RELATIVE EFFICIENCY OF SOIL AND FOLIAR APPLIED NUTRIENTS IN IRRIGATED RICE OF PALAKKAD

by

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(2011-11-114)

THESIS

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DECLARATION

I, hereby declare that the thesis entitled **"Relative efficiency of soil and foliar applied nutrients in irrigated rice of Palakkad"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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Certified that the thesis, entitled **"Relative efficiency of soil and foliar applied nutrients in irrigated rice of Palakkad"** is a record of research work done independently by **Ms. Nissa Latheef (2011-11-114)** 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.

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We, the undersigned members of the advisory committee of **Ms. Nissa Latheef (2011-11-114)** a candidate for the degree of **Master of Science in Agriculture**, with major field in Agronomy, agree that the thesis entitled **"Relative efficiency of soil and foliar applied nutrients in irrigated rice of Palakkad"** may be submitted by **Ms. Nissa Latheef (2011-11-114)**, in partial fulfilment of the requirement for the degree.

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DEDICATED TO MY VAPPI, UMMACHI AND BELOVED ONES

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

Introduction

I. INTRODUCTION

Rice - Rice cropping system covers more than 6 m ha in India and represents the country's most important food production system. Declining rate of yield increase within this intensive irrigated system is a serious cause for concern. Incidence and expansion of multi-nutrient deficiencies in the soils under intensive cropping in general, and in rice-based cropping systems in particular, can be linked to inadequate and unbalanced nutrient input and are considered major reasons for observed declines in productivity associated with fertilizer use (Singh *et al.*, 2009).

Intensive cultivation with high yielding crop varieties, use of high analysis NPK fertilizers devoid of secondary and micronutrients, loss of top soil by erosion, loss of micro nutrients through leaching, liming of acid soils, limited use of organic manures and restricted recycling of crop residues accelerated the exhaustion of secondary and micronutrients from the soil (Ray, 2011).

The stagnation in crop productivity has been found due to deficiency of some secondary and micronutrients. Deficiency of secondary and micronutrients resulted in the drastic reduction of yield to the tune of 25-60% (Varughese and Jose, 1993). Hence secondary and micronutrients have assumed increasing importance in crop production under modern agriculture (Sakal, 2001). The balanced use of primary, secondary and micronutrients help in maintaining yield stability through correction of marginal deficiencies of these nutrients and enhancing efficiencies of applied nutrients (Banerjee *et al.*, 2006.)

Soil factors such as pH, redox potential, CEC, clay content and nutrient balance influence the availability of secondary and micronutrients. For rice, the most significant factor influencing the nutrient availability is the kinetics of electrochemical changes during soil submergence. Soils of Kerala are generally lateritic and acidic with low CEC and high AEC. They not only suffer from the deficiencies of secondary nutrients, *viz.*, Ca, Mg and S, but also micronutrients such as Zn, B and Cu. The high concentrations of Fe and Mn in lowland condition result in the toxicity of these nutrients (Samui and Mandal, 2003). 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.

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. Use efficiency of micronutrients is hardly 2-4% (Yadav, 2012). The efficiency of fertilizers can be increased and the losses reduced by matching supply with crop demand, optimizing split application, method of application, and site specific management. Any extent of agronomic management cannot produce high efficiency out of an imbalanced fertilization (Hegde *et al.*, 2007). The method of application include soil, foliar, seed treatment and seedling dip. Of these soil and foliar application on crops are the most widely used methods.

Sometimes the soil application of nutrients cannot correct the deficiencies because of the negative effect of pH and nutrient interactions. 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). Sources of magnesium include magnesite, dolomite and magnesium sulphate. Magnesium sulphate was found to perform better compared to other sources because of its higher solubility (Varughese and Jose, 1993).

Zinc deficiency is corrected through the application of $ZnSO_4$. Soluble $ZnSO_4$ is superior than less soluble ZnO and Zn frits (Katyal *et al.*, