and micronutrients in soil (Zayed *et al.*, 2011; Muralidharan and Jose, 1994). These factors may vary from region to region and even within the same region. Hence availability of nurients to plants is a very dynamic process. According to Pirzadeh *et al*. (2010) climate, farm management, and crop variety also play an important role in the uptake of micronutrients by the plants.

2.4.1 Soil pH

Soil pH is probably the most important soil parameter. 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).

Micronutrient deficiency of plants occur more frequently in soils with high pH such as those found in arid and semiarid regions (Alloway, 2008). At higher pH (>6), there is a decrease in uptake of micronutrients (Fageria and Baligar, 1999).

Cationic micronutrients become less plant available as soil pH increases (Cavallaro and McBride, 1984). Fox (1968) found that at high pH, high calcium solutions restrict the plant uptake of B by 50%. The high pH has a negative effect on soil boron availability to rice (Dunn *et al*., 2005). Lindsay (1972) reported that the soluble Mn^{2+} decreased 100-fold for each unit increase in pH.

Lin *et al*. (2009) reported the positive effects of soil pH on Cu in grain and soil and Mn in grain. Sidhu and Sharma (2010) observed a significant and negative correlation between soil pH and available contents of Mn and Fe. The solubility and mobility of Zn in soil and its deposition in grain is highly pH dependent and decreases 100-fold for each unit increase in pH (Mandal *et al*., 2000, Slaton *et al*., 2005, Ponnusamy, 2006, Chandel *et al*., 2010).

Extractable Cu and Zn were increased up to about pH 5.5 and then decreased in a quadratic mode with increasing soil pH. The low pH causes low availability of calcium and favours the increased availability of P (Papadopoulos *et al*., 2009).

2.4.2 Organic matter

The availability and distribution of all forms of the micronutrients are markedly controlled by soil Organic C. Organic C has a positive effect on available Zn, Cu, Mn, Fe, B and Mg (Katyal and Sharma 1991, Chandel *et al*., 2010). Sidhu and Sharm (2010) reported that DTPA Zn decreased with increased soils clay content. The relatively poor correlation of Zn with OM and CEC could be attributed to the slight adsorption effect of OM on this element (Papadopoulos *et al*., 2009). Zn deficiecy is reported in soils having low organic matter contents (Fageria *et al*., 2002). A significant positive correlation has been reported between soil extractable Zn and organic matter content (Alloway, 2004).

Increased organic matter in soil increases availability of Zn, whereas Cu and Mn availability to plants is decreased (Singh *et al*. 2010, Fan *et al*. 2011). The available B was found to be positively and significantly correlated with organic carbon (Debnath and Ghosh, 2012). Marzadori *et al*. (1991) reported that soil organic matter appears to be responsible for occluding important adsorbing sites and plays a positive role in B release from soil surfaces.

2.4.3 Calcium carbonate content

The availability of Zn, Cu, Mn, and Fe has negative correlation with CaCO3 content in soil (Shuman 1986). DTPA-extractable micronutrients such as Fe, Mn, Zn, Cu, Co generally showed a decrease in concentration with increasing pH and CaCO3 contents that exert a major influence on the availability of the micronutrients (Yerima *et al*., 2013).

The negative effect of liming on Zn and Cu availability occurs mainly because of the increase in the soil cation exchange capacity, which depends on the presence of pH-dependent charges in the soil. As the pH increases, the number of negative pH-dependent charges also increases and the micronutrients available for the plant decrease. 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). $CaCO_3$ content buffers soils in the general pH range of 7.4 to 8.5 and Fe oxides attain their minimum solubility, and Fe deficiency in plants is most severe.

2.4.4 Nutrient interaction and Status of micronutrients in soil

The availability of Zn depends on the concentrations of Zn^{2+}, Fe^{2+}, Mn^{2+}, and P in soil solution. Greater concentrations of Fe^{2+} and Mn^{2+}, in the soil solution antagonize Zn absorption (Mandal *et al*., 2000). The uptake, translocation, metabolism, and plant use of Zn is inhibited by high P availability or greater rates of P fertilizer applications (Lindsay 1979; Papadopoulos *et al*., 2009). Fe/Zn levels of native soil showed significant effects on grain and Zn content (Chandel *et al*., 2010). The micronutrient concentrations originally in the soils are related to the parent material. The availability of Zn recently added in acid soils increases with Zn addition because of the increasing proportions of Zn in the most available forms (Nascimento *et al*., 2007). High B application lowers the uptake of Zn, Fe, and Mn but increased Cu uptake (Fageria et al., 2002). Soils with high content of Ca and Mg reduce the uptake of B by plants. Iron availibity is reported to be decreased with the presence P, Zn Cu and Mn in soil (Follett *et al*., 1981).

2.4.5 Climate and manegement practices

It has been found that factors such as climate, physiographic position, and soil development may affect variability of some soil properties and thereby macro- and micronutrient availability (Ghiri et al., 2013). Sharma et al. (2000) indicated that DTPA-extractable Zn, Cu, Mn, and Fe concentrations is high in aquic, moderate in ustic,and low in aridic moisture regime.

Humid tropical climate has resulted accumulation of hydroxides of iron and aluminium in Kerala soil (NBSS and LUP, 1999). High rainfall leads to the nutrient loss through run off and leaching. Dry weather also limits B availability because it restricts water flow, which transports available B in solution (Niaz *et al*., 2013). Moisture regimes and seasonal temperature also influence the distribution and availability of micronutrients. When moisture regime become drier, DTPA extractable Zn, Cu, Mn and Fe contents became lower. This negative effect was led by a coinciding increase in pH and lime and decrease in organic matter. Compared to dry regions, leaching is a prominent phenomenon in humid regions and B is susceptible to leaching (Katyal and Ratttan, 2003).

The availability of Mn in soil is controlled by the combined effects of soil properties, plant characteristics, and the interactions of plant roots and the surrounding soil (Godo and Reisenauer, 1980). Irrigation and fertilizer management have also been reported to increase the accumulation of Zn in rice grains (Hao *et al*., 2007). Soils in arid and semi-arid climatic are low in organic matter content which results in limited soil available pools of Zn (Sidhu and Sharma, 2010).

2.5 Irrigated rice

Rice is grown mainly under two ecosystems, known as upland and lowland. Lowland rice, also known as irrigated rice or flooded rice is grown on levelled lands with bunds and with irrigation facilities. Under normal conditions, lowland rice fields are flooded with water about 3 to 4 weeks after sowing. The water level of about 10 to 15 cm is maintained during the crop growth cycle and is drained before harvest. Flooding helps to reduce the incidence of disease, insects, and weeds in low land rice compared to upland rice. Flooding or water logging eliminates oxygen from the rhizosphere and causes changes in the soil chemical properties. Because of flooding, chemistry of lowland rice soils changes, which affect physical, chemical, and biological properties and consequently rice yields. In addition, flooding also has major effects on the availability of macro and micronutrients. Some nutrients are increased in availability to the crop, whereas others are subject to greater fixation or loss from the soil as a result of flooding (Patrick and Mikkelsen, 1971).

The pH of acidic soils increases and alkaline soils decreases as a result of flooding. Overall, pH of most soils tends to change toward neutral after flooding. 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.

Oxidation reduction potential of highly reduced soil is in the range of –100 to –300 mV (Fageria *et al*., 2008). Redox potential decreased with flooding of rice soils. Reducing conditions in flooded rice soils change concentration and forms of applied as well as native soil nutrients. In flooded soils, SO_4^{-2} ion is reduced to hydrogen sulfide. H_2S will be converted to insoluble iron sulfide by combining with Fe^{2+}. Calcium and magnesium deficiencies are rare in lowland rice. Changes in Ca and Mg concentrations are minimum in flooded soils. The Fe^{3+} reduces to Fe^{2+} and Mn^{4+} reduces to Mn^{2+} hence uptake of these elements increased in the flooded rice soils (Ponnamperuma, 1972).

Indirect toxicity creates nutrient imbalance in plants. The most important nutrient deficiencies observed in irrigated or flooded rice are P, K, and Zn (Fageria *et al*., 2008). Zinc and copper concentrations generally decreased after flooding rice soils. The decrease in concentration with the flooding may be associated with increase in soil pH after flooding. Boron concentration seems to remain more or less constant after submergence of rice soils. Molybdenum concentration in rice soils was found to increase after submergence due to the increased pH (Ponnamperuma, 1975).

2.6 Soil and foliar application of nutrients

Fertilizer use efficiency can be achieved by the appropriate method of application of fertilizers to the field. It can be by soil application, foliar application or fertigation. Generally essential nutrients are supplied to plants mainly through soil and foliage for achieving maximum economic yields.

2.6.1 Soil application of nutrients

Soil application method is more common and most effective for nutrients, which is required in higher amounts. It is effective not only for macro but also for micronutrients (Fageria *et al*., 2009). Soil applications of fertilizers are mainly done on the basis of soil tests. The dose of fertilizer depends on the initial soil fertility status and moisture availability conditions (Yadav and Choudhary, 2012). The dose of fertilizers are also depends on the nutrient requirement of crops. Application of Mg as basal dose in the form of $MgSO_4$ (10% MgO) or Magnesite (40%) at 20 kg MgO ha^{-1} significantly increased grain and straw yield of rice in Mg deficient soil (KAU, 2011). $MgSO_4$ at 10 kg ha^{-1} almost doubled the biomass production under normal supply of 25 kg $ZnSO_4$ ha^{-1} largely due to increased tillering, hastened the process of heading, increased the filled-grains and grain size leading to yield enhancement significantly (Singh and Singh., 2005).

Soil application of Zn is prophylactic treatment and has a relatively long residual effect. Rattan *et al*. (2008) observed that general application rate of Zn is 5-11 kg Zn ha^{-1} as $ZnSO_4$. Zn deficiency can be corrected by applying 25 kg $ZnSO_4$ (21% Zn) or 16 kg Zinc sulphate monohydrate (33% Zn) per acre by broadcasting method at the time of transplanting (Bhatt, 2011). According to Stalin *et al.* (2011) basal application of $ZnSO_4$ at 25 kg ha^{-1} increased grain yield to 6137 kg ha^{-1} compared to control. Kumar and Kumar (2009) reported that the soil application of $ZnSO_4$ @ 45kg ha^{-1} is superior to foliar application of $ZnSO_4$ @ 0.75%. Zn application as basal dose at the time of sowing or transplanting is more efficient (Rattan *et al*., 2008). Applications of Zn fertilizers, most typically as $ZnSO_4$ at rates of 5–10 kg Zn ha^{-1} is suitable to correct soil Zn deficiency (Dobermann and Fairhurst 2000; Qadar 2002) but higher rates of 14–15 kg Zn ha^{-1} are not uncommon in parts of Northern India (Singh et al. 2005). The application of Zn to rice seedlings prior to transplanting, either through fertilizer applications to nursery beds or through dipping seedling roots in Zn solution is an alternative to fertilizer broadcast in fields (Rashid *et al.* 2000; Dobermann and Fairhurst 2000). Khanda *et al.* (1997) reported that long time existance of zinc deficiency in rice soils can be corrected by blanket soil application of 5-20 kg ha^{-1} of $ZnSO_4$. However,the residual response of applied $ZnSO_4$ persists for two or more years depending on soil characteristics and rate of application.

Soil application of B is a common method but its availability has been limited due to its immobile nature (Tulasi *et al*., 2011). Soil application of boron leads to fixation and unavailability of this nutrient. Soil application of borax is effective in enhancing the yield of various crops (Rattan *et al*., 2008). The recommended rate for soil application of B varies from 0.5 - 2 kg B ha^{-1} (Prasad *et al*., 1998). Soil application of Boron (1.5 kg/hm^2) at the transplanting, tillering, flowering and grain formation stages of rice improved the number of grains per panicle, 1000-grain weight, grain yield, harvest index, net economic income and ratio of benefit to cost.

For improving rice performance and maximizing the net economic returns, B might be applied as soil application at flowering (Hussain et al., 2012).

2.6.2 Foliar application of nutrients

Foliar application is one of the most effective and safest approaches to enrich essential micronutrients in crop grain (Fang *et al*., 2008). Nowadays foliar fertilization is gaining importance in plant nutrition due to the greater awareness of soil water pollution resulting from indiscriminate or excessive soil fertilization and adverse soil conditions which favours soil fixation of nutrients. Micronutrients are required in small amounts and foliar application of these nutrients is more uniform compared to soil application (Fageria *et al*., 2009). Jin *et al*. (2008) reported that foliar spray of different micronutrients has been reported to be equally or more effective than soil application because of higher uptake efficiency.

Soluble inorganic salts are generally as effective as synthetic chelates in foliar sprays and inorganic salts are usually chosen because of lower costs. Correction of deficiency symptoms usually occur within the first several days and then the entire field could be sprayed with the appropriate micronutrient source. $MgSO_4$, $ZnSO_4$ and sodium borate at 3-10, 1.5-2.5 and 0.25–0.5 kg respectively per 500 litre is used for foliar application (Fageria and Baligar, 1997).

For efficient absorption of foliar fertilization, leaf stomata should be open and temperature should not be too high to cause burning of plant foliage. In the afternoon, when air temperature is low, is the best time for foliar fertilization. There should be at least 3 to 4 hours for the applied nutrient to be absorbed by plant foliage. Hence, there should not be rain for at least 3 to 4 hours after application of the nutrient solution. Windy days should be avoided for foliar spray as it causes drifting of the spray solution. When applying a nutrient solution as a spray, some sticking material should be added to the solution to stick the spray drops to plant foliage (Fageria *et al*., 2009).

Foliar fertilization requires higher leaf area index for absorbing applied nutrient solution in sufficient amount. It provides more rapid utilization of nutrients and permits the correction of observed deficiencies in less time than would be required by soil application. At early growth stage when plant roots are not well developed, foliar fertilization is more advantageous in absorption compared to soil application (Fageria *et al*., 2009). It may be necessary to have more than one application depending on severity of nutrient deficiency.

Foliar spraying resulted in better absorption of micronutrients, increased photosynthetic activities by delaying the onset of leaf senescence and effective translocation to storage organs which resulted in an increased yield in rice (Datta and Dhiman, 2001). Boron, which is immobile in plant tissues, sprayed directly towards developing tissues such as flower buds and flowers ensure adequate supply at critical stages of development (Brown and Shelp, 1997). The dry matter production was more efficient when boron fertilizer was applied through foliage than it was applied to the roots (Prado *et al*., 2013).

The foliar application of 0.5% of $CuSO_4$, $ZnSO_4$, $FeSO_4$, $MnSO_4$ + 0.05% boric acid + 0.010% sodium molybdate at active tillering, panicle initiation and flowering increased the absorption of these nutrients in grain (Stalin *et al*., 2011). Zn applied as foliar spray had the effect on uptake of Zn and other micronutrients in plants (Kaya and Higgs, 2001). The foliar application of Zn is a therapeutic treatment. Biweekly foliar sprays with 0.5% + 0.25 % lime suspension are recommended using 500 liters of water per hectare on crops exhibiting Zn deficiency symptoms (Rattan *et al*., 2008). Sodium tetra borate at 0.2% is used for foliar application of B and 2 - 3 sprays may be required (Prasad *et al*., 1998). Zn concentration in rice was increased by 25 % by foliar application of ZnSO4.7H2O at the rate of 0.5 % (w/v)) and only 2.4 % by soil Zn application at the rate of 50 kg ZnSO4.7H2O ha^{-1} (Phattarakul *et al.,* 2012).

Foliar application of Zn and B (Zn + B at 6 + 3 kg/acre) were gave higher growth and yield response in rice. The plant height, tiller/plant, panicle length, kernels/plant, filled kernel/plant, productive kernel, straw, paddy and biological yield increased up to 29.75, 38.40, 28.19, 25.81, 36.52, 38.52, 32.47, 38.27 and 31.79%, respectively. The chlorophyll contents, B and Zn contents in rice plant also increased significantly as compared to the control (Arif et al., 2012).

Foliar application of B at rate of 1.74 kg per hectare (0.07 mg/l)proved better for number of grains (164.7/panicle), 1000-grain weight (21.07 g) and paddy yield (3.2 Mg/ha). Concentration of boron in both rice straw and paddy increased with B application but there was no effect of B on NPK concentration of strawand paddy (Shafiq and Maqsood., 2010).

Foliar application of Fe over soil application is preferred because after application in the soil Fe gets oxidized and residual effects are nil. Foliar application was superior to soil application even up to 200 kg ferrous sulphate ha^{-1} (Sadana and Nayyar, 2000). Five foliar applications of balanced amounts of macro and micro nutrients at the seedling stage (two sprays), tillering (single spray) and panicle (two sprays at panicle initiation and panicle differentiation) stages increased the number of panicles/m^2, 1000 grain weight, biological and grain yield (Shayganya *et al*., 2012).

Advantages of foliar sprays include lower application rates compared to that of soil application, uniform application, immediate response to the applied nutrient and deficiencies can be corrected during the growing season itself (Zayed *et al.*, 2011).

In the long run foliar applications cause depletion of soil Zn (Katyal *et al*., 2004). Foliar fertilization cannot substitute for soil application and can only complement the soil fertilization. It is simply a nutrient corrective technique in crops when soil application is ineffective due to immobilization of soil applied nutrients (Fe and Mn) and also for the nutrients (Ca, Mg and Mn) which are not easily translocated to leaves within the plant (Shayganya *et al*., 2012).

2.7 Combined application of fertilizers

Nowadays labour shortage is the main problem affecting the agriculture sector. Being rice cultivation highly labour intensive, labour shortage makes the rice cultivation very difficult. Even though farm mechanization is a very efficient remedy for transplanting and harvesting in rice, fertilizer application still depends on the farm labourers. Individual application of each of the macro and micro nutrient fertilizers is very difficult, time consuming, labour intensive and increases the cost of production. Hence combined application of nutrients either as soil application or as foliar application is an alternative to this.

Combined soil application of N, P, Zn and B increased 1000 grain weight over control and application of N and P alone (Ghani et al., 1990; Rajan, 1993). According to Abbas *et al.* (2013) combined soil application of Zn and B at the rate 150g $ZnSO_4$ and 17g boric acid resulted higher 1000 grain weight of 25.7g, paddy yield of 12.6 t ha^{-1}, protein content of 11.1% and fat content of 2.5%. Cao et al. (2004) reported that combined application of N application along with Zn increased protein content of rice grain.

Combined soil application of S, Zn and B at the rate of 20, 2, 1 kg ha^{-1} respectively along with recommended dose of NPK (100:30: 60 kg ha^{-1}) increased yield attributes like plant height, number of tillers/hill, filled grain/panicle, and 1000 grain weight as compared to the control (Uddin et al., 2002). Paddy yield was significantly higher with the application of micronutrients (Zn, B and Mo) alone or in combination with each other (Hossain, *et al*., 2001). Combined soil application of B (3 kg per acre) and Zn (5 kg per acre) resulted in increased number of productive tillers m^{-2}, 1000 grain weight and grain yield compared to the individual application and control (Sarwar et al., 2013). Concentration of Fe, and Zn increased significantly in rice grain with combined foliar application of these nutrients (Jin *et al*., 2008).

Concentration of Fe, B and Zinc contents increased significantly in rice grain with combined foliar application of these nutrients (Jin *et al*., 2008). Combined spray of 0.1% (w/v) $FeSO_4 .7H_2O$ and 0.2% (w/v) H_3BO_3 significantly increased the concentration of Fe in seed by 18.9% and that of Zn by 26.7% compared to the control (Jin *et al*., 2008).

Combined foliar application of the micronutrients Zn, Fe and Mn (16%Zn +12%Fe +14%Mn) significantly improved rice growth, dry matter production, leaf area index, chlorophyll content (SPAD value), plant height and panicle length compared to the control. Rice grain yield, straw yield, harvest index and yield components viz., panicle numbers, panicle weight, filled grains/panicle and 1000-grain weight were significantly increased by combined application of micronutrients. Micronutrient application especially through foliage is beneficial for rice growth and yield under saline soil conditions (Zayed et al., 2011).

3. Economics of rice cultivation

Rice is the most important food grain in India. To get maximum profits by reducing cost in rice cultivation, it requires balance dose of fertilizers along with organic manures to increase the yield and quality. Recommended dose of seed, fertilizer, plant protection measures, intercultural operations *etc.* are required for high yield and maximum economic returns (Verma *et al*., 2010). Soil test based and integrated plant nutrient system nutrient management along with or without crop residue incorporation could be suitable for getting economically higher grain yield and B:C ratio (3.17) of rice by keeping improvement in soil health (Jahan *et al*., 2015). According to Prakasha *et al*. (2010) combined application of organic manures along with fertilizers improved soil fertility and thus increased yield of rice which ultimately resulted in high B:C ratio compared to the application of fertilizers alone. Ramtech *et al*. (1998) reported that net returns increased due to the application of FYM along with fertilizers. Mauriya and Mauriya (2013) reported that integrated application of micronutrients such as Zn, B and Mn along with the recommended dose of NPK fertilizers produced higher B:C ratio of 1.47 as compared to the application of NPK fertilizers alone. Combined application of B (3 kg/acre) and Zn (5 kg/acre) was found to be economical having more B;C ratio (2.05) compared to control (1.29) (Sarwar *et al*., 2013). According to Latheef (2013) foliar application of 0.5% $ZnSO_4$ produced highest B:C ratio of 2.11 and all the treatments which received the application of secondary nutrient Mg and micronutrients Zn and B recorded higher B:C ratio than treatment which received POP recommendation for rice.

MATERIALS AND METHODS

III. MATERIALS AND METHODS

The present study entitled "Efficiency of foliar and soil applied nutrients in irrigated rice" was coducted in the farmer's field, Thathamangalam, Palakked during the 2ndcrop season (*Mundakan*) from October 2014 to February 2015. The materials used and methodology adopted for the study is described in this chapter.

3.1 General details

3.1.1 Location

Palakkad is the highest rice producing district of Kerala situated in the South West Coast of India. Pudunagaram, the experimental field lies in Palakkad district between $10^0$68' N latitude and $76^0$70' E longitude and at an altitude of 67.2 m above MSL.

3.1.2 Weather and Climate

The area is having humid tropical climate. The temperature of the district ranges from 20^0C to 40^0C. The maximum and minimum temperatures during the cropping period were35.1^0C and 29.1^0C respectively.

3.1.3 Soil

The texture of the soil was sandy clay loam. The physico – chemical characteristics of the soil of experimental field is presented in the Table 3.1.

3.1.4 Crop and Variety

The rice cv. Uma (MO-16), a medium duration, red kernelled variety suited to all the three seasons especially to the additional crop season of Kuttanad. It is a BPH resistant, non-lodging, dwarf and medium tillering variety capable of producing more than 5 t ha^{-1}yieldunder favourable conditions.

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

Properties	Value
a. Physical properties	
Particle size composition	
Sand (%)	53.30
Silt (%)	12.90
Clay (%)	33.60
Texture	Sandy clay loam
b. Chemical properties	
Soil reaction (pH)	6.2
Electrical conductivity (ds m^{-1})	0.136
Organic carbon (%)	1.43
Available N (kg ha^{-1})	127.56
Available P_2O_5 (kg ha^{-1})	6.53
Available K_2O (kg ha^{-1})	470.77
Available Ca (mg kg^{-1})	1237.20
Available Mg (mg kg^{-1})	367.08
Available S (mg kg^{-1})	18.20
Available Fe (mg kg^{-1})	504.98
Available Zn (mg kg^{-1})	1.17
Available B (mg kg^{-1})	1.62
Available Cu (mg kg^{-1})	1.28
Available Mn (mg kg^{-1})	110.49

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.

3.2 Experimental methods

The experiment was conducted in farmer's field (Sri. Mohanan K., Polanikkalam, Thathamangalam, Palakked) during the 2nd crop season (*Mundakan*) from October 2014 to February 2015. The design of the experiment was RBD with 14 treatments replicated 3 times. The individual plot size was 5.0 m x 4.0 m and seedlings are transplanted at a spacing of 20 cm x10 cm. The layout of the experiment is depicted in Fig.3.1. The treatment details of the experiment are given in the Table 3.2.

3.2.1 Treatment details

Table 3.2 Treatment details

Treatments	
T_1	Soil test based all nutrient package inclusive of FYM
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM
T_3	Soil test based all nutrient package but N based on C:N ratio
T_4	Existing POP inclusive of FYM
T_5	POP NPK
T_6	POP NPK + $MgSO_4$ at 80 Kg / ha
T_7	POP NPK + $ZnSO_4$ at 20 Kg / ha
T_8	POP NPK + Borax at 10 Kg / ha
T_9	POP NPK + $MgSO_4$ foliar – 1%
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%
T_{11}	POP NPK + Borax foliar – 0.25%
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)
T_{14}	Absolute control

N

R_1 R_2 R_3 5 m 4 m

T_{10}	T_4	T_5	T_1	T_6	T_{14}
T_6	T_9	T_{11}	T_3	T_{11}	T_8
T_{14}	T_{13}	T_{13}	T_2	T_1	T_3
T_5	T_1	T_9	T_7	T_{13}	T_7
T_7	T_{11}	T_4	T_{12}	T_4	T_{10}
T_{12}	T_8	T_6	T_{10}	T_9	T_{12}
T_3	T_2	T_{14}	T_8	T_2	T_5

Fig. 3.1 Lay out of the experimental plot

T_1: Soil test based all nutrient package + FYM, T_2: Soil test based all nutrient package but N at 90 kg/ha + FYM, T_3: Soil test based all nutrient package but N based on C:N ratio, T_4: POP NPK + FYM, T_5: POP NPK without FYM, T_6: POP NPK + $MgSO_4$ 80 kg/ha,T_7: POP NPK + $ZnSO_4$ 20 kg/ha, T_8: POP NPK + Borax 10 kg/ha, T_9: POP NPK + $MgSO_4$ 1%, T_{10}: POP NPK + $ZnSO_4$ 0.5%,T_{11}: POP NPK + Borax 0.25%, T_{12}: POP NPK + $MgSO_4$ 80 kg/ha+ $ZnSO_4$ 20 kg/ha+ Borax 10 kg/ha, T_{13}: POP NPK + $MgSO_4$ 1%+ $ZnSO_4$ 0.5%+ Borax 0.25%, T_{14}: Absolute Control

T_1 indicates nutrient supply based on soil test results including FYM, where the N, P_2O_5 and K_2O recommendation is 70.2:52.65:11.25 kg ha^{-1}.T_2 means the supply of nutrients based on soil test results but N is applied as 90 kg ha^{-1}including FYM. InT_1 and T_2, FYM is applied as per POP recommendation as 5 t ha^{-1} .T_3indicates nutrient application based on soil test results but N supply based on C:N ratio (29:1) at 95.4 kg ha^{-1} without FYM. T_4 is the supply of nutrients according to the POP NPK at 90:45:45 kg N, P_2O_5 and K_2O ha^{-1} along with FYM at 5 t ha^{-1}. T_5 include the application of fertilizers based on POP NPK recommendation for rice at 90:45:45 kg N, P_2O_5 and K_2O ha^{-1} without FYM.

3.2.2 Fertilizers

Urea, factamphos, muriate of potash, magnesium sulphate, zinc sulphate and boron were used as the sources for different nutrients. The nutrient content of these fertilizers are given in the Table 3.3.

Table 3.3 Sources of nutrients

Nutrients	**Fertilizer**	**Nutrient content (%)**
Nitrogen	Urea	46
	Factamphos	20
Phosphorus	Factamphos	20
Potassium	Muriate of potash	60
Magnesium	Magnesium sulphate	10
Zinc	Zinc sulphate	23
Boron	Borax	11

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 Kerala agricultural University (KAU, 2011). Seeds of the variety

Uma were obtained from Regional Agricultural Research Station, Pattambi. Nineteen days old seedlings were transplanted from the nursery in to a well puddled and levelled field at a spacing of 20 cm x 10 cm at 2-3 seedlings /hill. Date of nursery sowing, transplanting and harvesting are given in the Table 3.4.

Table 3.4 Sowing, transplanting and harvesting date of crops

Particulars	**Date**
Sowing (nursery)	07-10-2014
Transplanting	26-10-2014
Harvesting	18-02-2015

Soil application of Mg, Zn and B were done as basal according to the treatments. The entire quantity of P, $1/3^{rd}$ of N and $1/3^{rd}$ of K were applied as basal. Remaining N and K fertilizers were applied as two top dressings at maximum tillering and panicle initiation stage at equal splits.

Foliar spray of Mg, Zn and B were given at 20 and 40 DAT of rice according to the treatments. Spray volume used was 250 l ha^{-1}. The quantity of fertilizers used for foliar application is given in the Table 3. 5.

Table 3.5 Quantity of fertilizers used for foliar application

<table>
<tr><th>Fertilizers</th><th>Quantity/ha</th><th>Spray volume/ha</th></tr>
<tr><td>Magnesium sulphate</td><td>2.5 kg</td><td rowspan="3">250 l</td></tr>
<tr><td>Zinc sulphate</td><td>1.25 kg</td></tr>
<tr><td>Borax</td><td>0.625 kg</td></tr>
</table>

3.3.2 After cultivation and plant protection

The fields were kept weed free by hand weeding. Plant protection measures were taken up against leaf roller (Quinalphos 1000 ml of 25EC per ha) and rice bug (Malathion 1000 ml of 50 EC per ha).

3.3.3 Harvesting

The crop was harvested at maturity. Plants in the two border rows on all sides of each plot were harvested first and removed. Net plots were harvested by cutting at the base. Threshing was manually done and weight of grain and straw were recorded. The weight of grain is expressed at 12% 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

The height of ten random plants from each plot 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

The number of tillers per plant was counted from ten randomly selected plants from each plot and the mean was worked out at 30 DAT, 60 DAT and at harvest.

3.4.1.3 Dry matter production

Three plants were taken for finding out dry matter production. They were cut at the base, cleaned, air dried and then oven dried at 80^0C till a constant dry weight was obtained and it was recorded in g at 30 DAT, 60 DAT and at harvest.

3.4.1.4 Leaf area index

Leaf area is the ratio of leaf area to land area. Three randomly selected plants from each plot at 60 DAT were used for leaf area determination. The leaf area was calculated using Leaf Area Meter (CI-202 Area Meter). The leaf samples were put back to determine the dry weight.

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

3.4.1.5 Number of panicles per hill

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

3.4.1.6 Number of spikelets per panicles

The number of spikelets per panicles was counted from fifteen panicles randomly selected from each plot and the mean was worked out.

3.4.1.7.Percentage of filled grain

Grains collected from the randomly selected fifteen panicles were separated in to filled grains and chaff. The number of filled grains and chaff were counted separately and the mean was worked out. The percentage of filled grains was then calculated.

3.4.1.8 Thousand grain weight

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

3.4.1.9 Yield

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

3.4.2 Physiological characters

3.4.2.1 Chlorophyll content

The top fully opened leaves (3^{rd} or 4^{th} leaf) were selected from three hills for chlorophyll estimation. For analysis, 0.2 gm of finely cut leaf samples were taken in a beaker and 10 ml DMSO (Dimethyl Sulphoxide) solution was added. This was kept in a dark place overnight and the next day, made up to 25 ml in a volumetric flask with DMSO after filtering. The chlorophyll content was estimated colorimetrically (Yoshida *et al.,* 1972) in a spectronic-20 spectrophotometer at two wave lengths i.e., 663 and 645 nm. Using the equation given below, chlorophyll a, chlorophyll b and total chlorophyll contents were calculated at 60 DAT.

Chlorophyll a = 12.7x OD @ 663nm- 2.69xOD@ 645nm x V/Wx1000
Chlorophyll b = 22.9x OD @ 645nm- 4.63xOD@ 663nm x V/Wx1000
Total chlorophyll = 8.02x OD @ 663nm + 20.2xOD@ 645nm x V/Wx1000
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. Soil samples were collected from the experimental plots following standard procedures. Soil samples air dried powdered and passed through 0.5 mm sieve for analyzing organic carbon and 2 mm sieve for analyzing physio-chemical characteristics of the soil. The various methods used for the analysis are given in the Table 3.6.

3.4.3.2 Plant analysis

For plant analysis three hills were selected at random from each plot at 30 DAT, 60 DAT and at harvest. Plant samples were cleaned; the leaf blades and sheath were separated and dried in hot air oven at 60^0C, powdered well and analyzed for different nutrients. The method used for the analysis of different nutrients is given in the Table 3.5.

3.4.4 Economics of cultivation

The cost of cultivation, gross returns and benefit: cost ratio (gross returns/cost of cultivation) was calculated on the basis of prevailing market price of different inputs and outputs. The price of paddy and that of straw at current local market prices were taken as Rs. 19 and Rs. 6 per kg respectively. Benefit cost ratio was worked out by dividing the gross returns with total expenditure per hectare.

3.5 Statistical analysis

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

Table 3.6 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. Lay out of the plot

Plate 2. Fertilizer application

Plate 3. Foliar spray of fertilizers

Plate 4. General view of the plot

RESULTS

IV. RESULTS

A field experiment to compare the efficiency of foliar and soil applied nutrients in irrigated rice was conducted in the farmer's field, Thathamangalam, Palakked during the 2nd crop season (*Mundakan*) from October 2014 to February 2015. 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 effects 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, 60 DAT and harvest ranged from 58.94 to 62.49 cm, 71.29 to 82.01 cm and from 88.03 to 100.26 cm respectively. Even though soil test based all nutrient package but N based on C:N ratio (T_3) produced tallest plants at harvest, it is on par with other treatments except control. Soil test based nutrient application such as T_1, T_2 and T_3 recorded tallest plants than plants receiving POPR for rice (T_5) at harvest. Individual soil application of Mg, Zn and B along with POP NPK (T_6, T_7 and T_8) produced tallest plants at harvest compared to the individual foliar application of the same nutrients (T_9, T_{10} and T_{11}). But the plant height for combined soil and combined foliar application of Mg, Zn and B along with POP NPK (T_{12} and T_{13} respectively) are on par at harvest.

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 is significantly higher for treatment receiving soil test based all nutrient package inclusive of FYM (T_1) compared to other

Table 4.1 Effect of treatments on plant height (cm)

Treatments		30 DAT	60 DAT	Harvest
T_1	Soil test based all nutrient package inclusive of FYM	62.49^{a}	80.04^{ab}	99.54^{a}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	59.78^{a}	80.14^{ab}	98.62^{a}
T_3	Soil test based all nutrient package but N based on C:N ratio	61.06^{a}	81.97^{a}	100.26^{a}
T_4	Existing POP inclusive of FYM	61.15^{a}	82.01^{a}	99.73^{a}
T_5	POP NPK	59.58^{a}	77.94^{b}	96.76^{a}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	58.94^{a}	82.38^{a}	98.47^{a}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	60.38^{a}	78.78^{b}	100.02^{a}
T_8	POP NPK + Borax at 10 kg / ha	60.81^{a}	80.35^{ab}	97.57^{a}
T_9	POP NPK + $MgSO_4$ foliar – 1%	60.04^{a}	79.74^{ab}	97.58^{a}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	60.64^{a}	82.50^{a}	96.87^{a}
T_{11}	POP NPK + Borax foliar – 0.25%	59.76^{a}	79.64^{ab}	95.94^{a}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	59.81^{a}	79.94^{ab}	97.83^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	60.08^{a}	78.66^{b}	96.88^{a}
T_{14}	Absolute control	59.23^{a}	71.29^{c}	88.03^{b}

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	Soil test based all nutrient package inclusive of FYM	19.80^{a}	20.07^{ab}	14.33^{a}	28.61^{a}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	18.03^{cd}	18.37^{ab}	14.53^{a}	20.06^{a}
T_3	Soil test based all nutrient package but N based on C:N ratio	17.80^{cd}	19.83^{ab}	14.97^{a}	23.24^{a}
T_4	Existing POP inclusive of FYM	19.63^{ab}	20.47^{a}	14.07^{a}	31.26^{a}
T_5	POP NPK	18.93^{abc}	18.07^{ab}	14.30^{a}	20.70^{a}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	18.40^{abcd}	18.40^{b}	14.20^{a}	22.42^{a}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	18.63^{abcd}	18.63^{ab}	14.77^{a}	20.19^{a}
T_8	POP NPK + Borax at 10 kg / ha	19.70^{a}	19.27^{ab}	14.23^{a}	25.94^{a}
T_9	POP NPK + $MgSO_4$ foliar – 1%	19.67^{ab}	19.37^{ab}	14.23^{a}	26.20^{a}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	18.43^{abcd}	19.27^{ab}	14.50^{a}	24.25^{a}
T_{11}	POP NPK + Borax foliar – 0.25%	19.67^{ab}	18.37^{ab}	15.30^{a}	15.91^{a}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	18.27^{bcd}	18.33^{ab}	14.40^{a}	21.42^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	19.60^{ab}	18.40^{ab}	15.53^{a}	15.59^{a}
T_{14}	Absolute control	17.43^{d}	13.30^{c}	10.87^{b}	23.73^{a}

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

treatments except T_8, T_9, T_{11} and T_{13}. However POPR for rice (T_4) produced significantly higher tiller count compared to other treatments at 60 DAT. Individual foliar application of Mg and Zn along with POP NPK (T_9 and T_{10}) resulted in more number of tillers than individual soil application of Mg and Zn along with POP NPK (T_6 and T_7) and vice versa in the case of individual soil and foliar application of B along with POP NPK (T_8 and T_{11}) even though they are on par at 60 DAT. Combined foliar application of Mg, Zn and B along with POP NPK (T_{13}) produced highest tiller count(15.53) and it is on par with other treatments except control (10.87). The tiller decline is highest in T_4 which received POPR for rice and lowest in T_{13} (combined foliar application of Mg, Zn and B along with POP NPK) which is similar to T_{11} (individual foliar application of B along with POP NPK). At the harvest stage the numbers of tillers were similar (14-15.3) in all the treatments except control (10.87).

4.1.3 Leaf area index (LAI)

The data on LAI are given in Table 4.3. The treatments T_{12} (combined soil application of Mg, Zn and B along with POP NPK) and T_{13} (combined foliar application of Mg, Zn and B along with POP NPK) resulted in significantly higher LAI which is on par with other treatments except T_4, T_5, T_8 and control which had the lowest LAI.

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. Only for chlorophyll a, there was significant difference among the treatments; the chlorophyll b and total chlorophyll content were statistically similar in all the treatments. Combined foliar application of Mg, Zn and B along with POP NPK (T_{13}) produced highest chlorophyll a content (2 mg/kg). But the existing POPR for rice (T_4) resulted in highest chlorophyll b (0.52 mg/kg) and total chlorophyll (2.43 mg/kg) at 60 DAT even though all the treatments were on par. The control treatment which did not

Table 4.3 Effect of treatments on LAI

Treatments		LAI 60 DAT
T_1	Soil test based all nutrient package inclusive of FYM	4.54^{ab}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	4.27^{abc}
T_3	Soil test based all nutrient package but N based on C:N ratio	4.62^{ab}
T_4	Existing POP inclusive of FYM	3.95^{bc}
T_5	POP NPK	3.78^{cd}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	4.51^{ab}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	4.45^{abc}
T_8	POP NPK + Borax at 10 kg / ha	4.00^{bc}
T_9	POP NPK + $MgSO_4$ foliar – 1%	4.21^{abc}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	4.62^{ab}
T_{11}	POP NPK + Borax foliar – 0.25%	4.36^{abc}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	4.70^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	4.69^{a}
T_{14}	Absolute control	3.13^{d}

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

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

Treatments		Chl. a	Chl. b	Total chl.
T_1	Soil test based all nutrient package inclusive of FYM	1.63[ab]	0.42[a]	2.05[a]
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	1.85[ab]	0.42[a]	2.22[a]
T_3	Soil test based all nutrient package but N based on C:N ratio	1.71[ab]	0.37[a]	2.07[a]
T_4	Existing POP inclusive of FYM	1.93[ab]	0.52[a]	2.43[a]
T_5	POP NPK	1.60[abc]	0.33[a]	1.88[a]
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	1.89[ab]	0.42[a]	2.31[a]
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	1.89[ab]	0.44[a]	2.32[a]
T_8	POP NPK + Borax at 10 kg / ha	1.92[ab]	0.49[a]	2.40[a]
T_9	POP NPK + $MgSO_4$ foliar – 1%	1.60[abc]	0.45[a]	2.04[a]
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	1.66[ab]	0.41[a]	2.07[a]
T_{11}	POP NPK + Borax foliar – 0.25%	1.57[bc]	0.49[a]	2.06[a]
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	1.63[ab]	0.38[a]	1.99[a]
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	2.00[a]	0.27[a]	2.26[a]
T_{14}	Absolute control	1.20[c]	0.36[a]	1.86[a]

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

received any fertilizer nutrients resulted in the lowest chlorophyll a and total chlorophyll content of 1.20 and 1.86 mg/kg respectively.

4.1.5 Dry matter production

The dry matter production observed at 30 DAT, 60 DAT and at harvest by the application of various treatments is presented in Table 4.5. Soil test based nutrient application such as T_1, T_2 and T_3 recorded a constant and steady improvement in dry matter production at all stages. Even though the dry matter production is not significantly different at 60 DAT, the individual foliar application of Mg, Zn and B along with POP NPK (T_9, T_{10} and T_{11}) resulted higher dry matter production than individual soil application of Mg, Zn and B along with POP NPK (T_6, T_7 and T_8). The same trend was seen in combined foliar application of Mg, Zn and B along with POP NPK (T_{13}) compared to combined soil application of Mg, Zn and B along with POP NPK (T_{12}) at 60 DAT. At harvest, the highest dry matter production was observed in treatment receiving individual soil application of B along with POP NPK (T_8) and it was on par with other treatments except T_5 and control. The lowest dry matter production was observed in control along with POP NPK alone.

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 4.6. The highest number of panicles/hill was observed in T_{13} (combined foliar application of Mg, Zn and B along with POP NPK) as 15.53 even though which is on par with other treatments except control. The control resulted in the lowest number of panicles (10.87).

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

Treatments		30 DAT	60 DAT	Harvest
T_1	Soil test based all nutrient package inclusive of FYM	2.62[a]	6.43[a]	12.30[a]
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	2.22[a]	6.18[a]	12.50[a]
T_3	Soil test based all nutrient package but N based on C:N ratio	2.31[a]	6.77[a]	11.78[a]
T_4	Existing POP inclusive of FYM	2.08[a]	6.17[a]	11.53[a]
T_5	POP NPK	2.51[a]	5.93[a]	9.76[b]
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	2.18[a]	5.05[a]	12.17[a]
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	2.48[a]	5.96[a]	11.16[ab]
T_8	POP NPK + Borax at 10 kg / ha	2.37[a]	6.31[a]	12.57[a]
T_9	POP NPK + $MgSO_4$ foliar – 1%	2.02[a]	6.13[a]	12.32[a]
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	2.56[a]	6.30[a]	11.25[a]
T_{11}	POP NPK + Borax foliar – 0.25%	2.24[a]	6.51[a]	12.47[a]
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	2.28[a]	6.14[a]	12.29[a]
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	2.45[a]	6.74[a]	12.08[a]
T_{14}	Absolute control	1.58[a]	5.60[a]	7.92[c]

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

Table 4.6 Effect treatments on yield attributes of rice

Treatments		Yield Attributes			
		Panicle/ hill	Spikelets/ panicle	Filled grains/ panicle (%)	1000 grain wt.(g)
T_1	Soil test based all nutrient package inclusive of FYM	14.33[a]	132.00[ab]	77.85[d]	26.67[ab]
T_2	Soil test based all nutrient package except N + FYM + N 90 Kg / ha	14.53[a]	149.00[a]	84.18[abcd]	26.39[ab]
T_3	Soil test based all nutrient package except N, N based on C:N ratio	14.97[a]	146.33[ab]	81.05[cd]	26.87[a]
T_4	Existing POP inclusive of FYM	14.07[a]	134.00[ab]	80.31[cd]	26.02[b]
T_5	POP NPK	14.30[a]	143.33[ab]	79.36[cd]	26.66[ab]
T_6	POP NPK + $MgSO_4$ at 80 Kg / ha	14.20[a]	146.67[ab]	86.06[abc]	27.14[a]
T_7	POP NPK + $ZnSO_4$ at 20 Kg / ha	14.77[a]	145.00[ab]	89.50[ab]	27.18[a]
T_8	POP NPK + Borax at 10 Kg / ha	14.23[a]	129.67[ab]	81.52[cd]	26.37[ab]
T_9	POP NPK + $MgSO_4$ foliar – 1%	14.23[a]	130.67[ab]	82.14[bcd]	26.45[ab]
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	14.50[a]	131.67[ab]	90.42[a]	26.40[ab]
T_{11}	POP NPK + Borax foliar – 0.25%	15.30[a]	125.67[b]	81.91[cd]	26.71[ab]
T_{12}	POP NPK + Soil application of $MgSO_4$ (80Kg / ha) + $ZnSO_4$ (20 Kg / ha) + Borax (10 Kg / ha)	14.40[a]	134.00[ab]	84.55[abcd]	26.73[ab]
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	15.53[a]	149.00[a]	81.16[cd]	26.49[ab]
T_{14}	Absolute control	10.87[b]	99.33[c]	77.80[d]	25.09[c]

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

4.2.2 Spikelets/panicle

The effect of various treatments on spikelets/panicle is shown in Table 4.6. The number of spikelets varied from 99.33 to 149. T_2 (soil test based all nutrient package but N @ 90 kg ha^{-1}along with FYM and) and T_{13} (combined foliar application of Mg, Zn and B along with POP NPK) produced higher number of spikelets/panicle (149). Individual soil application of Mg, Zn (T_6 and T_7) produced higher number of spikelets/panicle as compared to individual foliar application of the same (T_9 and T_{10}) and they are on par. Soil application of B (T_8) followed the same trend however its foliar application resulted in a lower spikelet number. Control recorded lowest number of spikelet/panicle.

4.2.3 Filled grains/ panicle

The effects of treatments on filled grains/ panicle is given in Table 4.6. The highest percentage of filled grains/panicle was observed with T_{10} which received foliar application of Zn (90.42%) closely followed by soil application of the same (T_7). The lowest percentage of filled grains/panicle was shown by control with 77.80 percentage.

4.2.4 Thousand grain weight

The data on thousand grain weight is shown in Table 4.6. The treatment which received individual soil application of Zn along with POP NPK (T_7) produced significantly higher 1000 grain weight which was on par with all treatments except T_4 and T_{14}. The test weight has also increased over control when the nutrients (Mg, Zn and B) were individually or jointly applied either in soil or foliage. The control treatment resulted with significantly lowest 1000 grain weight of 25.09 g.

4.3 Yield

4.3.1 Grain yield

The effect of various treatments on grain yield is shown in Table 4.7. The highest grain yield of 6.28 t ha^{-1} was obtained for the treatments which received combined soil application of Mg, Zn and B (T_{12}) closely followed by soil test based nutrient package but N @ 90 kg ha^{-1} inclusive of FYM (T_2) with 6.18 t ha^{-1} and soil test based all nutrient package inclusive of FYM (T_1) with 6.05 t ha^{-1}, combined foliar application of Mg, Zn and B (T_{13}) with 6.13 t ha^{-1} and soil and foliar application of individual nutrients which all were at par. Treatments which received POP NPK alone (T_5) or POP with FYM (T_4) soil and foliar application of Zn were at par. The control treatment resulted in lowest grain yield of 3.89 t ha^{-1}.

4.3.2 Straw yield

The treatment effects on straw yield are shown in Table 4.7. Highest straw yield is recorded by soil application of B along with POP NPK (T_8) as 6.38 t ha^{-1} even though it is on par with other treatments except T_5 and control. Individual soil application of Mg, Zn and B along with POP NPK (T_6, T_7 and T_8) produced highest straw yield compared to the individual foliar application of the same nutrients (T_9, T_{10} and T_{11}). Combined soil and foliar application of Mg, Zn and B along with POP NPK (T_{12} and T_{13}) produced statistically similar yields.

4.4 Harvest Index

The effect of various treatments on harvest index is shown in Table 4.7. The harvest index varied from 0.470 to 0.506 and there was not any significant difference among them. However, combined soil application of Mg, Zn and B along with POP NPK (T_{12}) resulted in highest HI of 0.506.

Table 4.7 Effect of treatments on grain and straw yield (t ha^{-1}) and HI

Treatments		Yield (t ha^{-1})		Harvest Index
		Grain	Straw	
T_1	Soil test based all nutrient package inclusive of FYM	6.05^{a}	6.25^{a}	0.493^{a}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	6.18^{a}	6.32^{a}	0.493^{a}
T_3	Soil test based all nutrient package but N based on C:N ratio	5.73^{ab}	6.05^{a}	0.483^{a}
T_4	Existing POP inclusive of FYM	5.67^{ab}	5.87^{ab}	0.493^{a}
T_5	POP NPK	4.69^{bc}	5.07^{b}	0.477^{a}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	5.89^{a}	6.29^{a}	0.487^{a}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	5.19^{ab}	5.97^{a}	0.470^{a}
T_8	POP NPK + Borax at 10 kg / ha	6.18^{a}	6.38^{a}	0.490^{a}
T_9	POP NPK + $MgSO_4$ foliar – 1%	6.10^{a}	6.22^{a}	0.500^{a}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	5.59^{ab}	5.66^{ab}	0.497^{a}
T_{11}	POP NPK + Borax foliar – 0.25%	6.12^{a}	6.35^{a}	0.487^{a}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	6.28^{a}	6.12^{a}	0.506^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	6.13^{a}	6.15^{a}	0.499^{a}
T_{14}	Absolute control	3.89^{c}	4.03^{c}	0.463^{a}

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 4.8. Nitrogen content at 30 DAT was varying significantly from 2.10 to 2.86 %. The treatment which received soil test based nutrient package but N based on C:N ratio (T_3) resulted in significantly high N content of 2.86% which was at par with treatments which received soil test based all nutrient package inclusive of FYM (T_1), soil test based nutrient package but N @ 90 kg ha^{-1} inclusive of FYM (T_2), POP NPK inclusive of FYM (T_4), soil application of B (T_8), foliar application of Mg (T_9) and foliar application of Zn (T_{10}). The lowest N content was resulted in control treatment with 2.10%.

At 60 DAT, there was no significant difference among the treatments in N content. Even though the N content ranged from 1.40%, the highest percentage of 1.93% resulted with treatment which received soil test based nutrient package but N based on C:N ratio (T_3).

Significant difference in grain N content was observed and it varied from 0.90% in control treatment to 1.29% in treatment which received combined soil application of Mg, Zn and B (T_{12}) which was closely followed by the treatment which received combined foliar application of the same (T_{13}) and treatment which received foliar application of Zn (T_{11}).

N content of straw in control treatment was the lowest (0.42%) and it was significantly low compared to all other treatments. The significantly high N content in straw was observed with 0.68% in treatment which received combined soil application of Mg, Zn and B (T_{12}).

4.5.2 Phosphorus

The phosphorus content of plant at 30 DAT, 60 DAT and harvest are shown in Table 4.9. P content varied from 0.13 to 0.26% at 30 DAT., however the difference was not significant. At 60 DAT also, there was not much significant

Table 4.8 Effect of treatments on nitrogen content (%) of rice

Treatments		30DAT	60 DAT	Harvest	
				Grain	Straw
T_1	Soil test based all nutrient package inclusive of FYM	2.78[ab]	1.49[a]	1.06[bc]	0.58[ab]
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	2.71[abc]	1.69[a]	1.07[bc]	0.64[a]
T_3	Soil test based all nutrient package but N based on C:N ratio	2.86[a]	1.93[a]	1.11[ab]	0.59[ab]
T_4	Existing POP inclusive of FYM	2.68[abc]	1.75[a]	1.17[ab]	0.64[a]
T_5	POP NPK	2.40[cdef]	1.51[a]	1.11[ab]	0.58[ab]
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	2.45[bcdef]	1.75[a]	1.05[bc]	0.58[ab]
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	2.19[ef]	1.69[a]	1.05[bc]	0.53[bc]
T_8	POP NPK + Borax at 10 kg / ha	2.54[abcde]	1.63[a]	1.17[ab]	0.58[ab]
T_9	POP NPK + $MgSO_4$ foliar – 1%	2.51[abcde]	1.75[a]	1.17[ab]	0.58[ab]
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	2.63[abcd]	1.81[a]	1.23[ab]	0.58[ab]
T_{11}	POP NPK + Borax foliar – 0.25%	2.45[bcdef]	1.81[a]	1.17[ab]	0.58[ab]
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 Kg / ha) + Borax (10 kg / ha)	2.28[def]	1.69[a]	1.29[a]	0.68[a]
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	2.45[bcdef]	1.49[a]	1.24[ab]	0.63[ab]
T_{14}	Absolute control	2.10[f]	1.40[a]	0.90[c]	0.42[c]

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

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

Treatments		30DAT	60 DAT	Harvest	
				Grain	Straw
T_1	Soil test based all nutrient package inclusive of FYM	0.13^{a}	0.21^{a}	0.16^{abcd}	0.25^{a}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	0.13^{a}	0.24^{a}	0.18^{ab}	0.21^{a}
T_3	Soil test based all nutrient package but N based on C:N ratio	0.18^{a}	0.27^{a}	0.14^{cd}	0.24^{a}
T_4	Existing POP inclusive of FYM	0.17^{a}	0.24^{a}	0.16^{abcd}	0.23^{a}
T_5	POP NPK	0.16^{a}	0.26^{a}	0.14^{cd}	0.22^{a}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	0.19^{a}	0.24^{a}	0.14^{cd}	0.23^{a}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	0.19^{a}	0.24^{a}	0.15^{bcd}	0.19^{a}
T_8	POP NPK + Borax at 10 kg / ha	0.17^{a}	0.20^{a}	0.16^{abcd}	0.21^{a}
T_9	POP NPK + $MgSO_4$ foliar – 1%	0.26^{a}	0.22^{a}	0.14^{cd}	0.25^{a}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	0.22^{a}	0.20^{a}	0.15^{bcd}	0.22^{a}
T_{11}	POP NPK + Borax foliar – 0.25%	0.14^{a}	0.20^{a}	0.16^{abcd}	0.21^{a}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	0.20^{a}	0.20^{a}	0.19^{a}	0.22^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	0.16^{a}	0.22^{a}	0.18^{ab}	0.20^{a}
T_{14}	Absolute control	0.15^{a}	0.14^{a}	0.10^{e}	0.12^{b}

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

difference in P content even though it varied from 0.14 to 0.27%. Significant difference in grain P content was observed and it varied from 0.107% in control treatment (T_{14}) to 0.194 % in T_{12} where combined soil application of Mg, Zn and B is made. The combined foliar application of the same also resulted in 0.181% P content which was at par with soil application. P content of straw in control treatment was the lowest (0.120%), significantly lower to all other treatments.

4.5.3 Potassium

The potassium content of plant at 30 DAT, 60 DAT and harvest are presented in Table 4.10. K content in rice ranged from 2.23 to 2.89 % at 30 DAT. At 60 DAT, it varied from 1.88 to 2.80 %. In grain and straw it ranged from 0.42 to 0.47 % and 1.44 to 2.26 % respectively. At 30 DAT, foliar application of Zn (T_{10}) recorded highest K content followed by foliar application of Mg (T_9) and soil application of B (T_8) even though they were not significantly different. Soil application of Zn (T_7) recorded significantly higher K content of 2.80% at 60 DAT and it is on par with other treatments except T_9, T_1 and control. The lowest K content of 1.86% was observed in grain in the control treatment and the highest was observed in the treatment which received combined foliar application of Mg, Zn and B (T_{13}). There was no significant difference in the straw K content however absolute control resulted in lowest K content of 1.44% where the highest K content of 2.26% was observed for foliar application of Mg (T_7).

4.5.4 Calcium

The effects of various treatments on Ca content in plant at 30 DAT, 60 DAT and at harvest are shown in Table 4.11. Highest Ca content was recorded in T_{12} (combined soil application of Mg, Zn and B along with POP NPK) and lowest in control at 30 DAT. T_9 (POP NPK + $MgSO_4$ foliar – 1%) showed highest Ca content at 60 DAT and it was same in T_7 (POP NPK + $ZnSO_4$ at 20 Kg / ha). The lowest Ca content was recorded in T_2 (soil test based all nutrient package but N 90 kg / ha + FYM) and T_{14} and on par with T_{13} (combined foliar application of Mg, Zn and B along with POP NPK). In grain, lowest Ca content was seen in

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

	Treatments	30DAT	60 DAT	Harvest	
				Grain	Straw
T_1	Soil test based all nutrient package inclusive of FYM	2.47^{cde}	2.39^{c}	0.43^{a}	1.87^{a}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	2.57^{bcd}	2.50^{abc}	0.47^{a}	2.11^{a}
T_3	Soil test based all nutrient package but N based on C:N ratio	2.65^{abcd}	2.78^{ab}	0.44^{a}	2.25^{a}
T_4	Existing POP inclusive of FYM	2.71^{abc}	2.61^{abc}	0.44^{a}	2.15^{a}
T_5	POP NPK	2.63^{abcd}	2.48^{abc}	0.44^{a}	1.94^{a}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	2.44^{de}	2.51^{abc}	0.46^{a}	2.21^{a}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	2.70^{abcd}	2.80^{a}	0.45^{a}	2.11^{a}
T_8	POP NPK + Borax at 10 kg / ha	2.80^{ab}	2.51^{abc}	0.46^{a}	2.10^{a}
T_9	POP NPK + $MgSO_4$ foliar – 1%	2.87^{a}	2.40^{bc}	0.46^{a}	2.26^{a}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	2.89^{a}	2.53^{abc}	0.45^{a}	2.10^{a}
T_{11}	POP NPK + Borax foliar – 0.25%	2.72^{abc}	2.58^{abc}	0.42^{a}	2.06^{a}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	2.66^{abcd}	2.53^{abc}	0.42^{a}	2.05^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	2.64^{abcd}	2.53^{abc}	0.47^{a}	2.01^{a}
T_{14}	Absolute control	2.23^{e}	1.88^{d}	0.42^{a}	1.44^{a}

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

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

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	Soil test based all nutrient package inclusive of FYM	0.46[bc]	0.58[cd]	0.24[a]	0.16[a]
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	0.44[bcd]	0.35[e]	0.24[a]	0.16[a]
T_3	Soil test based all nutrient package but N based on C:N ratio	0.52[bc]	0.68[bc]	0.24[a]	0.17[a]
T_4	Existing POP inclusive of FYM	0.44[bcd]	0.55[de]	0.24[a]	0.22[a]
T_5	POP NPK	0.49[bc]	0.47[de]	0.23[a]	0.21[a]
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	0.62[ab]	0.49[cde]	0.24[a]	0.19[a]
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	0.50[bc]	0.91[a]	0.24[a]	0.19[a]
T_8	POP NPK + Borax at 10 kg / ha	0.33[cd]	0.49[cde]	0.24[a]	0.17[a]
T_9	POP NPK + $MgSO_4$ foliar – 1%	0.49[bc]	0.91[a]	0.24[a]	0.20[a]
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	0.53[b]	0.47[de]	0.24[a]	0.27[a]
T_{11}	POP NPK + Borax foliar – 0.25%	0.55[ab]	0.86[ab]	0.23[a]	0.16[a]
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	0.75[a]	0.41[de]	0.24[a]	0.25[a]
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	0.43[bcd]	0.36[e]	0.24[a]	0.24[a]
T_{14}	Absolute control	0.25[d]	0.35[e]	0.22[a]	0.19[a]

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

T_{14} (control) even though they were statistically on par with all other treatments. In straw, highest Ca content was recorded in foliar application of Zn (T_{10}) and lowest in foliar application of B (T_{11}) even though they did not differ significantly.

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 4.12. Significantly higher Mg content was recorded in treatment which received POP NPK inclusive of FYM (T_4) and which is statistically on par with other treatments except T_1, T_{11}, T_8 and control and the lowest was recorded at T_8 at 30 DAT. There was a gradual increase in the Mg content from 30 DAT to 60 DAT. The highest Mg content at 60 DAT is recorded in T_{12} (combined soil application of Mg, Zn and B) which was at par with all treatments which received Mg as individual or combined application either in soil or in foliage. The Mg content in grain was highest in the combined foliar application of Mg, Zn and B with 0.077% and it was par with all the treatments which received Mg. The Mg content in straw also followed a similar trend. At all stages in rice, the Mg content was lowest in absolute control treatment.

4.5.6 Sulphur

The effects of various treatments on S content in plant at 30 DAT, 60 DAT and at harvest are shown in Table 4.13. There was no significant difference in the S content of rice at 30 DAT and 60 DAT. The S content varied from 0.19% in absolute control to 0.29% in T_8 (POP NPK + Borax @ 10 kg ha^{-1}) at 30 DAT. At 60 DAT, S content varied from 0.15% in control to 0.25% in treatment which received foliar spray of Mg. S content in grain was highest (0.18%) in the treatment which received combined soil application of Mg, Zn and B followed by its foliar application treatment. S content in straw also followed a similar trend. S content in rice grain and straw were lowest in the absolute control treatment.

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

	Treatments	30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	Soil test based all nutrient package inclusive of FYM	0.159^{bcd}	0.213^{bcd}	0.046^{cde}	0.093^{abcde}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	0.240^{a}	0.228^{bcd}	0.035^{e}	0.070^{e}
T_3	Soil test based all nutrient package but N based on C:N ratio	0.226^{ab}	0.199^{cd}	0.044^{cde}	0.089^{bcde}
T_4	Existing POP inclusive of FYM	0.256^{a}	0.275^{abc}	0.047^{bcde}	0.094^{abcde}
T_5	POP NPK	0.254^{a}	0.295^{ab}	0.042^{de}	0.084^{de}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	0.237^{a}	0.295^{ab}	0.062^{abcd}	0.123^{abcd}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	0.193^{abcd}	0.259^{abc}	0.043^{de}	0.087^{cde}
T_8	POP NPK + Borax at 10 kg / ha	0.138^{d}	0.241^{bcd}	0.068^{abc}	0.135^{ab}
T_9	POP NPK + $MgSO_4$ foliar – 1%	0.217^{abc}	0.253^{bc}	0.061^{abcd}	0.122^{abcd}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	0.204^{abcd}	0.289^{abc}	0.060^{abcd}	0.119^{abcd}
T_{11}	POP NPK + Borax foliar – 0.25%	0.162^{bcd}	0.243^{bcd}	0.062^{abcd}	0.123^{abcd}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	0.208^{abc}	0.348^{a}	0.071^{ab}	0.141^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	0.195^{abcd}	0.283^{abc}	0.077^{a}	0.132^{abc}
T_{14}	Absolute control	0.158^{cd}	0.157^{d}	0.043^{de}	0.065^{e}

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

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

Treatments		30 DAT	60 DAT	Harvest	
				Grain	**Straw**
T_1	Soil test based all nutrient package inclusive of FYM	0.24^{a}	0.18^{a}	0.11^{bc}	0.11^{ef}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	0.20^{a}	0.18^{a}	0.12^{bc}	0.14^{bcd}
T_3	Soil test based all nutrient package but N based on C:N ratio	0.25^{a}	0.18^{a}	0.13^{bc}	0.12^{def}
T_4	Existing POP inclusive of FYM	0.22^{a}	0.21^{a}	0.13^{bc}	0.11^{ef}
T_5	POP NPK	0.21^{a}	0.17^{a}	0.11^{bc}	0.12^{def}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	0.29^{a}	0.20^{a}	0.13^{bc}	0.14^{bcd}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	0.22^{a}	0.20^{a}	0.13^{bc}	0.13^{cde}
T_8	POP NPK + Borax at 10 kg / ha	0.29^{a}	0.21^{a}	0.12^{bc}	0.13^{cde}
T_9	POP NPK + $MgSO_4$ foliar – 1%	0.25^{a}	0.25^{a}	0.13^{bc}	0.14^{bcd}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	0.23^{a}	0.23^{a}	0.10^{c}	0.15^{bc}
T_{11}	POP NPK + Borax foliar – 0.25%	0.25^{a}	0.18^{a}	0.12^{bc}	0.13^{bcde}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	0.22^{a}	0.22^{a}	0.18^{a}	0.16^{b}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	0.23^{a}	0.22^{a}	0.14^{ab}	0.19^{a}
T_{14}	Absolute control	0.19^{a}	0.15^{a}	0.10^{c}	0.10^{f}

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

4.5.7 Iron

The effects of various treatments on Fe content of rice plant at 30DAT, 60 DAT and at harvest are shown in Table 4.14. There was no significant difference in the Fe content of rice at 30 DAT and 60 DAT. Though Fe content varied from 610 ppm in treatment which received POP NPK alone (T_5) to 1144.75 ppm in treatment which received POP inclusive of FYM (T_4) at 30 DAT, at 60 DAT, Fe content varied from 517.50 ppm in control (T_{14}) to 888.75 ppm in soil application of (B). At harvest there was significant difference in the Fe content of both grain and straw. In grain, the highest Fe content was resulted in treatment which received POP NPK (T_5) with 248.54 ppm which was on par with soil test based nutrient package except N inclusive of FYM (T_2). The lowest Fe content was observed in T_3 (soil test based all nutrient package except N, N based on C: N ratio) with 50.25 ppm. The lowest Fe content in straw was resulted in treatment which received soil test based all nutrient package except N inclusive of FYM (T_2) with 453 ppm. Combined soil application of Mg, Zn and B (T_{12}) recorded highest Fe content of 1471.80 ppm which was closely followed by combined foliar application of the same with 1224.45 ppm.

4.5.8 Manganese

The manganese content of rice plant analyzed at 30 DAT, 60 DAT and at harvest is shown in Table 4.15. Significant difference in Mn content in rice was observed at 30 DAT and 60 DAT. At 30 DAT highest Mn content was observed in treatment which received soil test based all nutrient package except N inclusive of FYM (T_2) with 218.24 ppm and which was on par with treatments which received soil test based nutrient package inclusive of FYM (T_1), combined soil application of Mg, Zn and B (T_{12}), soil test based nutrient package and N based on C:N ratio (T_3), POP NPK inclusive of FYM (T_4) and combined foliar application of Mg, Zn and B (T_{13}). At 60 DAT, soil application of Zn (T_7) recorded the highest Mn content of 241.45 ppm closely followed by soil application of B (T_8) with 239.43 ppm and foliar application of Mg (T_9) with

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

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	Soil test based all nutrient package inclusive of FYM	674.63[a]	842.58[a]	155.20[bc]	780.95[bcd]
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	799.13[a]	576.92[a]	213.60[ab]	453.00[d]
T_3	Soil test based all nutrient package but N based on C:N ratio	900.50[a]	600.75[a]	50.25d	546.83[cd]
T_4	Existing POP inclusive of FYM	1144.75[a]	626.17[a]	74.41[cd]	654.00[cd]
T_5	POP NPK	610.00[a]	616.50[a]	248.54[a]	999.10[abc]
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	1035.38[a]	590.50[a]	137.89[bcd]	694.05[bcd]
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	704.50[a]	869.00[a]	131.94[bcd]	783.55[bcd]
T_8	POP NPK + Borax at 10 kg / ha	841.75[a]	888.75[a]	100.99[cd]	620.85[cd]
T_9	POP NPK + $MgSO_4$ foliar – 1%	920.50[a]	827.42[a]	110.53[cd]	885.98[bcd]
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	711.75[a]	694.42[a]	72.42[cd]	585.15[cd]
T_{11}	POP NPK + Borax foliar – 0.25%	707.75[a]	634.33[a]	105.87[cd]	651.55[cd]
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	751.00[a]	570.83[a]	121.49[bcd]	1471.80[a]
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	792.13[a]	646.00[a]	109.78[cd]	1224.45[ab]
T_{14}	Absolute control	910.75[a]	517.50[a]	55.89[d]	706.90[bcd]

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

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

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	Soil test based all nutrient package inclusive of FYM	187.69^{ab}	194.83^{abc}	109.91^{a}	182.44^{a}
T_2	Soil test based all nutrient package but N 90 Kg / ha + FYM	218.24^{a}	192.85^{abc}	112.57^{a}	129.50^{bcde}
T_3	Soil test based all nutrient package butN based on C:N ratio	172.06^{abcd}	195.35^{abc}	105.98^{a}	131.64^{bcd}
T_4	Existing POP inclusive of FYM	171.61^{abcd}	156.44^{bcd}	114.20^{a}	108.61^{cdef}
T_5	POP NPK	131.55^{cdef}	141.51^{cd}	118.94^{a}	100.85^{ef}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	149.93^{bcde}	143.81^{cd}	121.96^{a}	135.79^{bc}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	114.70^{ef}	241.45^{a}	126.21^{a}	104.17^{def}
T_8	POP NPK + Borax at 10 kg / ha	158.26^{bcde}	239.43^{a}	109.88^{a}	130.83^{bcd}
T_9	POP NPK + $MgSO_4$ foliar – 1%	163.35^{bcde}	226.69^{a}	108.95^{a}	114.81^{cdef}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	112.63^{ef}	203.52^{ab}	115.61^{a}	156.30^{ab}
T_{11}	POP NPK + Borax foliar – 0.25%	126.35^{def}	191.06^{abc}	126.03^{a}	137.53^{bc}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	181.24^{abc}	192.30^{abc}	138.20^{a}	133.88^{bc}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	171.40^{abcd}	148.79^{bcd}	108.88^{a}	134.11^{bc}
T_{14}	Absolute control	80.76^{f}	117.88^{d}	82.17^{a}	98.04^{f}

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

226.69 ppm. The Mn content in grain was not significantly different, even though the highest Mn content was observed in treatment which received combined soil application of Mg, Zn and B (T_{12}) with 138.20 ppm. In straw, significantly highest Mn content was observed in treatment which received soil test based nutrient package inclusive of FYM (T_1) as 182.44 ppm and was on par with treatment which received foliar application of Zn (T_{10}). In all the stages of rice growth, absolute control recorded the lowest Mn content.

4.5.9 Zinc

The data on Zn content of plant at 30 DAT, 60 DAT and at harvest are shown in Table 4.16. In all the stages of rice growth, Zn content resulted in significant difference among the treatments. At 30 DAT, highest Zn content of 20.36 ppm was resulted in treatment which received foliar application of Zn (T_{10}) which was at par with all the treatments which received Zn as individual or combined either as soil or as foliar application. The lowest Zn content of 9.93 ppm was resulted in T_2 (soil test based all nutrient package but N 90 kg / ha + FYM). At 60 DAT, T_3 (soil test based all nutrient package but N based on C:N ratio) and T_6 (POP NPK + $MgSO_4$ at 80 kg / ha) recorded significantly higher Zn content of 31.33 ppm and 31.17 ppm respectively closely followed by all the treatments which received individual or combined Zn application irrespective of method of application, soil or foliar application of Mg and B and soil test based all nutrients inclusive of FYM and soil test based all nutrient package except N inclusive of FYM . In grain, highest Zn content was observed in treatment which received foliar application of Zn (T_{10}) with 20.09 ppm closely followed by soil application of Zn (T_7) with 19.65 ppm and combined soil application of Mg, Zn and B (T_{12}) with 18.99 ppm. In straw, highest Zn content was observed with soil and foliar application of Zn (T_7 and T_{10}) with 22.73 and 22.38 ppm respectively and which was closely followed by combined soil and foliar application of Mg, Zn and B (T_{12} and T_{13}). Control recorded lowest Zn content at 60 DAT and in grain and straw.

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

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	Soil test based all nutrient package inclusive of FYM	13.86^{bcde}	26.43^{abc}	17.77^{bcde}	20.62^{ab}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	9.93^{e}	30.78^{ab}	18.13^{bcd}	18.90^{bc}
T_3	Soil test based all nutrient package but N based on C:N ratio	10.28^{de}	31.33^{a}	16.83^{de}	18.42^{c}
T_4	Existing POP inclusive of FYM	15.36^{bc}	25.09^{bcd}	16.96^{de}	18.54^{bc}
T_5	POP NPK	15.72^{bc}	22.92^{cd}	17.20^{cde}	18.51^{bc}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	16.10^{abc}	31.17^{a}	17.61^{cde}	17.72^{cd}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	17.32^{ab}	30.81^{ab}	19.65^{ab}	22.73^{a}
T_8	POP NPK + Borax at 10 kg / ha	14.50^{bcd}	27.03^{abc}	17.88^{bcd}	17.80^{cd}
T_9	POP NPK + $MgSO_4$ foliar – 1%	12.55^{cde}	27.10^{abc}	17.64^{cde}	17.91^{cd}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	20.36^{a}	28.12^{abc}	20.09^{a}	22.38^{a}
T_{11}	POP NPK + Borax foliar – 0.25%	16.56^{abc}	24.66^{cd}	17.37^{cde}	18.08^{c}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	16.27^{abc}	26.39^{abc}	18.99^{abc}	22.06^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	16.33^{abc}	28.40^{abc}	17.91^{bcd}	21.72^{a}
T_{14}	Absolute control	13.86^{cde}	20.30^{d}	15.98^{e}	15.76^{d}

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 4.17. B content in rice was significantly different at all stages of the growth. At 30 DAT, the rice B content varied from 5.02 ppm in treatment which received soil application of Zn (T_7) to 11.37 ppm in treatment which received combined foliar application on Mg, Zn and B (T_{13}) and which was at par with all the B applied treatments except foliar application of B. At 60 DAT, significantly higher B content was observed in treatment which received soil application of B (T_8) with 14.71 ppm which was at par with all the other B applied treatments. The lowest B content was observed for control with 5 ppm. B content of grain varied from 5.34 ppm in control to 14.56 ppm in treatment which received soil application of Mg which was followed by foliar application of B (T_{11}) with 13,35 ppm, soil application of B (T_8) with 10.93 ppm and combined soil application of Mg, Zn and B (T_{12}) with 10.31 ppm. In straw, combined foliar application of Mg, Zn and B resulted in significantly high B content of 13.44 ppm which was at par with foliar application of B (12.52 ppm), combined soil application of Mg, Zn and B (11.29 ppm) and soil application of Zn (12.32 ppm). The lowest B content in straw was observed in control treatment.

4.5.11 Copper

The copper content at 30 DAT, 60 DAT and at harvest is presented in Table 4.18. The Cu content at 30 DAT differs significantly and the highest Cu content of 8.42 ppm was observed in treatment which received soil application of Mg (T_6) which was on par with treatments received POP NPK alone (T_5) with 7.91 ppm and soil test based nutrient package inclusive of FYM (T_1) with 7.78 ppm. The lowest Cu content was resulted in control with 3.68 ppm. There was no any significant difference among the treatments in Cu content at 60 DAT even though the highest Cu of 10.30 ppm recorded with treatment which received soil application of Zn (T_7) and lowest in control (5.22 ppm). Significant difference in Cu content was observed both in grain and in straw. In grain, the highest Cu

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

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	Soil test based all nutrient package inclusive of FYM	10.71^{ab}	9.47^{bcd}	9.95^{bc}	9.27^{cde}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	6.82^{cd}	7.94^{cd}	10.20^{bc}	9.07^{cde}
T_3	Soil test based all nutrient package but N based on C:N ratio	9.46^{abc}	9.93^{bc}	9.47^{cd}	7.63^{def}
T_4	Existing POP inclusive of FYM	7.56^{bcd}	10.10^{abc}	9.62^{c}	6.61^{ef}
T_5	POP NPK	6.76^{cd}	10.58^{abc}	7.77^{cde}	10.56^{abc}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	6.80^{cd}	11.78^{abc}	14.56^{a}	8.64^{cdef}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	5.02^{d}	8.71^{cd}	6.07^{def}	12.32^{ab}
T_8	POP NPK + Borax at 10 kg / ha	9.20^{abc}	14.71^{a}	10.93^{bc}	10.06^{bcd}
T_9	POP NPK + $MgSO_4$ foliar – 1%	10.30^{abc}	13.71^{ab}	8.50^{cde}	8.67^{cdef}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	10.89^{ab}	12.48^{abc}	3.16^{f}	6.75^{ef}
T_{11}	POP NPK + Borax foliar – 0.25%	7.61^{bcd}	11.98^{abc}	13.35^{ab}	12.52^{ab}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	8.84^{abc}	10.11^{abc}	10.31^{bc}	11.29^{abc}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	11.37^{a}	10.92^{abc}	9.71^{c}	13.14^{a}
T_{14}	Absolute control	7.69^{abcd}	5.00^{d}	5.34^{ef}	5.91^{f}

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

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

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T_1	Soil test based all nutrient package inclusive of FYM	7.78^{abc}	8.42^{a}	6.50^{bcd}	12.45^{bcd}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	5.54^{de}	7.47^{a}	3.73^{e}	10.89^{cde}
T_3	Soil test based all nutrient package except N, N based on C:N ratio	5.20^{de}	8.15^{a}	8.28^{ab}	4.95^{f}
T_4	Existing POP inclusive of FYM	5.85^{cd}	9.53^{a}	5.42^{cde}	7.10^{e}
T_5	POP NPK	7.91^{ab}	7.43^{a}	5.30^{cde}	12.51^{bcd}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	8.42^{a}	7.38^{a}	4.02^{de}	9.81^{de}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	4.76^{de}	10.30^{a}	4.08^{de}	9.70^{de}
T_8	POP NPK + Borax at 10 kg / ha	5.97^{bcd}	8.12^{a}	10.69^{a}	14.61^{ab}
T_9	POP NPK + $MgSO_4$ foliar – 1%	6.33^{bcd}	8.62^{a}	5.09^{cde}	13.64^{bc}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	5.15^{de}	8.63^{a}	6.34^{bcd}	17.66^{a}
T_{11}	POP NPK + Borax foliar – 0.25%	6.29^{bcd}	9.50^{a}	7.04^{bc}	14.24^{b}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	5.82^{cd}	6.69^{a}	4.85^{cde}	10.01^{de}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	5.52^{de}	7.99^{a}	4.62^{cde}	15.63^{ab}
T_{14}	Absolute control	3.68^{e}	5.22^{a}	2.94^{e}	7.81^{ef}

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

content was observed with soil application of B (T_8) as 10.69 ppm which was at par with soil test based all nutrient package and N based on C:N ratio (T_3). In grain, the lowest Cu content was observed in control with 2.94 ppm. In straw, highest Cu content was resulted in treatment which received foliar application of Zn (T_{10}) with 17.66 ppm which was at par with soil application of B (T_8) with 14.61 ppm. The lowest was observed with soil test based nutrient package but N based on C:N ratio (T_3) with 4.95 ppm.

4.6 Nutrient uptake

4.6.1 Nitrogen

The data pertaining to nitrogen uptake by the crop at harvest is shown in Table 4.19. The N uptake in grain was significantly high for the treatment which received combined soil application of Mg, Zn and B (T_{12}) with 79.74 kg ha^{-1} and lowest in control. Similar trend was observed in the case of N uptake by straw and also total uptake. Highest total N uptake of 121.27 kg ha^{-1} was observed for the treatment which received combined soil application of Mg, Zn and B (T_{12}). Control recorded the lowest N uptake in straw and total N uptake.

4.6.2 Phosphorus

The effect of various treatments on P uptake by the crop is presented in Table 4.20. P uptake in grain was significantly high with combined soil application of Mg, Zn and B (T_{12}) closely followed by soil test based nutrient package except N inclusive of FYM (T_2), combined foliar application of Mg, Zn and B (T_{13}), soil test based nutrient package inclusive of FYM (T_1), soil application of B (T_8) and lowest in control treatment. The N uptake by straw was highest in treatment which received foliar application of Mg (T_9) with 15.70 kg ha^{-1} and lowest by control (4.70 kg ha^{-1}) and the treatments varied significantly. T_1 (soil test based all nutrient package inclusive of FYM) resulted in high total P uptake of 26.06 kg ha^{-1} closely followed by combined soil application of Mg, Zn and B (T_{12}) and soil test based nutrient package but N @ 90 kg ha^{-1} inclusive of FYM (T_2) and lowest was recorded by control with 9.83 kg ha^{-1}.

Table 4.19 Effect of treatments on N uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	Soil test based all nutrient package inclusive of FYM	64.04^{bcd}	36.46^{abc}	100.50^{b}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	65.03^{bcd}	40.60^{ab}	105.63^{b}
T_3	Soil test based all nutrient package but N based on C:N ratio	63.01^{bcd}	35.80^{abc}	98.81^{bc}
T_4	Existing POP inclusive of FYM	66.05^{abc}	37.46^{abc}	103.51^{b}
T_5	POP NPK	51.59^{d}	29.58^{c}	81.17^{d}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	61.82^{bcd}	36.84^{abc}	98.66^{bc}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	54.54^{cd}	31.33^{bc}	85.87^{cd}
T_8	POP NPK + Borax at 10 kg / ha	72.26^{ab}	37.35^{abc}	109.61^{ab}
T_9	POP NPK + $MgSO_4$ foliar – 1%	70.96^{ab}	36.64^{abc}	107.60^{ab}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	69.06^{ab}	33.03^{abc}	102.09^{b}
T_{11}	POP NPK + Borax foliar – 0.25%	71.24^{ab}	37.08^{abc}	108.31^{ab}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	79.74^{a}	41.53^{a}	121.27^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	73.87^{ab}	38.98^{ab}	112.85^{ab}
T_{14}	Absolute control	34.80^{e}	16.80^{d}	51.60^{e}

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

Table 4.20 Effect of treatments on P uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T_1	Soil test based all nutrient package inclusive of FYM	10.43^{abc}	15.62^{ab}	26.06^{a}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	11.70^{ab}	13.45^{abc}	25.15^{a}
T_3	Soil test based all nutrient package but N based on C:N ratio	8.49^{cd}	14.27^{abc}	22.76^{abc}
T_4	Existing POP inclusive of FYM	8.94^{bcd}	13.27^{abc}	22.21^{abc}
T_5	POP NPK	6.79^{de}	11.23^{c}	18.03^{c}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	8.64^{cd}	14.14^{abc}	22.78^{abc}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	7.95^{cd}	11.49^{bc}	19.45^{bc}
T_8	POP NPK + Borax at 10 kg / ha	10.15^{abc}	13.56^{abc}	23.71^{ab}
T_9	POP NPK + $MgSO_4$ foliar – 1%	8.68^{bcd}	15.70^{a}	24.37^{ab}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	8.65^{cd}	12.57^{abc}	21.22^{abc}
T_{11}	POP NPK + Borax foliar – 0.25%	9.63^{abcd}	13.22^{abc}	22.85^{abc}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	11.98^{a}	13.27^{abc}	25.25^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	10.76^{abc}	12.36^{abc}	23.12^{abc}
T_{14}	Absolute control	4.22^{e}	4.70^{d}	8.92^{d}

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

4.6.3 Potassium

The effect of treatments on K uptake by the crop is shown in Table 4.21. The K uptake by grain was significantly high in soil test based all nutrient package except N inclusive of FYM (T_2) with 28.80 kg ha^{-1} which was on par with other treatments except T_5 and control. The lowest K uptake was observed in control with 16.50 kg ha^{-1}. K uptake by straw was significantly highest with foliar application of Mg (T_9) as 139.63 kg ha^{-1} which was closely followed by the soil application of the same with 139.08 kg ha^{-1}. Control recorded the lowest K uptake by straw with 58.22 kg ha^{-1}. The total uptake was high with foliar application of Mg (T_9) closely followed by T_6, T_8, T_2, T_3, T_{11} and the lowest was observed in control.

4.6.4 Calcium

The data on Ca uptake by the rice crop at harvest is shown in Table 4.22. Ca uptake by grain was significantly high in T_2 (soil test based all nutrient package but N 90 kg / ha + FYM) which was statistically on par with all other treatments except soil application of Zn, POP NPK alone and control. Combined soil application of Mg, Zn and B (T_{12}) resulted in the highest uptake of Ca with 15.44 kg ha^{-1} by straw even though it did not vary significantly from other treatments. Similarly, the total Ca uptake was highest in combined soil application of Mg, Zn and B (T_{12}) and which was at par with other treatments except T_3, T_7, T_5, T_{11} and control. The uptake of Ca by grain, straw and the total uptake were the lowest in control.

4.6.5 Magnesium

The magnesium uptake by the rice crop at harvest is shown in Table 4.23. In grain, significantly high Mg uptake was observed with combined foliar and soil application of Mg, Zn and B (T_{13} and T_{12}) with 4.54 kg ha^{-1} and 4.36 kg ha^{-1} respectively which was on par with all the treatments which received Mg application. Mg uptake by straw was significantly higher for soil application of B (T_8) with 8.65 kg ha^{-1} and combined soil application of Mg, Zn and B (T_{12}) with

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

	Treatments	Grain	Straw	Total
T_1	Soil test based all nutrient package inclusive of FYM	26.13^{ab}	116.79^{ab}	142.92^{ab}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	28.80^{a}	132.96^{a}	161.76^{a}
T_3	Soil test based all nutrient package but N based on C:N ratio	25.34^{ab}	135.95^{a}	161.30^{a}
T_4	Existing POP inclusive of FYM	24.96^{ab}	126.26^{ab}	151.22^{ab}
T_5	POP NPK	20.75^{bc}	98.42^{b}	119.17^{b}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	27.14^{a}	139.08^{a}	166.22^{a}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	23.50^{ab}	126.41^{ab}	149.91^{ab}
T_8	POP NPK + Borax at 10 kg / ha	28.54^{a}	133.74^{a}	162.28^{a}
T_9	POP NPK + $MgSO_4$ foliar – 1%	28.18^{a}	139.63^{a}	167.81^{a}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	25.04^{ab}	119.14^{ab}	144.18^{ab}
T_{11}	POP NPK + Borax foliar – 0.25%	25.55^{ab}	130.99^{a}	156.54^{a}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	25.64^{ab}	126.59^{ab}	152.22^{ab}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	27.74^{a}	123.89^{ab}	151.63^{ab}
T_{14}	Absolute control	16.50^{c}	58.22^{c}	74.71^{c}

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

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

	Treatments	Grain	Straw	Total
T_1	Soil test based all nutrient package inclusive of FYM	14.72[a]	10.28[a]	25.00[abc]
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	14.99[a]	10.20[a]	25.20[abc]
T_3	Soil test based all nutrient package but N based on C:N ratio	13.88[ab]	10.16[a]	24.04[bc]
T_4	Existing POP inclusive of FYM	13.45[ab]	12.49[a]	25.84[abc]
T_5	POP NPK	10.73[cd]	10.85[a]	21.58cd
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	14.05[ab]	12.02[a]	26.07[abc]
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	12.27[bc]	11.62[a]	23.89[bc]
T_8	POP NPK + Borax at 10 kg / ha	14.90[a]	10.91[a]	25.81[abc]
T_9	POP NPK + $MgSO_4$ foliar – 1%	14.88[a]	12.83[a]	27.70[abc]
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	13.63[ab]	15.05[a]	28.68[ab]
T_{11}	POP NPK + Borax foliar – 0.25%	14.30[ab]	9.85[a]	24.15[bc]
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	14.95[a]	15.44[a]	30.39[a]
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	14.40[ab]	14.96[a]	29.35[ab]
T_{14}	Absolute control	8.79[d]	7.78[a]	16.58[d]

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

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

Treatments		Grain	Straw	Total
T_1	Soil test based all nutrient package inclusive of FYM	2.72^{bcdef}	5.84^{abcd}	8.56^{abcde}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	2.18^{def}	4.45^{cde}	6.63^{de}
T_3	Soil test based all nutrient package but N based on C:N ratio	2.63^{cdef}	5.35^{bcde}	7.98^{cde}
T_4	Existing POP inclusive of FYM	2.67^{cdef}	5.66^{abcde}	8.33^{bcde}
T_5	POP NPK	1.88^{ef}	4.25^{de}	6.14^{de}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	3.63^{abcd}	7.76^{ab}	11.39^{abc}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	2.23^{def}	5.49^{bcde}	7.72^{cde}
T_8	POP NPK + Borax at 10 kg / ha	4.23^{ab}	8.65^{a}	12.87^{a}
T_9	POP NPK + $MgSO_4$ foliar – 1%	3.71^{abcd}	7.43^{abc}	11.14^{abc}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	3.41^{abcde}	6.73^{abcd}	10.15^{abcd}
T_{11}	POP NPK + Borax foliar – 0.25%	3.78^{abc}	7.84^{ab}	11.62^{abc}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	4.36^{a}	8.66^{a}	13.02^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	4.54^{a}	8.13^{ab}	12.67^{ab}
T_{14}	Absolute control	1.71^{f}	2.63^{e}	4.34^{e}

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

8.66 kg ha^{-1} which was closely followed by combined foliar application of the same with 8.13 kg ha^{-1}. Similarly as in straw, the total Mg uptake was high for T_{12} and T_8 which was on par with all the treatments except T_2, T_3, T_4, T_5, T_7 and control. The lowest uptake of Mg was observed in control for grain, straw and total uptake.

4.6.6 Sulphur

The effect of treatments on S uptake by the crop is shown in Table 4.24. The highest S uptake by grain was observed in treatment which received combined soil application of Mg, Zn and B (T_{12}) with 10.81 kg ha^{-1} which was at par with combined foliar application of the same with 8.59 kg ha^{-1}. The results of S uptake in straw and the total uptake was higher for T_{13} which received combined foliar application of Mg, Zn and B (11.46 kg ha^{-1} and 20.04 kg ha^{-1} respectively) and T_{12} received combined soil application of Mg, Zn and B (9.62 kg ha^{-1} and 20.43 kg ha^{-1} respectively) . Control resulted in lowest uptake of S in grain, straw and total uptake.

4.6.7 Iron

The effect of various treatments on Fe uptake by the rice crop is shown in Table 4.25. Fe uptake by grain was significantly high in treatment which received soil test based all nutrient package except N + FYM + N 90 Kg / ha (T_2) with 1.320 kg ha^{-1} which was closely followed by treatment which received POP NPK alone (T_5) with 1.160 kg ha^{-1} and lowest in control (0.213 kg ha^{-1}). In straw, T_{12} which received combined soil application of Mg, Zn and B resulted in high Fe uptake of 8.97 kg ha^{-1} which was at par with combined foliar application of the same (T_{13}) with 7.49 kg ha^{-1}. The lowest Fe uptake was from control with 2.80 kg ha^{-1}. Similarly as that in straw, the total Fe uptake was the highest for T_{12} which received combined soil application of Mg, Zn and B with 9.54 kg ha^{-1} which was closely followed by combined foliar application of the same (T_{13}) with 8.11 kg ha^{-1}. The lowest Fe uptake was observed in control with 3.01 kg ha^{-1}.

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

Treatments		Grain	Straw	Total
T_1	Soil test based all nutrient package inclusive of FYM	6.68^{bcd}	7.00^{de}	13.68^{bc}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	7.13^{bcd}	9.41^{bc}	16.53^{b}
T_3	Soil test based all nutrient package but N based on C:N ratio	6.68^{bcd}	7.54^{cde}	14.21^{bc}
T_4	Existing POP inclusive of FYM	7.31^{bcd}	6.51^{e}	13.82^{bc}
T_5	POP NPK	5.07^{de}	6.39^{e}	11.46^{c}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	7.60^{bc}	8.84^{bcd}	16.44^{b}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	6.63^{bcd}	7.65^{bcde}	14.28^{bc}
T_8	POP NPK + Borax at 10 kg / ha	7.07^{bcd}	8.21^{bcde}	15.27^{b}
T_9	POP NPK + $MgSO_4$ foliar – 1%	7.57^{bc}	9.23^{bc}	16.79^{b}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	5.74^{cde}	8.62^{bcd}	14.36^{bc}
T_{11}	POP NPK + Borax foliar – 0.25%	7.50^{bc}	8.36^{bcde}	15.87^{b}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	10.81^{a}	9.62^{ab}	20.43^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	8.59^{ab}	11.46^{a}	20.04^{a}
T_{14}	Absolute control	3.69^{e}	4.10^{f}	7.79^{d}

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

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

Treatments		Grain	Straw	Total
T_1	Soil test based all nutrient package inclusive of FYM	0.957^{abc}	4.88^{bc}	5.84^{bcd}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	1.320^{a}	2.86^{c}	4.19^{cd}
T_3	Soil test based all nutrient package but N based on C:N ratio	0.287^{de}	3.31^{c}	3.60^{cd}
T_4	Existing POP inclusive of FYM	0.420^{cde}	3.83^{c}	4.24^{cd}
T_5	POP NPK	1.160^{ab}	5.08^{bc}	6.24^{bc}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	0.800^{abcd}	4.37^{c}	5.17^{bcd}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	0.68^{7bcd}	4.16^{c}	4.85^{cd}
T_8	POP NPK + Borax at 10 kg / ha	0.630^{bcd}	3.94^{c}	4.57^{cd}
T_9	POP NPK + $MgSO_4$ foliar – 1%	0.680^{bcd}	5.54^{bc}	6.22^{bc}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	0.400^{de}	3.31^{c}	3.71^{cd}
T_{11}	POP NPK + Borax foliar – 0.25%	0.647^{bcde}	4.12^{c}	4.77^{cd}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	0.750^{bcde}	8.97^{a}	9.54^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	0.613^{bcde}	7.49^{ab}	8.11^{ab}
T_{14}	Absolute control	0.213^{e}	2.80^{c}	3.01^{d}

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

4.6.8 Manganese

The uptakes of Mn by the application of various treatments are shown in Table 4.26. In grain, T_{12} which received combined soil application of Mg, Zn and B resulted in significantly higher Mn uptake of 0.850 kg ha^{-1} which was at par with all the treatments except T_3, T_5 and control. The uptake of Mn in straw and the total uptake was significantly higher in T_1 which received soil test based all nutrient package inclusive of FYM with 1.140 kg ha^{-1} and 1.820 kg ha^{-1} respectively. Control showed the lowest uptake of Mn by grain, straw as well as the total uptake.

4.6.9 Zinc

The effect of various treatments on the uptake of Zn by rice crop is given in Table 4.27. In grain, Zn uptake was the highest in T_{12} which received combined soil application of Mg, Zn and B with 0.117 kg ha^{-1} which was statistically at par with all the treatments except T_5 and control. The lowest Zn uptake by grain was resulted in control with 0.062 kg ha^{-1}. In straw, T_{12} which received combined soil application of Mg, Zn and B resulted in highest Zn uptake of 0.135 kg ha^{-1} which was at par with all the other Zn applied treatments. Lowest Zn uptake by straw was resulted in control with 0.063 kg ha^{-1}. The total uptake was significantly higher with T_{12} which received combined soil application of Mg, Zn and B with 0.252 kg ha^{-1} and which was at par with all the Zn applied treatments. The lowest total Zn uptake was observed with control.

4.6.10 Boron

The data on B uptake by the crop is presented in Table 4.28. The uptake of B by grain significantly varied from 0.021 kg ha-1 in control to 0.085 kg ha^{-1} in treatment which received soil application of Mg (T_6) which was at par with both foliar and soil application of B (T_{11} and T_8) with 0.082 kg ha^{-1} and 0.066 kg ha^{-1} respectively. The B uptake by straw was significantly high for the treatment which received combined foliar application of Mg, Zn and B (T_{13}) with 0.081 kg ha^{-1} closely followed by treatment which received foliar application of B (T_{11})

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

Treatments		Grain	Straw	Total
T_1	Soil test based all nutrient package inclusive of FYM	0.680^{ab}	1.140^{a}	1.820^{a}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	0.703^{ab}	0.820^{bc}	1.523^{abc}
T_3	Soil test based all nutrient package but N based on C:N ratio	0.597^{b}	0.797^{bc}	1.393^{bcd}
T_4	Existing POP inclusive of FYM	0.650^{ab}	0.643^{cd}	1.287^{cd}
T_5	POP NPK	0.563^{b}	0.510^{de}	1.073^{d}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	0.727^{ab}	0.853^{bc}	1.577^{abc}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	0.653^{ab}	0.637^{cd}	1.293^{cd}
T_8	POP NPK + Borax at 10 kg / ha	0.683^{ab}	0.837^{bc}	1.520^{abc}
T_9	POP NPK + $MgSO_4$ foliar – 1%	0.663^{ab}	0.720^{bcd}	1.380^{bcd}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	0.647^{ab}	0.883^{b}	1.530^{abc}
T_{11}	POP NPK + Borax foliar – 0.25%	0.773^{ab}	0.873^{b}	1.643^{ab}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	0.850^{a}	0.817^{bc}	1.667^{ab}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	0.647^{ab}	0.827^{bc}	1.473^{bc}
T_{14}	Absolute control	0.317^{c}	0.393^{e}	0.717^{e}

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

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

Treatments		Grain	Straw	Total
T_1	Soil test based all nutrient package inclusive of FYM	0.108[a]	0.129[abc]	0.237[abc]
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM +	0.112[a]	0.119[abc]	0.231[abcd]
T_3	Soil test based all nutrient package but N based on C:N ratio	0.097[ab]	0.111[cd]	0.208[cd]
T_4	Existing POP inclusive of FYM	0.096[ab]	0.109[cd]	0.205[d]
T_5	POP NPK	0.081[bc]	0.094[d]	0.175[e]
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	0.103[ab]	0.112[cd]	0.214[bcd]
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	0.102[ab]	0.135[a]	0.237[abc]
T_8	POP NPK + Borax at 10 kg / ha	0.110[a]	0.114[bcd]	0.224[abcd]
T_9	POP NPK + $MgSO_4$ foliar – 1%	0.108[a]	0.111[cd]	0.219[bcd]
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	0.112[a]	0.127[abc]	0.239[ab]
T_{11}	POP NPK + Borax foliar – 0.25%	0.106[a]	0.115[abcd]	0.221[bcd]
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	0.117[a]	0.135[a]	0.252[a]
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	0.106[a]	0.134[ab]	0.240[ab]
T_{14}	Absolute control	0.062[c]	0.063[e]	0.125[f]

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

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

Treatments		Grain	Straw	Total
T_1	Soil test based all nutrient package inclusive of FYM	0.060^{c}	0.058^{bcd}	0.118^{bcd}
T_2	Soil test based all nutrient package but N 90 Kg / ha + FYM	0.063^{bc}	0.057^{bcd}	0.120^{bcd}
T_3	Soil test based all nutrient package but N based on C:N ratio	0.054^{cd}	0.046^{de}	0.101^{cd}
T_4	Existing POP inclusive of FYM	0.054^{cd}	0.038^{ef}	0.093^{d}
T_5	POP NPK	0.037^{de}	0.054^{cde}	0.091^{de}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	0.085^{a}	0.054^{cde}	0.139^{ab}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	0.031^{e}	0.075^{ab}	0.106^{bcd}
T_8	POP NPK + Borax at 10 kg / ha	0.066^{abc}	0.064^{abcd}	0.131^{abc}
T_9	POP NPK + $MgSO_4$ foliar – 1%	0.052^{cd}	0.054^{cde}	0.105^{bcd}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	0.017^{e}	0.038^{ef}	0.056^{ef}
T_{11}	POP NPK + Borax foliar – 0.25%	0.082^{ab}	0.079^{a}	0.161^{a}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	0.064^{bc}	0.068^{abc}	0.132^{abc}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	0.057^{c}	0.081^{a}	0.138^{ab}
T_{14}	Absolute control	0.021^{e}	0.024^{f}	0.045^{f}

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

with 0.079 kg ha^{-1} and was at par with other two B applied treatments (T_{12} and T_8). The total uptake of B was significantly highest for the foliar application of B (T_{11}) with 0.161 kg ha^{-1} and which was at par with all other B applied treatments. B uptake by straw and total uptake was lowest in control.

4.6.11 Copper

The uptake of Cu by rice crop due to the application of various treatments is given in Table 4.29. The highest Cu uptake by grain was observed in T_8 which received soil application of B with 0.066 kg ha^{-1} and lowest in control with 0.012 kg ha^{-1} and the treatments varied significantly. In straw, significantly higher Cu uptake was observed in foliar application of Zn (T_{10}) with 0.100 kg ha^{-1}. The total Cu uptake was significantly higher for T_8 which received soil application of B with 0.159 kg ha^{-1}. Cu uptake was lowest in control in all the cases.

4.7 Soil characteristics

4.7.1 pH

The effect of various treatments on pH of soil is given in Table 4.30. The pH of the soil after the experiment decreased and it varied from 5.42 to 5.62 however there was no significant difference among the treatments. The pH was lower than the initial value of 6.2 in all the treatments. The highest pH was observed with T_5 which received POP NPK and lowest with foliar application of B (T_{11}).

4.7.2 EC

The effect of various treatments on EC of soil after harvest is shown in Table 4.30. The EC of the soil decreased after the experiment compared to the initial value (0.136 dS/m).The highest EC value was observed with T_{12} and T_5 (0.395 and 0.398% respectively) and lowest by control (0.311%), however there was no significant difference among the treatments.

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

	Treatments	Grain	Straw	Total
T_1	Soil test based all nutrient package inclusive of FYM	0.039^{bcd}	0.078^{bcd}	0.117^{b}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	0.023^{ef}	0.069^{cde}	0.092^{c}
T_3	Soil test based all nutrient package but N based on C:N ratio	0.047^{b}	0.030^{f}	0.077^{c}
T_4	Existing POP inclusive of FYM	0.031^{cde}	0.053^{e}	0.084^{c}
T_5	POP NPK	0.024^{def}	0.063^{de}	0.088^{c}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	0.024^{def}	0.062^{de}	0.085c
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	0.021^{ef}	0.058^{de}	0.079^{c}
T_8	POP NPK + Borax at 10 kg / ha	0.066^{a}	0.093^{ab}	0.159^{a}
T_9	POP NPK + $MgSO_4$ foliar – 1%	0.031^{cde}	0.085^{abc}	0.116^{b}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	0.035^{bcde}	0.100^{a}	0.134^{b}
T_{11}	POP NPK + Borax foliar – 0.25%	0.044^{bc}	0.091^{ab}	0.134^{b}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	0.030^{cde}	0.061^{de}	0.091^{c}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	0.027^{def}	0.096^{ab}	0.123^{b}
T_{14}	Absolute control	0.012^{f}	0.031^{f}	0.042^{d}

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

Table 4.30 Effect of treatments on pH, EC and OC content of soil after the experiment

Treatments		pH	EC (dS/m)	OC (%)
T_1	Soil test based all nutrient package inclusive of FYM	5.50^{a}	0.339^{a}	1.02^{a}
T_2	Soil test based all nutrient package but N 90 Kg / ha + FYM	5.55^{a}	0.361^{a}	1.03^{a}
T_3	Soil test based all nutrient package but N based on C:N ratio	5.50^{a}	0.333^{a}	1.01^{a}
T_4	Existing POP inclusive of FYM	5.53^{a}	0.366^{a}	1.11^{a}
T_5	POP NPK	5.62^{a}	0.398^{a}	1.01^{a}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	5.52^{a}	0.359^{a}	1.01^{a}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	5.55^{a}	0.383^{a}	1.05^{a}
T_8	POP NPK + Borax at 10 kg / ha	5.50^{a}	0.318^{a}	1.01^{a}
T_9	POP NPK + $MgSO_4$ foliar – 1%	5.59^{a}	0.293^{a}	0.98^{a}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	5.43^{a}	0.370^{a}	1.04^{a}
T_{11}	POP NPK + Borax foliar – 0.25%	5.42^{a}	0.319^{a}	0.99^{a}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	5.58^{a}	0.395^{a}	1.11^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	5.45^{a}	0.340^{a}	1.03^{a}
T_{14}	Absolute control	5.54^{a}	0.311^{a}	0.99^{a}

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

4.7.3 Organic carbon

The organic carbon content of soil after harvesting of rice crop is given in Table 4.30. The organic carbon content of the soil after harvesting is reduced and varied from 0.98% to 1.11% even though they were at par statistically. The organic carbon content of the soil was lower than initial value of 1.438% in all the treatments. T_{12} and T_4 showed highest organic carbon content and lowest by T_9.

4.7.4 Available N

The data on available N in soil is shown in Table 4.31. The available N content of the soil after the experiment increased as compared to the initial value of 127.57 kg ha^{-1}except in control.. The treatment which received soil test based all nutrient package inclusive of FYM (T_1) showed significantly high available N content in soil of 219.25 kg ha^{-1} which was at par with treatment which received POP NPK inclusive of FYM with 183.98 kg ha^{-1}. The lowest available N content in soil resulted in control (T_{14}) with 112.90 kg ha^{-1}. All the FYM applied treatments (T_1, T_2 and T_4) showed higher available N content in soil compared to other treatments.

4.7.5 Available P

The data on available P in soil is shown in Table 4.31. Available P of soil decreased in all the treatments after experiment than the initial value of 6.53 kg ha^{-1} and ranged from 3.48 kg ha^{-1} to 5.71 kg ha^{-1}. T_2 which received soil test based all nutrient package but N based on C:N ratio resulted in highest available P content even though it was statistically on par with all other treatments.

4.7.6 Available K

The effect of various treatments on available K after harvest of rice crop is shown in Table 4.31. There was no significant difference in the available K content of the soil. However it ranged from 154.56 kg ha^{-1} to 201.23 kg ha^{-1}. The available K content decreased after the experiment compared to the initial value of

Table 4.31 Effect of treatments on available N, P and K (kg ha^{-1}) of soil after the experiment

Treatments		Available N	Available P	Available K
T_1	Soil test based all nutrient package inclusive of FYM	219.25^{a}	4.56^{a}	157.17^{a}
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	175.62^{bc}	5.71^{a}	154.56^{a}
T_3	Soil test based all nutrient package but N based on C:N ratio	167.25^{bc}	3.84^{a}	160.91^{a}
T_4	Existing POP inclusive of FYM	183.98^{ab}	4.46^{a}	178.45^{a}
T_5	POP NPK	175.62^{bc}	5.00^{a}	158.29^{a}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	171.43^{bc}	4.82^{a}	201.23^{a}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	142.17^{cde}	4.20^{a}	195.63^{a}
T_8	POP NPK + Borax at 10 kg / ha	163.07^{bcd}	3.66^{a}	165.76^{a}
T_9	POP NPK + $MgSO_4$ foliar – 1%	150.53^{bcd}	4.73^{a}	162.40^{a}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	163.07^{bcd}	4.02^{a}	175.47^{a}
T_{11}	POP NPK + Borax foliar – 0.25%	129.62^{de}	4.20^{a}	147.84^{a}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	154.73^{bcd}	3.75^{a}	184.05^{a}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	154.71^{bcd}	3.66^{a}	175.84^{a}
T_{14}	Absolute control	112.90^{e}	3.48^{a}	155.68^{a}

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

470.78 kg ha^{-1}. T_6 which received soil application of Mg resulted in highest available K with 201.23 kg ha^{-1} content and lowest by T_2 which received soil test based all nutrient package except N and N based on C:N ratio.

4.7.7 Available Ca

The available Ca content in soil after harvesting of rice crop is presented in Table 4.32. The available Ca content did not differ significantly which ranged from 1008.93 mg kg^{-1} to 1051 mg kg^{-1}. The treatment which received combined soil application of Mg, Zn and B (T_{12}) resulted in the highest available Ca content in the soil and lowest by treatment which received soil application of B (T_8). The available Ca content of the soil decreased after the experiment compared to the initial value of 1237.20 mg kg^{-1}.

4.7.8 Available Mg

The available Mg content in soil after harvesting of rice crop is given in Table 4.32. The available Mg in the soil ranged from 55.12 mg kg^{-1} with treatment which received foliar application of B (T_{11}) to 56.30 mg kg^{-1} with treatment which received combined soil application of Mg, Zn and B (T_{12}) even though the results were not significantly different statistically. After experiment, there was a decreasing trend of the available Mg content in the soil.

4.7.9 Available S

The effect of treatments on available S content of soil is shown in Table 4.32. The l available S content in soil increased after the experiment compared to the initial value of 18.20 mg kg^{-1}. The highest available S content was observed in treatment which received soil application of Mg (T_6) with 46.27 mg kg^{-1} and lowest by control with 25.70 mg kg^{-1}.

4.7.10 Available Fe

The available Fe content in soil after the harvest of rice crop is presented in Table 4.33. The available Fe content in soil after harvesting of rice crop

Table 4.32 Effect of treatments 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	Soil test based all nutrient package inclusive of FYM	1010.83[a]	55.32[a]	35.84[a]
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	1013.60[a]	55.38[a]	30.69[a]
T_3	Soil test based all nutrient package but N based on C:N ratio	1026.43[a]	55.49[a]	37.01[a]
T_4	Existing POP inclusive of FYM	1040.33[a]	55.83[a]	43.90[a]
T_5	POP NPK	1022.33[a]	55.26[a]	42.60[a]
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	1029.37[a]	55.62[a]	46.27[a]
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	1027.27[a]	55.74[a]	41.48[a]
T_8	POP NPK + Borax at 10 kg / ha	1008.93[a]	55.29[a]	27.23[a]
T_9	POP NPK + $MgSO_4$ foliar – 1%	1034.67[a]	55.60[a]	32.36[a]
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	1029.00[a]	55.52[a]	40.12[a]
T_{11}	POP NPK + Borax foliar – 0.25%	1019.00[a]	55.12[a]	30.35[a]
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	1051.00[a]	56.30[a]	39.99[a]
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	1024.87[a]	55.57[a]	29.64[a]
T_{14}	Absolute control	1029.00[a]	55.57[a]	25.70[a]

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

Table 4.33 Effect of treatments 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	Soil test based all nutrient package inclusive of FYM	1428.00^{a}	104.09^{abc}	20.62^{bc}
T_2	Soil test based all nutrient package but N 90 Kg / ha + FYM	2440.00^{a}	110.57^{a}	18.90^{cd}
T_3	Soil test based all nutrient package but N based on C:N ratio	2093.80^{a}	96.24^{abcde}	18.42^{d}
T_4	Existing POP inclusive of FYM	2116.00^{a}	96.92^{abcde}	18.54^{d}
T_5	POP NPK	1999.27^{a}	102.31^{abcd}	18.51^{d}
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	1982.00^{a}	89.55^{abcdef}	17.72^{d}
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	1294.60^{a}	91.93^{abcdef}	18.73^{d}
T_8	POP NPK + Borax at 10 kg / ha	1837.33^{a}	82.05^{def}	17.80^{d}
T_9	POP NPK + $MgSO_4$ foliar – 1%	1789.00^{a}	73.54^{f}	17.91^{d}
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	1493.67^{a}	82.87^{cdef}	18.39^{d}
T_{11}	POP NPK + Borax foliar – 0.25%	1432.37^{a}	104.85^{ab}	18.08^{d}
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	1313.70^{a}	104.48^{ab}	22.06^{ab}
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	1319.33^{a}	86.44^{bcdef}	23.03^{a}
T_{14}	Absolute control	1572.33^{a}	80.79^{ef}	17.76^{d}

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

increased compared to initial value of 504.98 mg kg^{-1}. Though available Fe varied from 1294.60 mg kg^{-1} with treatment which received soil application of Zn (T_7) to 2440.00 mg kg^{-1} with treatment which received soil test based all nutrient package except N and N based on C:N ratio (T_2) , 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 4.33. The treatment which received soil test based all nutrient package but N @ 90 kg ha^{-1} inclusive of FYM (T_2) recorded significantly higher available Mn content in soil with 110.57 mg kg^{-1} which was at par with all the treatments except T_8, T_9, T_{10} and control. The lowest Mn content of 73.54 mg kg^{-1} was observed with treatment which received foliar application of Mg (T_9).

4.7.12 Available Zn

The effect of treatments on available Zn content in soil is presented in Table 4.33. The available Zn in soil after the experiment increased compared to the initial value of 1.17 mg kg^{-1}. The treatment which received combined foliar application of Mg, Zn and B (T_{13}) recorded significantly higher available Zn content of 23.03 mg kg^{-1} and which was closely followed by treatment which received combined soil application of Mg, Zn and B (T_{12}) with 22.06 mg kg^{-1}. The individual soil application of Zn resulted in higher available Zn in soil compared to the individual foliar application of the same even though they were on par statistically. The lowest available Zn content of 17.72 mg kg^{-1} resulted in treatment which received soil application of Mg (T_6).

4.7.13 Available B

The effect of various treatments on available B in soil is shown in Table 4.34. The available B content in the soil is decreased after the experiment compared to the initial value of 1.62 mg kg^{-1}. Highest available B content in the soil was observed in treatment which received soil application of B (T_8) with 0.77

Table 4.34 Effect of treatments on available B, Cu (mg kg^{-1}) of soil after the experiment

Treatments		Available B (mg kg^{-1})	Available Cu (mg kg^{-1})
T_1	Soil test based all nutrient package inclusive of FYM	0.39[a]	5.03[a]
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	0.26[a]	4.82[a]
T_3	Soil test based all nutrient package but N based on C:N ratio	0.71[a]	5.18[a]
T_4	Existing POP inclusive of FYM	0.46[a]	5.29[a]
T_5	POP NPK	0.52[a]	4.73[a]
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	0.74[a]	4.95[a]
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	0.58[a]	5.33[a]
T_8	POP NPK + Borax at 10 kg / ha	0.77[a]	4.83[a]
T_9	POP NPK + $MgSO_4$ foliar – 1%	0.48[a]	4.76[a]
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	0.42[a]	5.05[a]
T_{11}	POP NPK + Borax foliar – 0.25%	0.60[a]	5.03[a]
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	0.69[a]	5.32[a]
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	0.45[a]	5.18[a]
T_{14}	Absolute control	0.24[a]	4.63[a]

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

mg kg^{-1} which was closely followed by T_6 and T_3 and lowest available B content in the soil of 0.24 mg kg^{-1} was resulted by control even though there was no significant difference among the treatments.

4.7.14 Available Cu

The effect of various treatments on available Cu in soil is shown in Table 4.34. There was no significant difference between the treatments. The highest Cu content in soil was recorded by treatment which received soil application of Zn (T_7) with 5.33 mg kg^{-1} closely followed by treatment which received combined soil application of Mg, Zn and B (T_{12}) and treatment which received POP NPK inclusive of FYM (T_4). The lowest available Cu content in soil was found in control with 4.63 mg kg^{-1}.

4.8 Economics of cultivation

The effect of various treatments on economics of cultivation is shown in Table 4.35. All the treatments showed B:C ratio of more than 2 except in control. The B:C ratio was higher for soil application of B and it was similar to its foliar application. All the nutrient applied treatments produced higher B:C ratio compared to the treatment which received POP NPK along with FYM. Combined application (soil or foliar) of Mg, Zn and B produced higher B:C ratio than that of package of practices recommendation for rice.

Table 4.35 Effect of treatments on economics of cultivation (Rs./ha)

Treatments		Cost of cultivation	Gross return	BC ratio
T_1	Soil test based all nutrient package inclusive of FYM	62026	1,52450	2.45
T_2	Soil test based all nutrient package but N 90 kg / ha + FYM	62268	1,55340	2.49
T_3	Soil test based all nutrient package but N based on C:N ratio	57333	1,45170	2.53
T_4	Existing POP inclusive of FYM	62787	1,42950	2.27
T_5	POP NPK	57787	1,19530	2.06
T_6	POP NPK + $MgSO_4$ at 80 kg / ha	60187	1,49650	2.48
T_7	POP NPK + $ZnSO_4$ at 20 kg / ha	59787	1,34430	2.24
T_8	POP NPK + Borax at 10 kg / ha	58787	1,55700	2.64
T_9	POP NPK + $MgSO_4$ foliar – 1%	59937	1,53220	2.55
T_{10}	POP NPK + $ZnSO_4$ foliar – 0.5%	60037	1,40170	2.33
T_{11}	POP NPK + Borax foliar – 0.25%	59912	1,54380	2.57
T_{12}	POP NPK + Soil application of $MgSO_4$ (80kg / ha) + $ZnSO_4$ (20 kg / ha) + Borax (10 kg / ha)	63187	1,56040	2.46
T_{13}	POP NPK + Foliar application of $MgSO_4$ (1%) + $ZnSO_4$ (0.5%) + Borax (0.25%)	60312	1,53370	2.54
T_{14}	Absolute control	51238	98090	1.91

DISCUSSION

V. DISCUSSION

An experiment was conducted to study the "Efficiency of foliar and soil applied nutrients in irrigated rice" in farmers field, Thathamangalam, Palakkad during the Mundakan season from October 2014 to February 2015 for comparing the relative efficiency of soil and foliar applied secondary and micronutrients alone or in combination in irrigated rice of Palakkad. The results obtained from the experiment reported in the previous chapter are discussed based on available literature.

5.1 Crop growth characters

All the soil test based nutrient application resulted in significantly higher plants at 60 DAT and harvest over control (Fig 5.1). Among them, the treatment which received soil test based all nutrients except N, and N based on C:N ratio produced the highest plants. The nutrient supply based on soil test helps to identify the nutrient supplying capacity of the soil and quantity of nutrient present in soil. It also helps to maintain the nutrient balance within the soil by the application of deficient nutrients and thereby the availability and absorption of nutrients by the plant increases. Soil application of Mg, Zn and B along with POP NPK resulted in better plant height compared to their foliar application. This might be due to the continuous supply of nutrients from the soil compared to foliar spray. Foliar application of nutrients is generally recommended during nutrient deficiency situations and in small concentrations. The joint application of Mg, Zn and B together with POP NPK produced tallest plants at harvest irrespective of the method of application.

Tiller count at 30 DAT was significantly higher for treatment receiving soil test based all nutrient packages inclusive of FYM. In soil test based nutrient application, all the nutrients were applied according to the need of the nutrients for

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

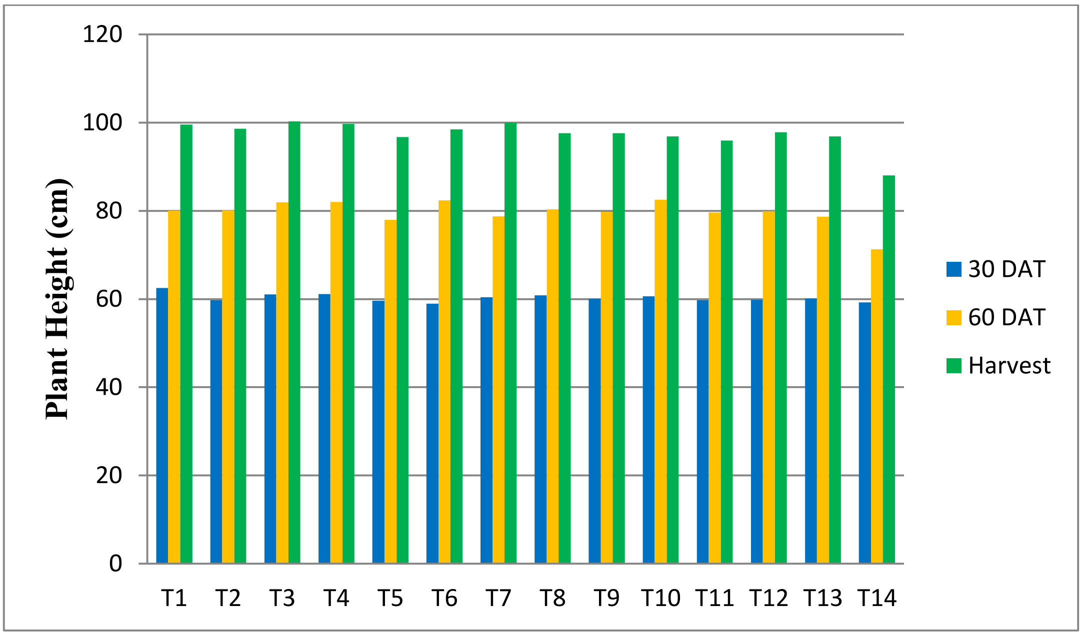
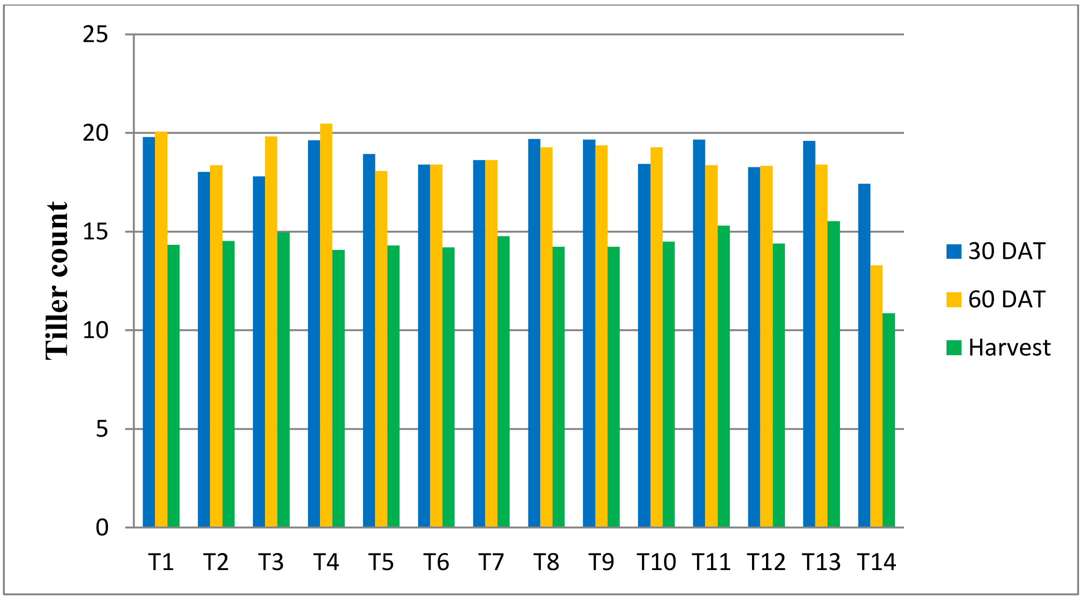


Fig. 5.2 Effect of treatments on tiller count at 30, 60 DAT & harvest



the crop and nutrient supplying capacity of the soil. Since FYM is the store house of nutrients particularly micronutrients, this together with fertilizers enhances the nutrient availability to the crop thereby increases the vegetative growth and tiller production. Organic manures supply almost all the essential nutrients for growth and development of plants thereby helping in production of new tissues and development of new shoots ultimately increasing the plant height and tiller number (Chaudhary *et al*., 2014). Tiller count at 60 DAT is significantly higher for present POP for rice nutrition along with FYM (T_4) and which is similar to the tiller count of treatment which received soil test based all nutrient packages inclusive of FYM. Combined foliar application of Mg, Zn and B together with POP NPK recorded highest tiller count at harvest.

All the vegetative tillers may not become productive. Only some of them will be converted to productive tiller and some may die, known as tiller decline. The highest tiller decline was observed in treatment which received POP NPK along with FYM. Combined foliar application of Mg, Zn and B along with POP NPK showed lowest tiller decline which was similar to the treatment having foliar application of B along with POP NPK.

Both the combined application of Mg, Zn and B irrespective of the method of application recorded significantly high LAI. In the presence of these three nutrients, the growth of rice enhanced which resulted in higher LAI. Mg is the key component of chlorophyll and the Mg application resulted in better photosynthesis and caused increased leaf width (Varughese and Jose, 1993). Photosynthesis was also enhanced in the presence of B and led to the higher leaf width and area. Control treatment without any nutrient recorded lowest LAI. The control treatment without any micronutrient application gave the lowest values of LAI (Zayed *et al*., 2011).

Chlorophyll a is the precursor for the production of chlorophyll b. But the significant difference among treatments as seen in the case of chlorophyll a was not observed for chlorophyll b. Even though combined foliar application of Mg, Zn and

B along with POP NPK produced highest chlorophyll a content, the chlorophyll b and total chlorophyll content were highest for treatment which received POP NPK along with FYM. It might be due to the combined effect of application of organic manures and fertilizers.

Even though there were no marked differences in dry matter production among the treatments both at 30 DAT and 60 DAT, all the soil test based nutrient application recorded a constant and steady improvement in dry matter production. Treatment receiving soil application of B along with POP NPK produced highest dry matter yield at harvest. In most of the plant species, B requirement is much higher for reproductive growth than for vegetative growth. Application of B increases the yield and dry matter production due to its role in plant physiological functions especially during reproductive phase. The enhancement of photosynthesis in the presence of B due to the activation of synthesis of tryptophan and precursor of IAA leads to the stimulation of plant growth and accumulation of biomass (Patil *et al*., 2008). These findings are in conformity with those of Ehsan-Ul-Haq *et al*. (2009) and Dunn *et al*. (2005). The lowest dry matter production was recorded by control treatment at all the stages of growth.

5.2 Yield and yield attributes

The yield (grain) attributes of rice include number of productive tillers or panicles/hill, spikelets/panicle, fertility or filled grain percentage and test weight of grain. There were no marked differences in number of panicle/hill due to treatments except control. Then also combined foliar application of Mg, Zn and B along with POP NPK showed highest tiller number. Foliar application of Zn and B at the rate of 6 kg/acre and 3 kg/acre recorded an increase of 38.40 percentage in productive tillers/plant compared to the control (Arif *et al*., 2012). Control treatment produced lowest number of productive tillers/hill. This might be either due to inadequate supply of nutrients or due to unbalanced supply of nutrients.

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

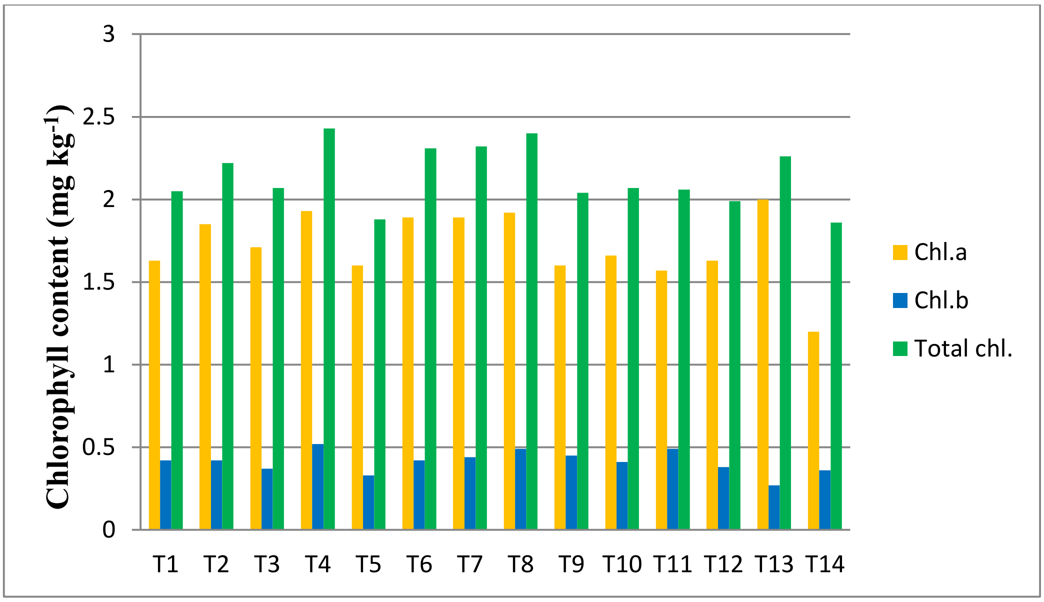
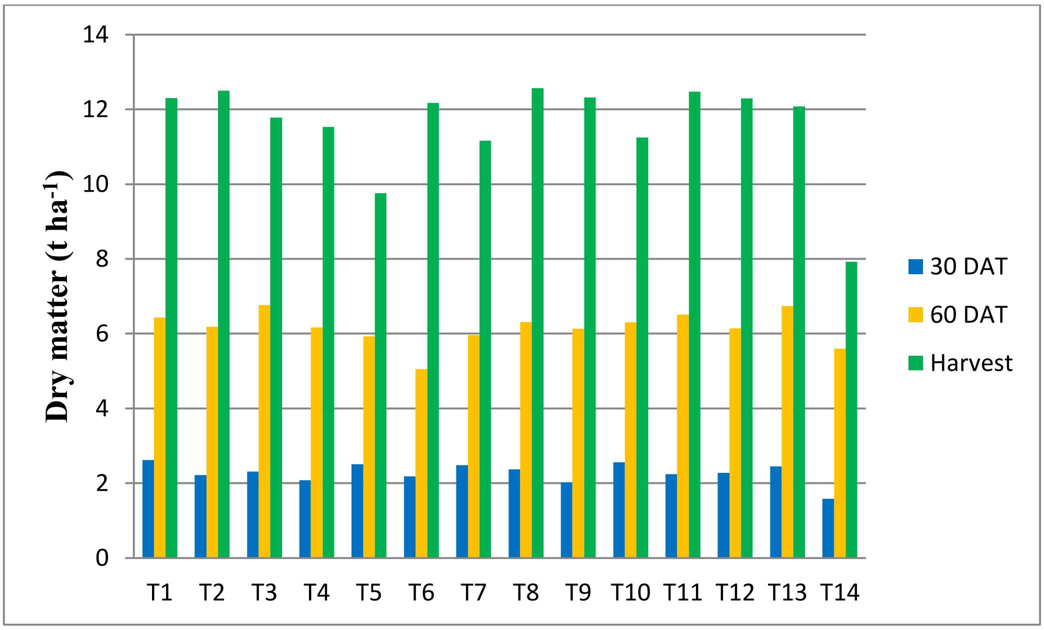


Fig. 5.4. Effect of treatments on dry matter production (t ha^{-1}) at 30, 60 DAT & harvest



The highest number of spikelet/panicle was produced by treatments which received combined foliar application of Mg, Zn and B along with POP NPK and soil test based all nutrient package except N inclusive of FYM. B enhances the translocation of carbohydrates and sugars to the reproductive organs which in turn improved the spikelet number and fertility and thereby increases the dry matter production and yield at maturity (Ahamad *et al*., 2009). B is also responsible for better pollination, seed setting, low spikelet sterility and more grain formation in rice (Aslam *et al*., 2002). There were reports that foliar application of B was effective to enhance the number of spikelets (Rao *et al*., 2013). Combined application of S, Zn and B along with NPK increased yield attributes like plant height, number of tillers/hill, filled grain percentage, thousand grain weight as compared to control (Uddin *et al*., 2002). Lowest number of spikelet/panicle was recorded by control treatment.

Irrespective of the method of application, Zn application enhanced the fertility percentage of grain compared to other treatments. Control showed lowest fertility percentage.

The individual application of Zn and Mg along with POP NPK recorded better thousand grain weight. This may be due to the increased transportation of photosynthates from source to sink due to Zn application as reported by Sriramachandra and Mathan (1998). The application of $MgSO_4$ increased tillering, hastened the process of heading, increased the filled grains and grain size leading to yield enhancement (Singh and Singh, 2005). Mg application leads to early completion of flowering which helps in uniform ripening of grains, thereby increasing the grain weight. The B application helps to produce bold grains. Test weight also increased over control when the nutrients (Mg, Zn and B) were individually or jointly applied either in soil or in foliage.

The application of nutrients increased the grain yield compared to the control. Combined soil application of Mg, Zn and B produced highest grain yield. It may be due to comparatively higher nutrient content in soil and plant especially N, P, K, Ca, Mg, S, Zn and B which gave excellent crop stand and higher yield. B has role in flower production, retention, pollen tube elongation, germination and grain development. Mg has important role in grain nutrition which leads to higher yield. All the FYM applied treatments resulted in higher grain yield compared to the treatment which received POP NPK alone. The application of FYM significantly improved the status of N, P, K, Ca, Mg and Zn in soil and plant which gave better yield in rice. This is in line with the study of Singh (2006). The application of FYM might have improved the properties of soil which ultimately increased the yield of crop (Bhatia and Shukla, 1982).

The straw yield was better in all the treatments except treatments which received POP NPK alone and control. The application of nutrients resulted in the increased growth of plants which leads to higher total dry matter yield and straw yield. Highest straw yield was recorded with soil application of B along with POP NPK. B application increased the yield due to the role of B in plant physiological functions especially during plant reproductive phase (Saleem *et al*., 2011). A significant increase in straw yield was reported by the application of B in Kerala soils by Sreedharan and George (1969). Combined soil and foliar application of Mg, Zn and B along with POP NPK resulted in statistically similar straw yields. This may be due to the combined effect of all the three nutrients in rice growth. Combined application of S, Zn and B along with NPK fertilizers increased plant height and number of tillers/hill which resulted in higher straw yield at harvest (Uddin *et al*., 2002).

All the treatments showed higher HI and there was no significant difference among them. Combined soil application of Mg, Zn and B along with POP NPK recorded the highest harvest index. This may be due to the higher biological yield and

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

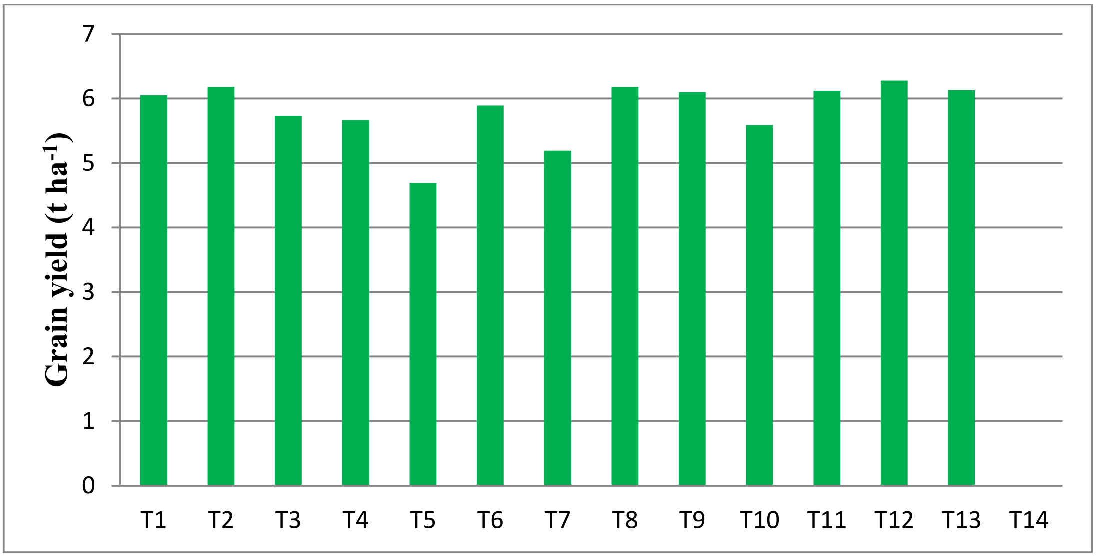
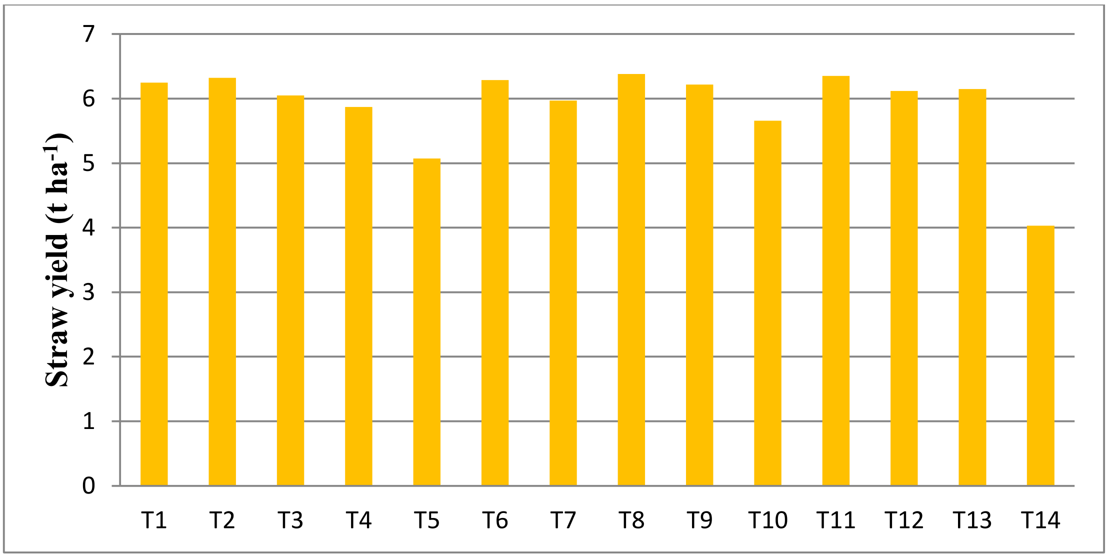


Fig. 5.6 Effect of treatments on straw yield (t ha^{-1})



grain yield due to the adequate supply of nutrients to the plants. The HI shown by control treatment was comparable with other treatments. High HI alone does not mean that it is a high yielder. High HI together with total yield will result in high yield.

5.3 Nutrient composition and uptake

The highest grain yield was recorded with the combined application of Mg, Zn and B along with POP NPK either applied in soil or as foliar. Higher nutrient content of plant especially N, P and K were also noticed in the same treatments. The N content in rice plant reduced according to the growth stages due to 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 grain compared to straw. Nutrient uptake is a product of content of nutrients and dry matter yield. The treatments which received combined soil and foliar application of Mg, Zn and B showed significantly higher N uptake by grain, straw and thereby total uptake. This may be due to the nutrient balance in the plant and soil which resulted in the increased absorption of all the nutrients including N. Mg fertilization significantly increased N uptake and recovery percentage of fertilizer N (Choudhury and Khanif, 2001). Zn found to enhance the uptake of N when it applied as Zn enriched urea followed by the foliar spray of Zn SO_4 at the rate of 0.2 percentage (Pooniya *et al*., 2011).

There was no significant variation in P content both at 30 DAT and 60 DAT. But the P content in grain and straw varied significantly. Combined soil application of Mg, Zn and B recorded the highest P content in grain and straw which was at par with the combined foliar application of the same. This may be due to the combined effect of Mg, Zn and B in absorption of P by rice. Mg is carrier of P in plants and promotes the uptake and translocation of P and helps in more P contents in plants as reported by Varghes and Money (1965). Mg plays an important role in phosphate metabolism (Fageri and Gheyi, 1999). B deficiency reduces the uptake of P by plant because of the positive interaction of B on the P uptake (Robertson and Loughman, 1974). The P content was highest in foliar application of Mg both at 30 DAT and in grain. The highest P uptake by grain was recorded in treatment which received combined soil application of Mg, Zn and B, whereas foliar application of Mg produced highest P uptake by straw. The highest total P uptake was observed in the soil test based on all nutrient package inclusive of FYM. This might be due to the favourable effect of physical and chemical environment of soil with FYM application which caused the continuous supply of nutrients. It was also reported by Chandrapala *et al*. (2010) and Singh (2006) that the decomposition of FYM released organic acids which enhanced the release of fixed forms of P in soil and it increases the uptake of P by rice.

There was a gradual reduction in K content according to the growth stages and the highest was at 30 DAT due to the active absorption. The foliar application of Zn with POP NPK resulted in higher K content in rice plant due the higher availability of K from the soil for the absorption by plants. There were reports that K concentration gets improved with foliar application of Zn (Singh et al., 2013). The positive interaction between Zn and K was reported by Grunes *et al*. (1998). Soil application of Zn recorded the higher K content at 60 DAT. In grain combined foliar application of Mg, Zn and B and soil test based all nutrient package except N including FYM recorded higher K content. This might be due to the integrated use of FYM with fertilizers, which supply higher K for the absorption by plants. Similar results were reported by Chandrapala *et al*. (2010). The availability of B enhanced the K content in plant because it acts as a catalyst in the uptake of K (Arif *et al*., 2012). The highest K content in straw was reported in foliar application of Mg along with POP NPK. The soil test based all nutrient package except N including FYM recorded the higher K uptake by grain due to the increased supply in the soil for the absorption by plants. This is in line with the reports of Chandrapala *et al*. (2010). Mg applied treatments irrespective of method of application resulted in higher K uptake in straw and total uptake by plant.

Combined soil application of Mg, Zn and B recorded the highest Ca content in grain. This might be due to the combined effect of Zn and B on the Ca uptake. Soil application of Zn resulted in higher Ca content at 60 DAT. The higher Ca content in straw was observed with foliar Zn applied treatment and foliar B applied treatment. There were reports that the application of Zn increased the Ca content in rice compared to the control (Singh and Singh, 2005). B application facilitated increased Ca content as reported by Muralidharan (1992). B is involved in a variety of physiological activities and synthesis of amino acids and proteins which necessitates uptake of Ca. There was no significant difference among treatments in grain Ca. Highest Ca uptake by grain was observed in soil test based all nutrient package except N inclusive of FYM. It might be due to the favorable effect of physical and chemical environment of soil with FYM application leading to the continuous supply of nutrients. It was also in line with 122 the study of Chandrapala *et al*. (2010) and Singh (2006). The Ca uptake by straw and total uptake was higher in combined soil application of Mg, Zn and B.

The Mg content was higher for the treatment which received POP NPK inclusive of FYM at 30 DAT. The application of FYM significantly improved the status of N, P, K, Ca, Mg and Zn in soil and plant which gave better yield in rice. This is in line with the study of Singh (2006). At 60 DAT, combined soil application of Mg, Zn and B recorded the higher Mg content in rice. The higher Mg content in grain and straw was observed with combined foliar application of Mg, Zn and B and it was at par with all the other Mg applied treatments. Muralidharan (1992) and Choudhury and Khanif (2001) reported that the application of $MgSO_4$ resulted in higher Mg content at tillering stage. Kobayashi *et al*., (2005) reported that in rice, the excess Mg treatment increased the Mg content of shoots and roots and the K and Cl contents of root, but slightly decreased the Ca and K content of shoots. The uptake of

Mg by grain and straw was observed high with combined soil and foliar application of Mg, Zn and B. The total uptake was high for combined soil application of the same and foliar application of Mg. This might be due to the increased Mg content and yield by the application of $MgSO_4$. Application of Zn enhanced the uptake of N, Mg and Cu. Sinha *et al*. (2000) noted a synergistic interaction between Zn and B.

The S content varied significantly in all the treatments both at 30 and 60 DAT. In both grain and straw, combined soil and foliar application of Mg, Zn and B showed highest S content. It might be due to the combined effect of S present in $MgSO_4$ and $ZnSO_4$. The uptake of S by grain, straw and total uptake was highest in combined soil and foliar application of Mg, Zn and B along with POP NPK. Application of S along with NPK significantly increased the uptake of S by rice compared to the NPK alone (Chandrapala *et al*., 2010).

Since rice was grown on acidic soil, the content of Fe was very high in all the stages of growth in rice. The Fe content in rice was not varied significantly both at 30 DAT and 60 DAT. But there was significant difference in Fe content during the harvest stage of rice. The treatment which received POP NPK alone recorded the lowest Fe content in grain. In straw, combined soil and foliar application of Mg, Zn and B resulted in highest Fe content. Fang *et al*. (2008) reported that Zn fertilizer application had a significant effect on Fe concentration of rice. Application of Mg generally improved the Fe content in plant as reported by Sahrawat *et al*. (1999). The Fe uptake by grain was significantly higher in treatment which received soil test based all nutrient package except N including FYM. This might be due to the combined application of nutrients along with FYM. FYM enhanced the soil condition and which resulted in the increased uptake of nutrients by plant. Both the Fe uptake by straw and total uptake was highest in treatment which received combined soil application of Mg, Zn and B. Both Zn and Mg application enhanced the Fe content and uptake of Fe by plant.

Higher Mn content at 30 DAT was recorded by the treatment which received soil test based all nutrient package except N inclusive of FYM and soil test based all nutrient package inclusive of FYM. In straw, soil test based all nutrient package inclusive of FYM resulted in higher Mn content. A small quantity of 1.32 kg Mn is added to the soil by the application of 1t of FYM depending upon its source (Kumar and Singh, 2010). So application of FYM may lead to increased availability of Mn in the soil for the absorption by plant which in turn increased its content in plant. At 60 DAT, soil application of Zn recorded the highest Mn content. Alloway (2004) reported that addition of Zn fertilizers to water logged soils increased the uptake and translocation of Mn in plants. The total uptake of Mn was the highest in treatment which received soil test based all nutrient package inclusive of FYM.

The application of Zn either as individual application or as combined application either in soil or in foliage showed higher Zn content in rice at all the stages. This might be due to the higher availability of Zn during the active growth stages of rice either from soil or directly from foliage. The uptake of Zn by grain and straw and total uptake was the highest in treatment which received combined soil application of Mg, Zn and B along with POP NPK. This was due to the high Zn content in plant along with the high dry matter production.

The application of B individually or combined either in soil or in foliage increased the content of B in rice plant compared to the POP NPK alone. The foliar application of B resulted in higher B uptake by straw and grain and total uptake. Increased B concentration in plant due to the foliar application of B together with the high yield led to the higher uptake of B.

The treatment which received soil application of B showed higher Cu content at 60 DAT and also in grain and straw at harvest stage. High B supplies resulted in increased absorption and content of Cu in plants (Fageria *et al*., 2002). The Cu content in plant was more at 60 DAT compared to 30 DAT even when the biomass

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

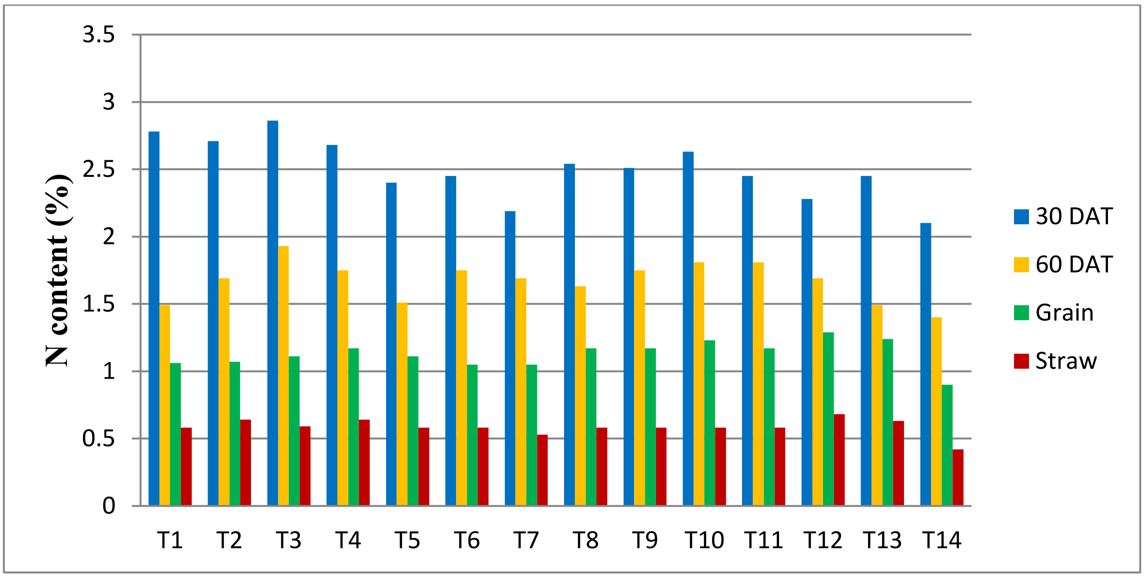


Fig. 5.8 Effect of treatments on phosphorus content (%) of rice at 30, 60 DAT & harvest

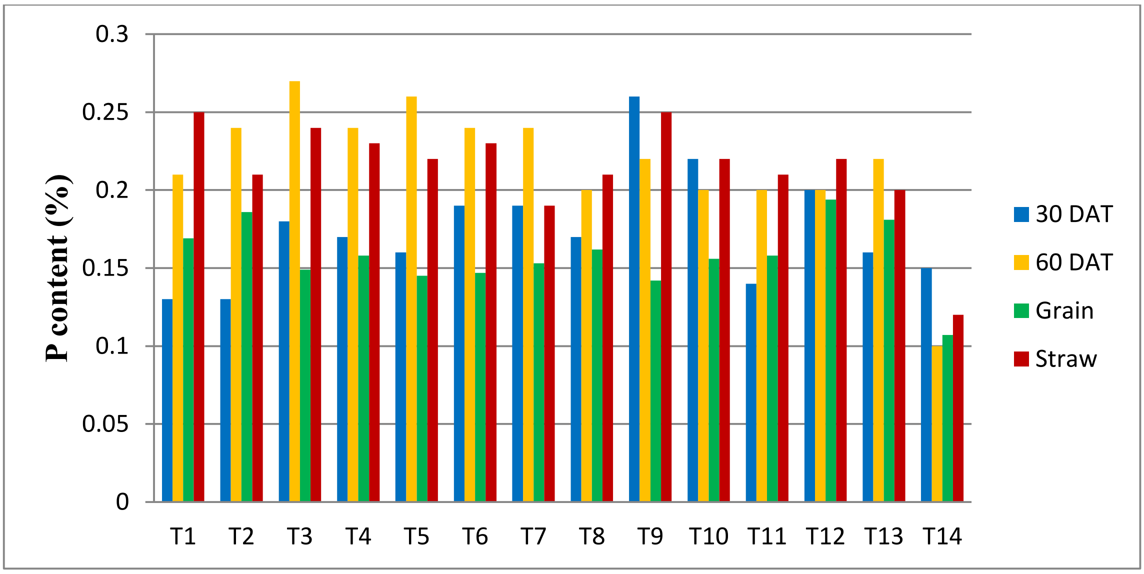


Fig. 5.9 Effect of treatments on potassium content (%) of rice at 30, 60 DAT & harvest

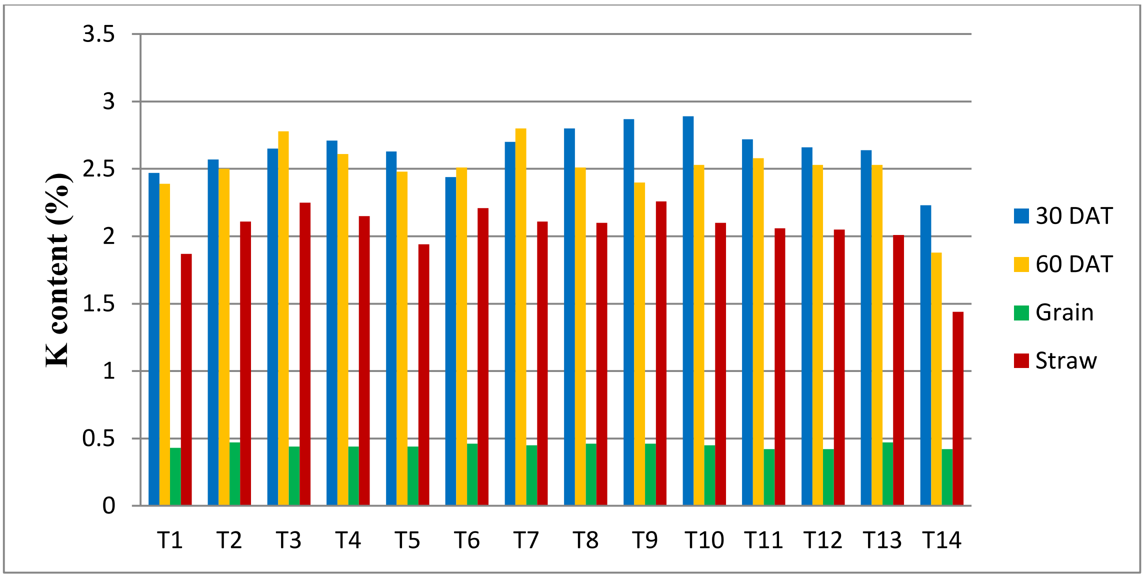


Fig. 5.10 Effect of treatments on calcium content (%) of rice at 30, 60 DAT & harvest

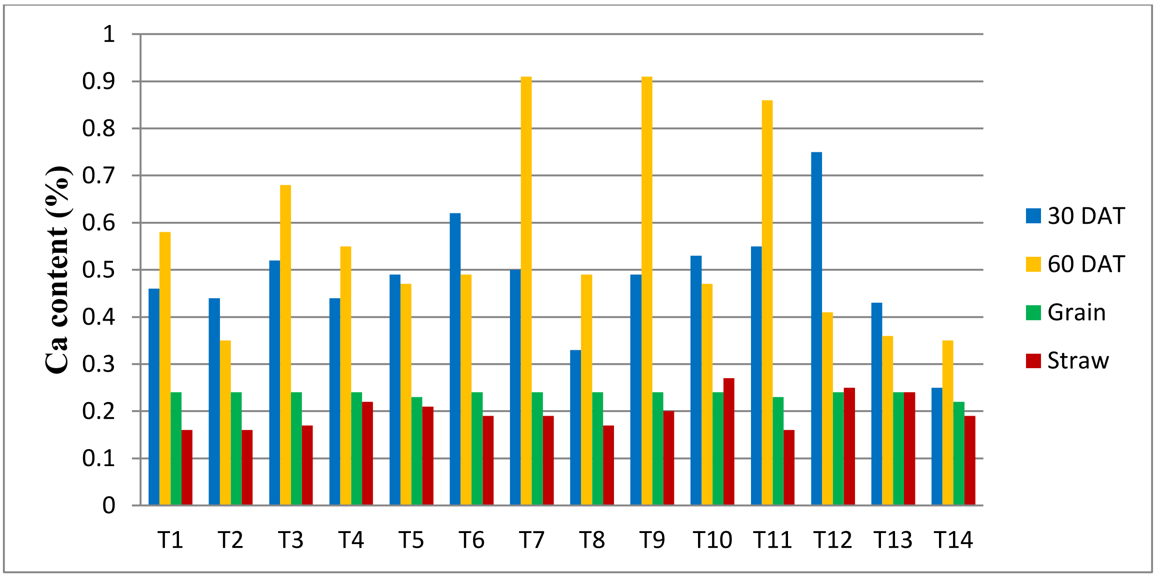


Fig. 5.11 Effect of treatments on magnesium content (%) of rice at 30, 60 DAT & harvest

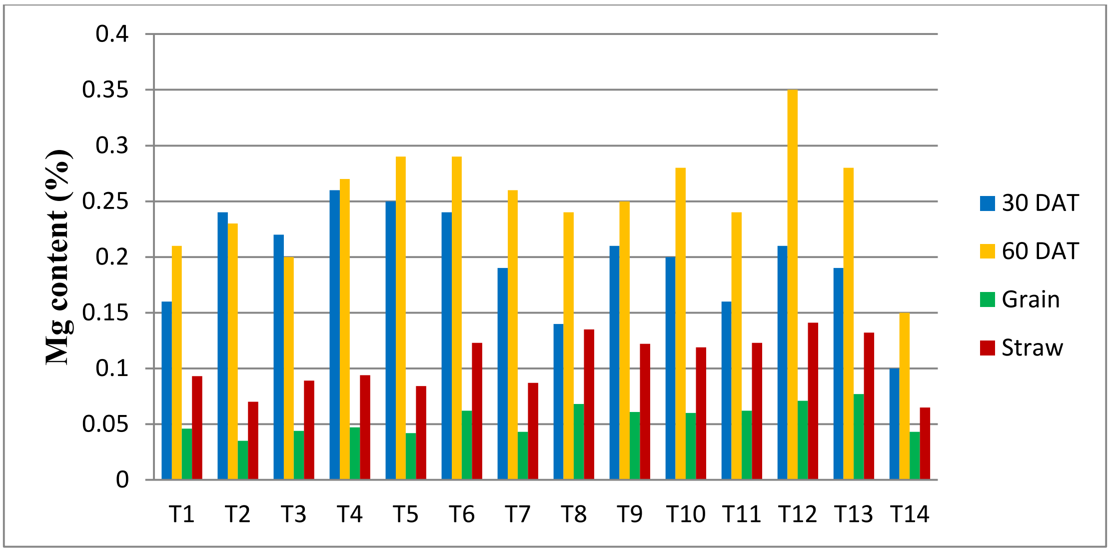


Fig. 5.12 Effect of treatments on sulphur content (%) of rice at 30, 60 DAT & harvest

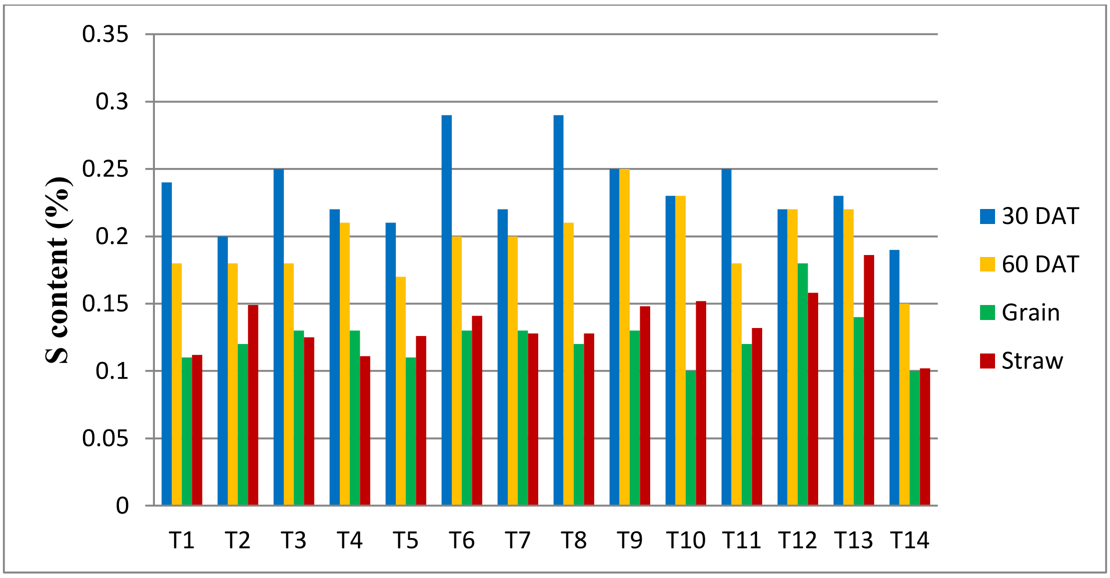


Fig. 5.13 Effect of treatments on iron content (mg kg^{-1}) of rice at 30, 60 DAT & harvest

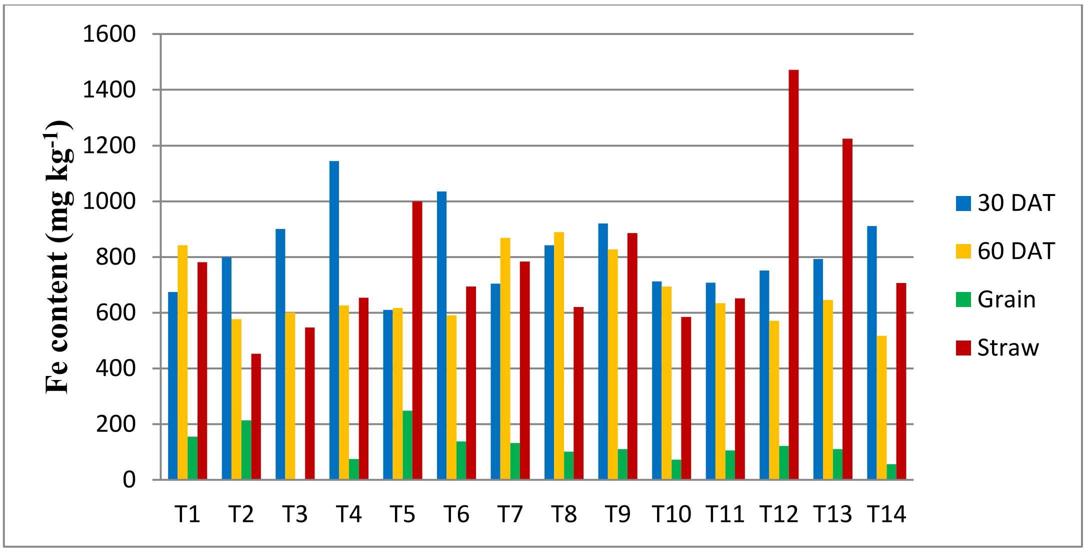


Fig. 5.14 Effect of treatments on manganese content (mg kg^{-1}) of rice at 30, 60 DAT & harvest

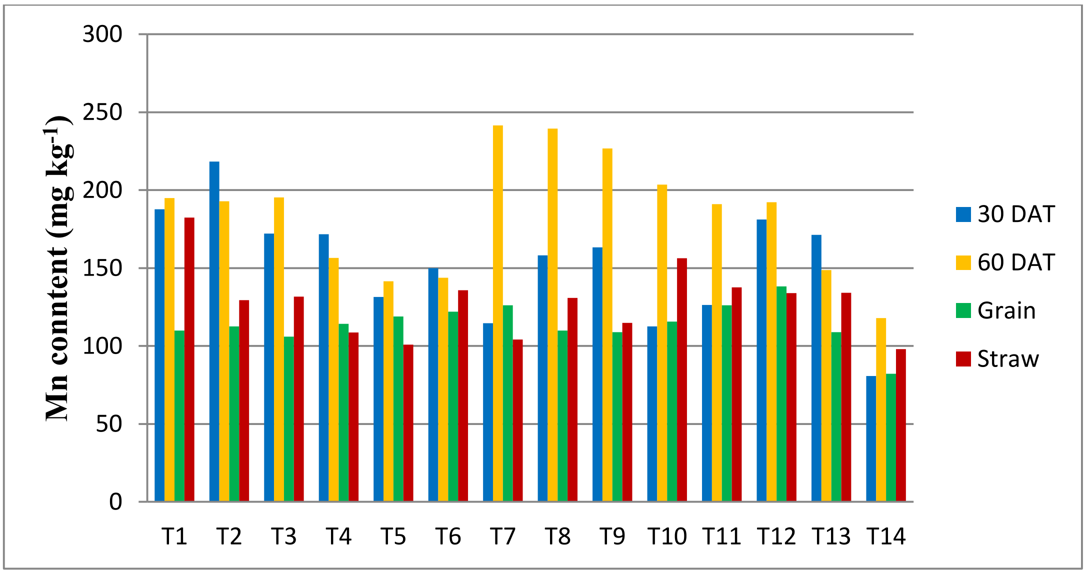


Fig. 5.15 Effect of treatments on zinc content (mg kg^{-1}) of rice at 30, 60 DAT & harvest

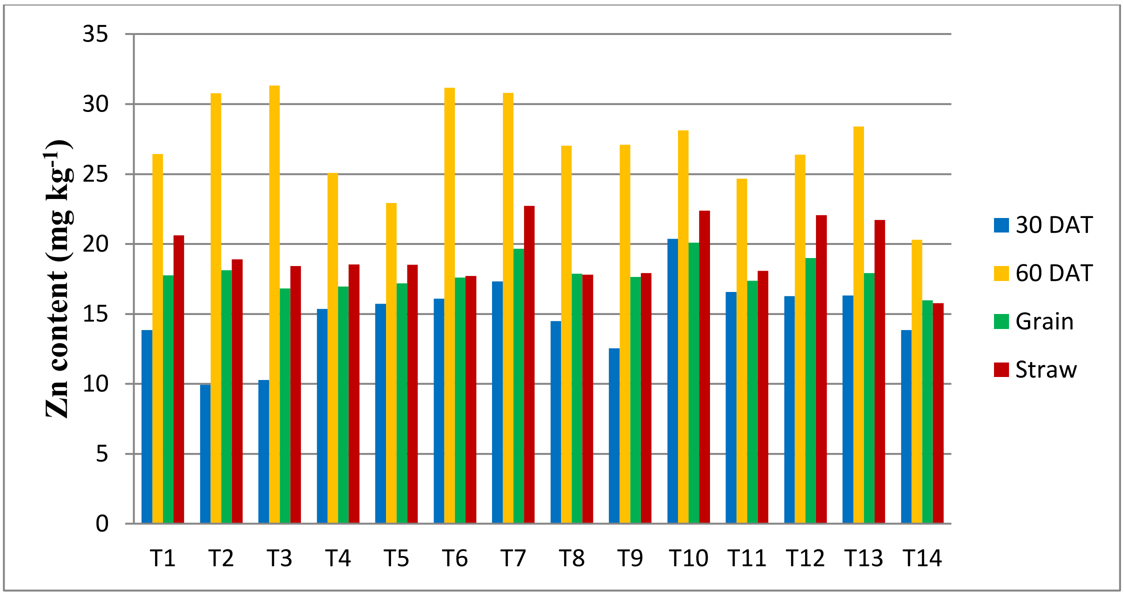


Fig. 5.16 Effect of treatments on boron content (mg kg^{-1}) of rice at 30, 60 DAT & harvest

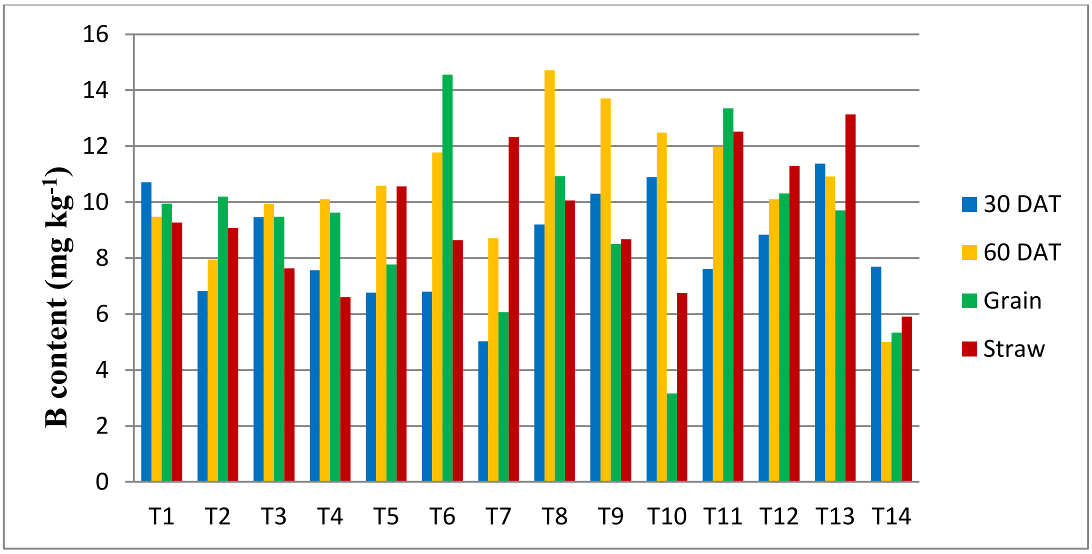
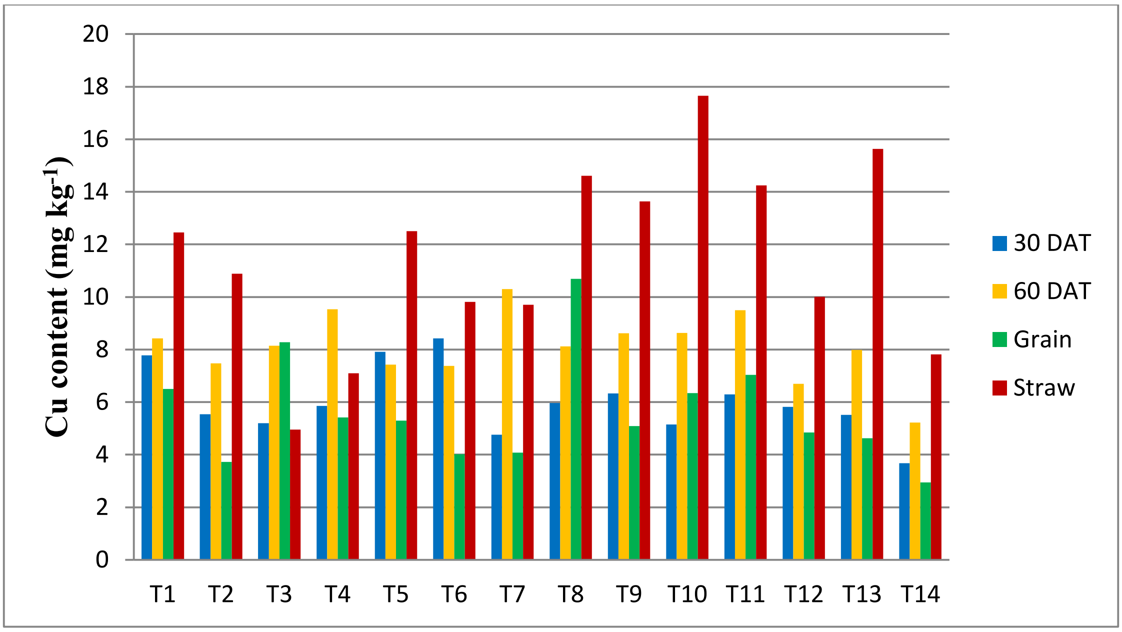


Fig. 5.17 Effect of treatments on copper content (mg kg^{-1}) of rice at 30, 60 DAT & harvest



went on increasing indicating that high rate of absorption of Cu was taking place from the soil. The Cu content in grain was less than that in straw in all the treatments. The treatment which received soil application of B recorded the highest uptake of Cu by straw, grain and total uptake. This might be due to the high content of Cu in plant coupled with the higher yield.

5.4 Soil characteristics

There was a decreasing trend in soil pH after the experiment compared to the initial value. The application of fertilizers has significant influence on soil pH changes. The application of N through urea led to decreasing pH which is in agreement with the findings of Fageria *et al*. (2010).

The EC of soil got increased after the experiment in all the treatments compared to the initial value. This might be due to the increased total soluble salts in soil due to the application of nutrients especially $MgSO_4$, $ZnSO_4$ and borax.

The organic carbon content of the soil after the experiment got reduced compared to the initial value. Organic matter decomposition and oxidation of C 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 enhanced the harvesting period.

The available N content of the soil was increased compared to the initial value in all the treatments except in control. This might be due to the application of fertilizers on the treatment applied plots. The treatment which received soil test based all nutrient package inclusive of FYM recorded significantly higher quantity of available N content after harvesting of crops. All the FYM applied treatments showed higher available N content in soil compared to other treatments. 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 fertilizers and FYM (Chandrapala *et al*., 2010).

The status of available phosphorus content after the harvesting of rice crop decreased from initial value. This might be due to low pH and dominance of Fe in the soil which led to the fixation of P (Dixit, 2006). The soil application of borax resulted in lower levels of P which might have resulted from high concentration of borate ions in soil solution which hindered the availability of P in soil. This is in line with the reports of Santhosh (2013) and Gaur and Singh (2010).

The available K content of the soil got reduced after the experiment. The decrease in soil K might be associated with crop uptake and losses under submerged condition. The available Ca content in soil was decreased after the experiment compared to the initial value.

The available Mg content in soil showed a decreasing value compared to the initial value attributed to the uptake of Mg by plants. The dissolution and release of Mg from Mg fertilizer had taken place very slowly in lateritic 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 application of $MgSO_4$ and $ZnSO_4$ increased available S content due to residual effect. This was also reported by Chandrapala *et al*. (2010).

The available Fe content in soil increased compared to the initial value. The continuous flooding of soil increased the availability of Fe in soil (Ponnamperuma, 1978). The availability of Mn decreased after the experiment. This could be due to the drainage of field before harvesting of the crop for two weeks which lowered the Mn availability.

The available Zn in soil after the experiment increased compared to the initial value. The availability of Zn in soil was more pronounced by the application of Zn to rice. Similar results were reported by Husain *et al*. (2009). Zinc being comparatively mobile in soil results in accumulation due to the application.

The available B in soil was decreased after the experiment. The treatment which received soil application of B showed greater B content in the soil after the experiment. The available Cu content increased after the experiment compared to the initial value. The status of available Cu in soil was sufficient enough to supply this nutrient in soil solution.

5.4 Economics of cultivation

Even though the highest grain yield was noted by combined soil application of Mg, Zn and B along with POP NPK, the soil application of B along with POP NPK resulted in higher B:C ratio. This may be due to the added cost of $MgSO_4$, $ZnSO_4$ and Borax. B:C ratio were increased in the combined foliar application of Mg, Zn and B compared to the combined soil application of the same due to the lower quantity of fertilizers required for foliar spray. However combined application of Mg, Zn and B irrespective of the method of application produced higher B:C ratio compared to the treatment which received POP NPK alone. Mauriya and Mauriya (2013) reported that integrated application of micronutrients such as Zn, B and Mn along with the recommended dose of NPK fertilizers produced higher B:C ratio as compared to the application of NPK fertilizers alone.

Fig. 5.18 Effect of treatments on available N (kg ha^{-1}) of soil after the experiment

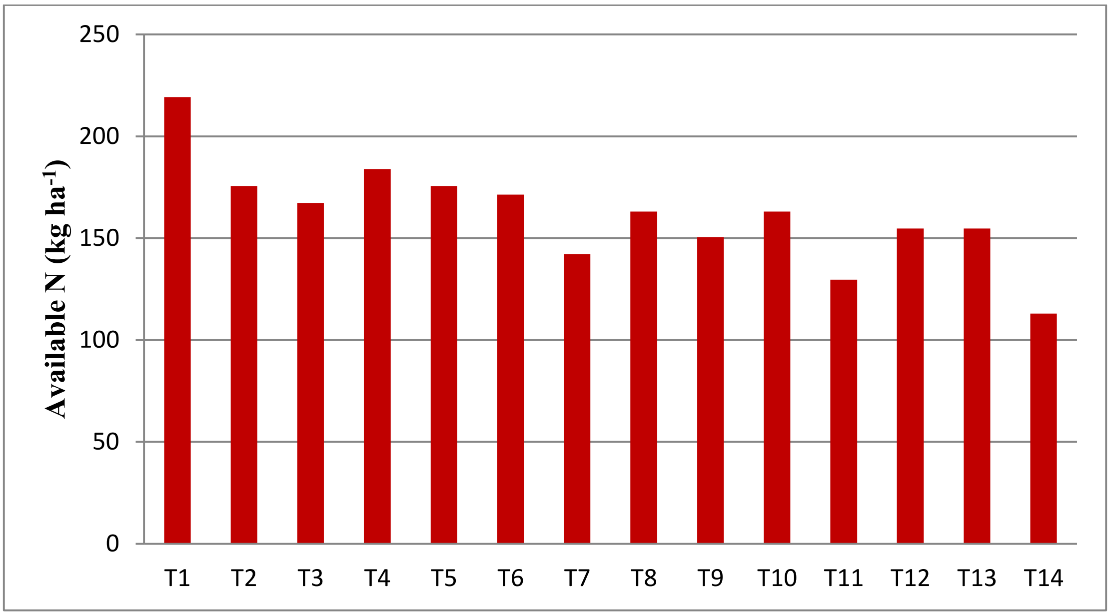


Fig. 5.19 Effect of treatments on available P (kg ha^{-1}) of soil after the experiment

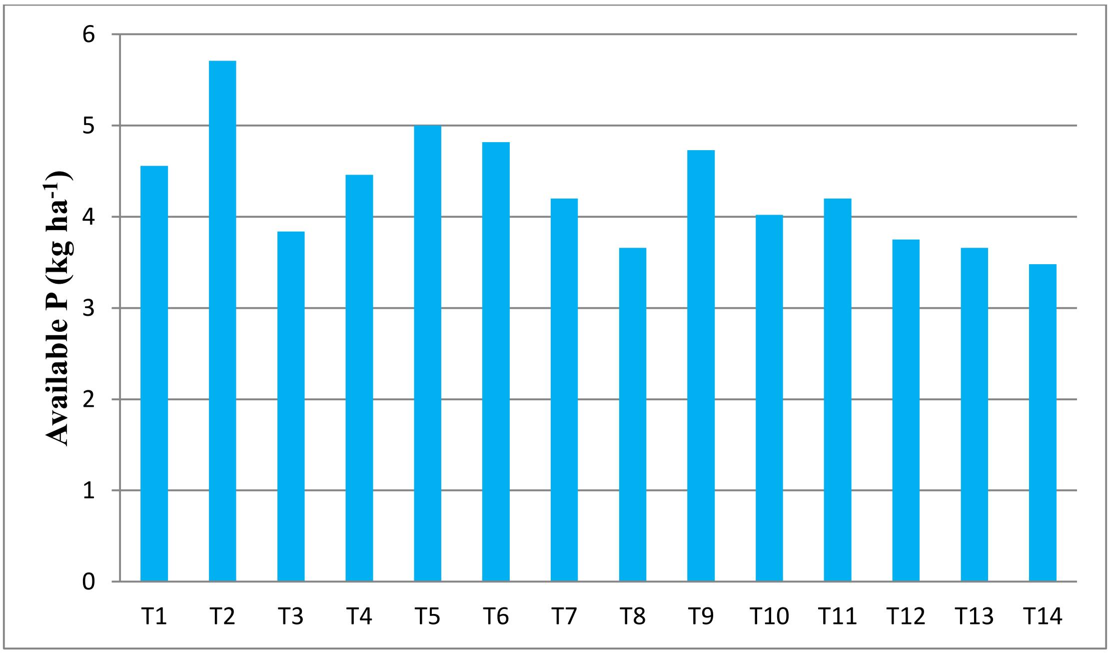


Fig. 5.20 Effect of treatments on available K (kg ha^{-1}) of soil after the experiment

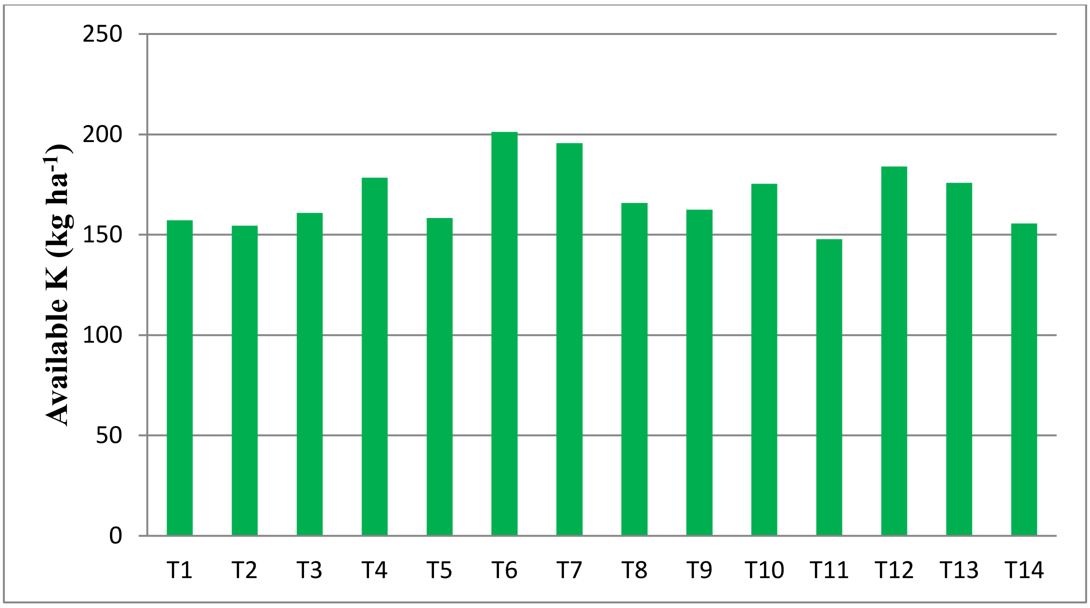


Fig. 5.21 Effect of treatments on available Ca (mg kg^{-1}) of soil after the experiment

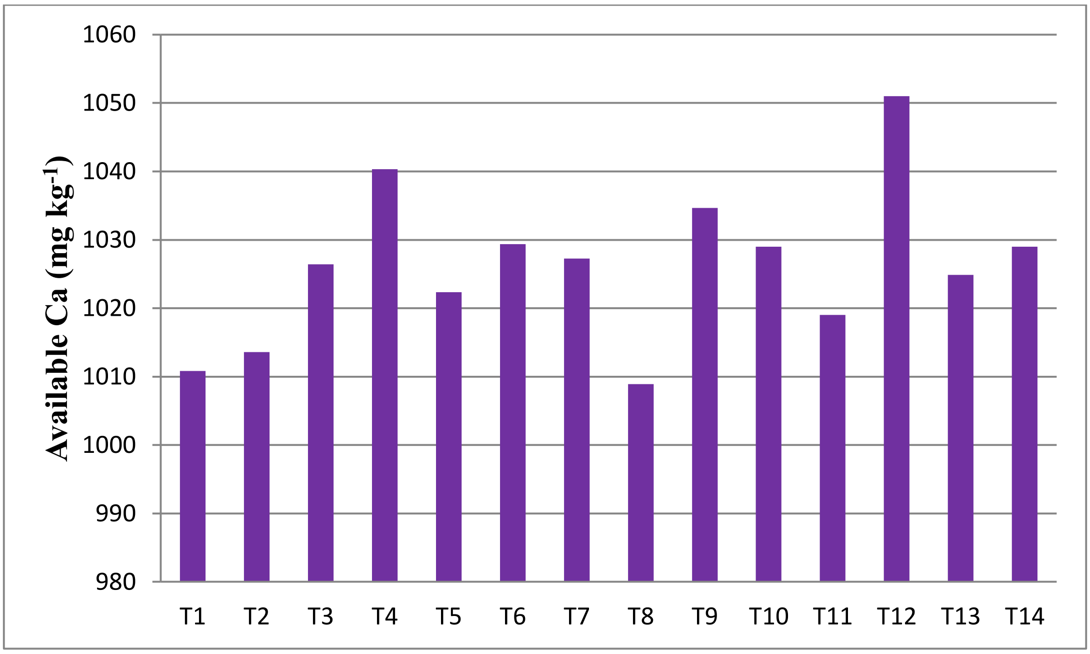


Fig. 5.22 Effect of treatments on available Mg (mg kg^{-1}) of soil after the experiment

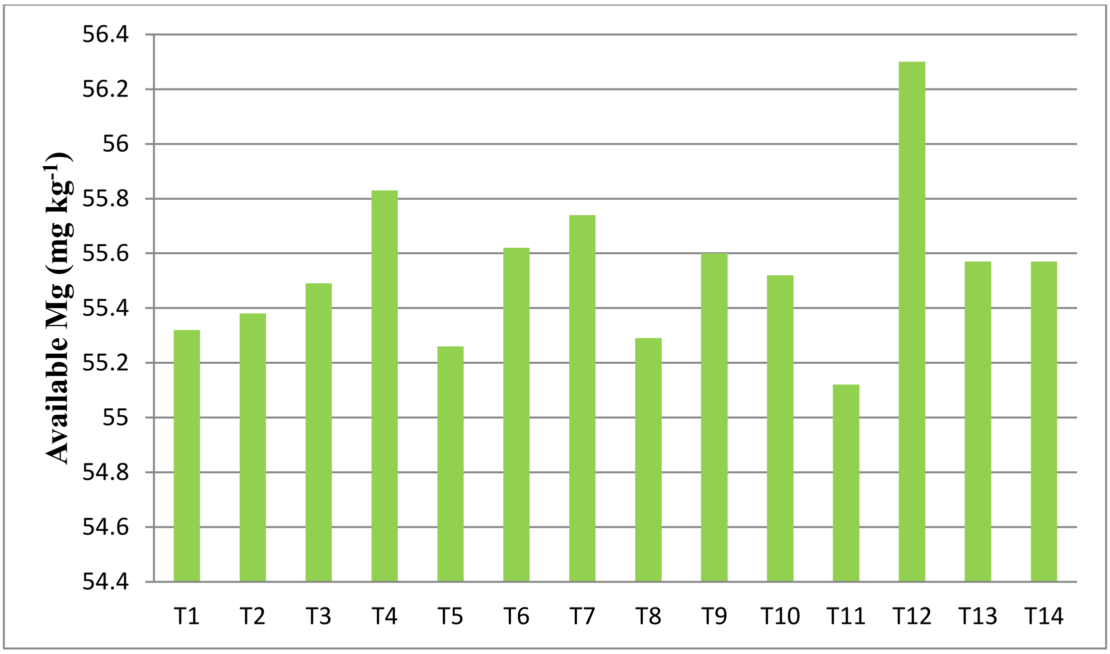


Fig. 5.23 Effect of treatments on available S (mg kg^{-1}) of soil after the experiment

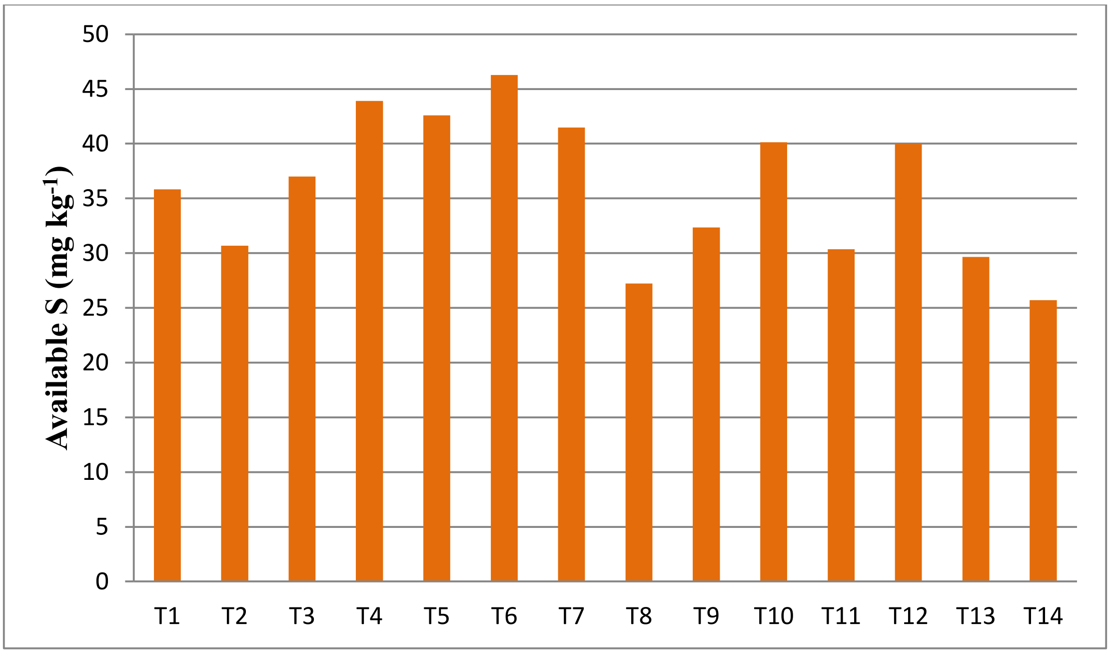


Fig. 5.24 Effect of treatments on available Fe (mg kg^{-1}) of soil after the experiment

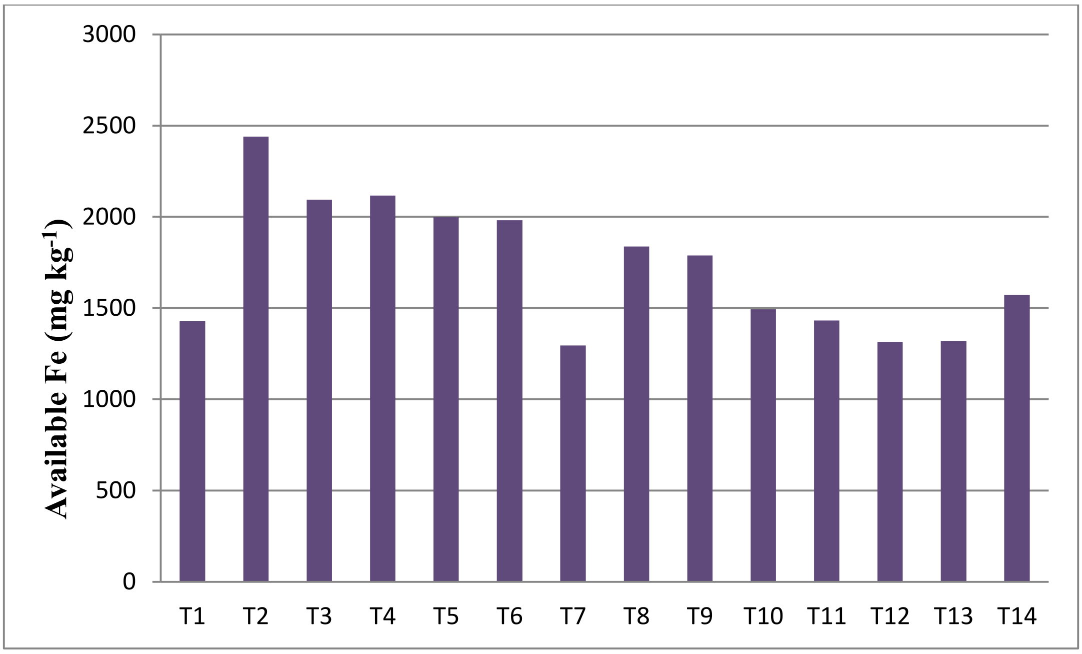


Fig. 5.25 Effect of treatments on available Mn (mg kg^{-1}) of soil after the experiment

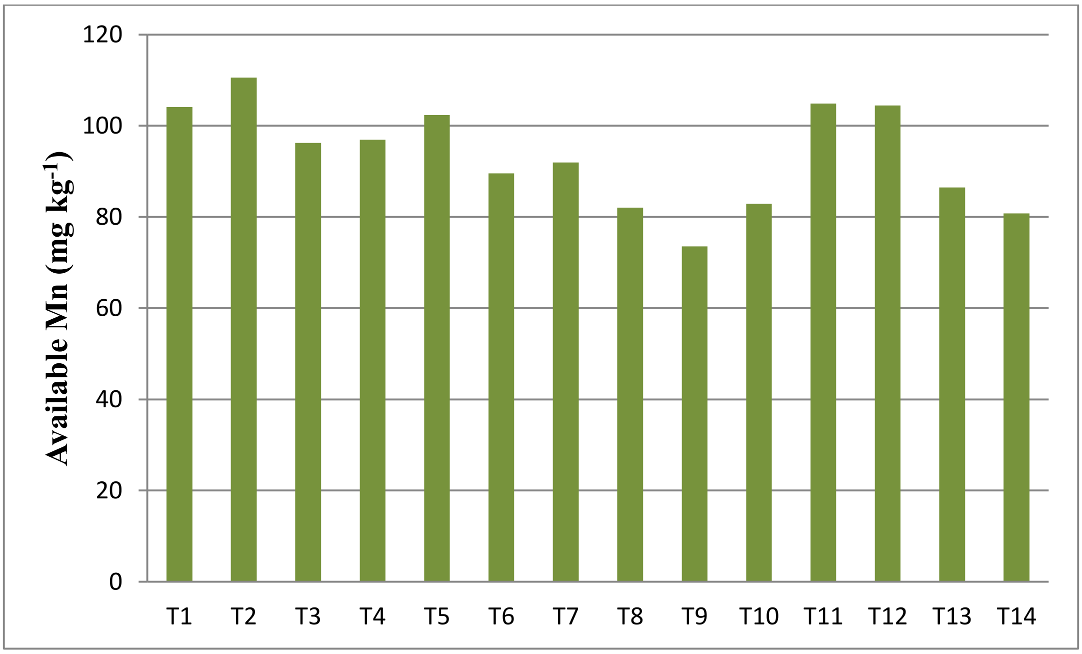


Fig. 5.26 Effect of treatments on available Zn (mg kg^{-1}) of soil after the experiment

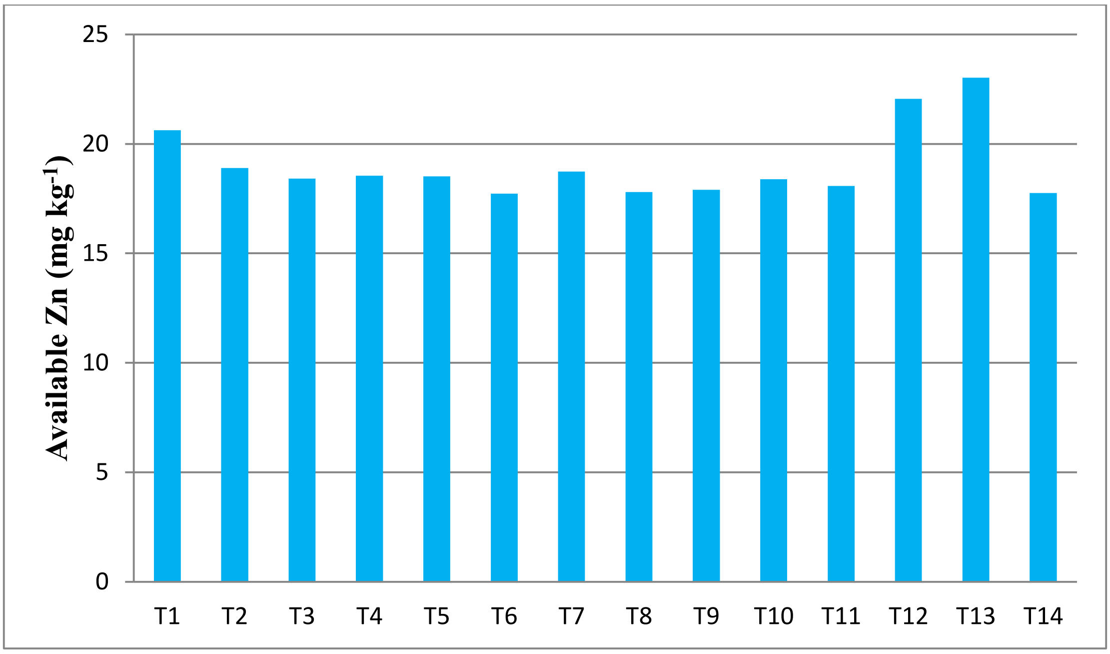


Fig. 5.27 Effect of treatments on available B (mg kg^{-1}) of soil after the experiment

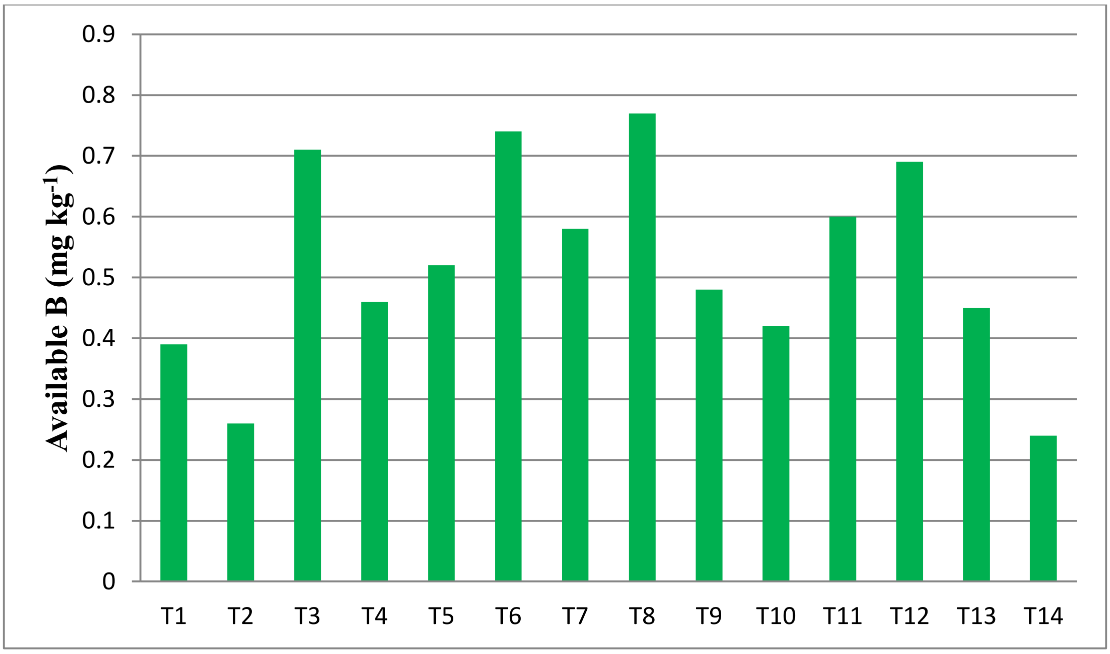
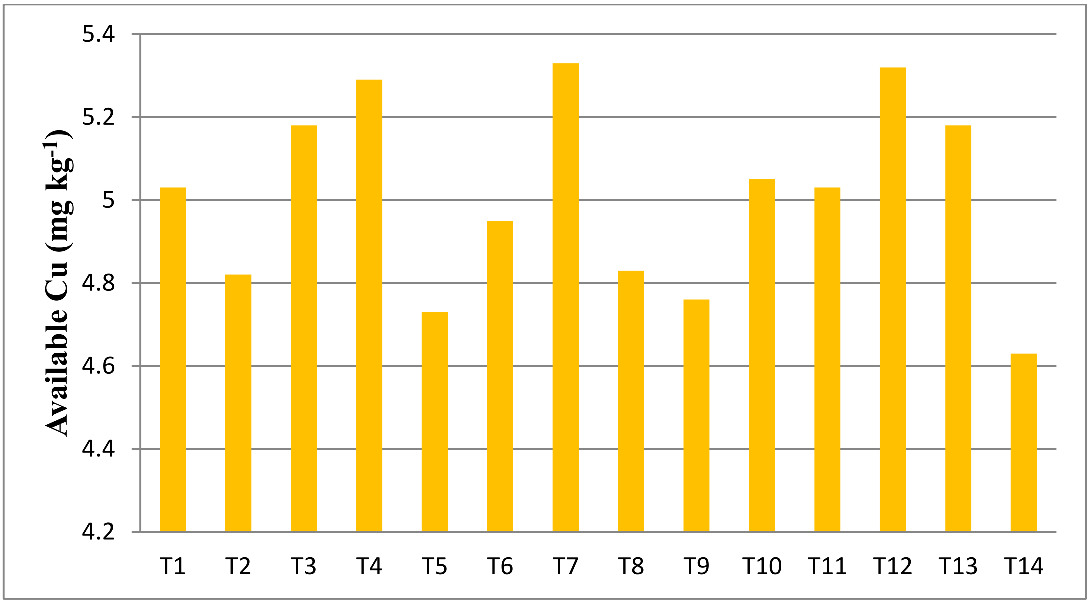


Fig. 5.28 Effect of treatments on available Cu (mg kg^{-1}) of soil after the experiment



SUMMARY

VI. SUMMARY AND CONCLUSION

The present study entitled "Efficiency of foliar and soil applied nutrients in irrigated rice" was carried out in the farmer's field, Thathamangalam, Palakkad during *Mundakan* season from October 2014 - February 2015 to compare the relative efficiency of soil and foliar applied secondary and micronutrients (Mg, Zn and B) alone or in combination in irrigated rice of Palakkad. The entire quantity of P, 1/3rd of N and 1/3rd of K were applied as basal and the remaining as top dressing at maximum tillering and panicle initiation stage in equal splits. Individual and combined soil application of Mg, Zn and B were done as basal according to the treatments. Mg, Zn and B as individual and combined foliar application were given at 20 and 40 DAT of rice according to the treatment.

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

1. Soil test based all nutrient package but N based on C:N ratio produced tallest plants at harvest followed by the soil application of $ZnSO_4$ @ 10 kg ha^{-1} along with POP NPK. Combined foliar and soil application of Mg, Zn and B along with POP NPK did not show any significant difference in height compared to all the other treatments except control.
2. Soil test based all nutrient package inclusive of FYM produced significantly higher tiller number at 30 DAT. However POP NPK along with FYM produced significantly higher tiller count compared to other treatments at 60 DAT. Combined foliar applications of Mg (1%), Zn (0.5%) and B (0.25%) along with POP NPK produced highest tiller number at harvest and it was at par with all the other treatments except control. The tiller decline was highest in POP NPK along with FYM and lowest in combined foliar application of Mg (1%), Zn (0.5%) and B

(0.25%) along with POP NPK which is similar to individual foliar application of B at 0.25% along with POP NPK.

3. Combined soil application of Mg, Zn and B along with POP NPK and combined foliar application of Mg, Zn and B along with POP NPK resulted in significantly higher LAI.
4. Combined foliar application of Mg, Zn and B along with POP NPK produced highest chlorophyll a content. But the existing POPR for rice resulted in highest chlorophyll b and total chlorophyll at 60 DAT even though all the treatments were on par. The control recorded lowest values for chlorophyll a, chlorophyll b and total chlorophyll.
5. The dry matter production at 30 DAT and 60 DAT did not vary significantly between treatments. At harvest, the highest dry matter production was observed in individual soil application of B at 10 kg ha^{-1} along with POP NPK and it was on par with other treatments except treatment which received POP NPK alone and control.
6. The panicles/hill was not significantly varied due to treatments. But the spikelet number was significantly higher in combined foliar application of Mg (1%), Zn (0.5%) and B (0.25%) along with POP NPK and soil test based all nutrient package but N @ 90 kg ha^{-1}along with FYM. The highest percentage of filled grains/panicle was observed with foliar application of Zn (0.5%) along with POP NPK closely followed by soil application of the same. The treatment which received individual soil application of Zn at 20 kg ha^{-1} along with POP NPK produced significantly higher 1000 grain weight. The test weight has also increased over control when the nutrients (Mg, Zn and B) were individually or jointly applied either in soil or foliage.
7. The highest grain yield was obtained for the treatment which received combined soil application of Mg, Zn and B along with POP NPK and was comparable with soil test based nutrient package but N @ 90 kg ha^{-1} inclusive of FYM, soil test based all nutrient package inclusive of FYM and combined foliar application of Mg, Zn and B. Highest straw yield is

recorded by soil application of B at 10 kg ha^{-1} along with POP NPK . The harvest index was not varied significantly. However, combined soil application of Mg, Zn and B along with POP NPK resulted in higher HI.

8. The treatment which received soil test based nutrient package but N based on C:N ratio resulted in significantly high N content at 30 DAT. The N content at 60 DAT was not varied significantly. At harvest, both in grain and straw highest N content and uptake were observed in combined soil supplication of Mg, Zn and B along with POP NPK.
9. There was no significant difference among the treatments in P content both at 30 DAT and 60 DAT. The straw P content was at par in all the treatments except control. In grain, significantly higher P content was observed with combined soil application of Mg, Zn and B along with POP NPK and it was at par with the combined foliar application of the same. Soil test based all nutrient package inclusive of FYM recorded highest P uptake.
10. The K content was significantly varied both at 30 and 60 DAT and the highest K content at 30 DAT was observed with foliar application of Zn along with POP NPK followed by the foliar application of Mg along with POP NPK. The soil application of Zn at 20 kg ha^{-1} recorded highest K content at 60 DAT. There was no significant difference in K content both in grain and straw. K uptake was highest for the foliar application of Mg.
11. The Ca content was highest in combined soil application of Mg, Zn and B along with POP NPK at 30 DAT. There was no significant difference in Ca content of grain and straw. Combined soil application of Mg, Zn and B along with POP NPK recorded the highest Ca uptake.
12. Combined soil and foliar application of Mg, Zn and B along with POP NPK produced higher Mg content in grain and straw and it was at par with all the other Mg applied treatments. Combined soil application of Mg, Zn and B along with POP NPK resulted in higher Mg uptake.
13. The S content at 30 DAT and 60 DAT was not varied significantly. The combined application of Mg, Zn and B resulted in higher S content both in

grain and straw. The highest S uptake was observed in combined soil application of Mg, Zn and B along with POP NPK.

14. Significant difference was not observed in the Fe content both at 30 DAT and 60 DAT. The POP NPK alone treatment showed highest Fe content in grain and the combined soil application of Mg, Zn and B resulted in higher Fe content in straw. Combined soil application of Mg, Zn and B along with POP NPK showed higher Fe uptake.
15. The Mn content of grain was not varied significantly. But in straw soil test based all nutrient package inclusive of FYM resulted in higher Mn content. Mn uptake was significantly higher with soil test based all nutrient package inclusive of FYM.
16. The highest Zn content was observed for the foliar application of $ZnSO_4$ (0.5%) along with POP NPK in grain and straw. Combined soil application of Mg, Zn and B recorded the highest Zn uptake.
17. Combined foliar application of Mg, Zn and B resulted in higher B content at 30 DAT and in straw whereas soil application of B at 10 kg ha-1 recorded higher B content at 60 DAT. B uptake was highest with the foliar application of B at 0.5% along with POP NPK.
18. Comparatively higher Cu content was observed in soil application of B at 10 kg ha-1 along with POP NPK in all the stages of growth. Soil application of B at 10 kg ha^{-1} recorded the highest Cu uptake.
19. There was no significant difference between the individual application and combined application of $MgSO_4$, $ZnSO_4$ and borax on the soil characteristics pH, EC, OC and available nutrient status of soil after the experiment.
20. The application of secondary nutrients and micronutrients must be done according to the soil test basis.

CONCLUSION

- The combined application of secondary nutrient Mg and micronutrients Zn and B gave the same result as that of individual application of these nutrients.
- The combined application of these nutrients can be done either soil or foliar application.
- Foliar application is better than soil application since it avoids large scale accumulation of nutrients especially Zn in soil and also reduces the cost of cultivation.
- If organic carbon status of the soil is high, the fertility of the soil is also high and there may not be any application of these nutrients in such soils.
- The soil test based nutrient application gave good results in case of growth and yield. So it is better to go for nutrients application based on soil test results

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* Originals not seen

APPENDIX

Appendix – 1

Details of cost of cultivation

Sl. No.	Particulars	Men/acre (Rs.400/day)	Women/acre (Rs.220/day)	Amount (Rs./ha)
Field operations				
1	Ploughing	-	-	4063/-
2	Nursery & transplanting(Machine)	-	-	11250/-
3	Fertilizer application	4	-	4000/-
4	Weeding (Twice)	-	10	11000/-
5	Water management	2	-	2000/-
6	Foliar spray of fertilizer	2	-	2000/-
7	Plant protection chemicals spraying	2	-	2000/-
8	Harvesting (Machine)	-	-	5000/-
9	Post harvesting	-	6	3750/-

Appendix – 2

Details of cost of inputs

Sl. No.	Particulars	Amount (Rs./kg)
1	Seed	29/-
2	FYM	1/-
3	Lime	10/-
4	Urea	5.6/-
5	Factamphos	20/-
6	MOP	20/-
7	Magnesium sulphate	30/-
8	Zinc sulphate	100/-
9	Borax	100/-

EFFICIENCY OF FOLIAR AND SOIL APPLIED NUTRIENTS IN IRRIGATED RICE

By

SREEDHU P. PREMAN

(2013-11-139)

ABSTRACT OF THE THESIS

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Department of Agronomy

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

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ABSTRACT

The research programme entitled "Efficiency of foliar and soil applied nutrients in irrigated rice" was conducted in the farmer's field, Thathamangalam, Palakkad during Mundakan season October 2014 – February 2015 to compare the relative efficiency of soil and foliar applied nutrients especially magnesium, zinc and boron alone or in combination in rice. The treatments included soil test based all nutrient package inclusive of FYM, soil test based all nutrients but N at 90 kg/ha inclusive of FYM, soil test based all nutrients but N based on C:N ratio, package of practices recommendation for rice manuring (POP NPK + FYM), NPK alone, soil application of $MgSO_4$ @ 80 kg ha^{-1}, $ZnSO_4$ @ 20 kg ha^{-1}, Borax @ 10 kg ha^{-1}, foliar spray of $MgSO_4$ @ 1%, $ZnSO_4$ @ 0.5%, Borax @ 0.25%, combined soil application of $MgSO_4$ @ 80 kg ha^{-1} + $ZnSO_4$ @ 20 kg ha^{-1} + Borax @ 10 kg ha^{-1}, combined foliar application of $MgSO_4$ @ 1% + $ZnSO_4$ @ 0.5% + Borax @ 0.25% and an absolute control. Soil application of Mg, Zn and B were done as basal, and foliar applications were given at 20 and 40 DAT of rice as per the treatments.

The growth characters of rice such as plant height, number of tillers, LAI and dry matter production were significantly increased by the application of $MgSO_4$, $ZnSO_4$ and Borax along with POP NPK irrespective of method of application whether as individual application or combined application. The application of POP NPK inclusive of FYM and the entire soil test based nutrient applications were also resulted in noticeable improvement in growth characters. Combined foliar application of Mg, Zn and B resulted in higher number of productive tillers and combined soil application of Mg, Zn and B produced higher LAI.

The combined foliar application of Mg, Zn and B significantly increased the number of spikelet/panicle along with soil test based all nutrients except N and Nat 90 kg/ha inclusive of FYM. Irrespective of the method of application, Zn

application enhanced the fertility percentage of grain compared to other treatments. Soil application of Mg and Zn produced significantly higher 1000 grain weight and it was statistically similar to all the nutrient applied plots irrespective of the method of application. The highest grain yield of 6.28 t ha^{-1} was observed with combined soil application of Mg, Zn and B along with POP NPK and it was similar to that of combined foliar application of Mg, Zn and B along with POP NPK. The application of B (either soil or foliar) also resulted in higher grain yield. The highest straw yield was observed in B applied treatments irrespective of method of application. The B:C ratio was higher for soil application of B and it was similar to its foliar application. Combined application (soil or foliar) of Mg, Zn and B produced higher B:C ratio than that of package of practices recommendation for rice.

The nutrient content of rice plants were also influenced by the application of $MgSO_4$, $ZnSO_4$ and Borax along with POP NPK. The combined application of Mg, Zn and B increased the content and uptake of Mg. The higher Zn content was observed in foliar application of $ZnSO_4$ along with POP NPK. The highest Zn uptake was observed in combined soil application of Mg, Zn and B. The combined foliar application of Mg, Zn and B increased the B content in rice. Foliar application of B resulted in higher B uptake.

There was no significant difference between the individual application and combined application of $MgSO_4$, $ZnSO_4$ and borax on the soil characteristics pH, EC, OC and available nutrient status of soil after the experiment. Available status of all the nutrients except S, Fe, Zn and Cu decreased after the experiment.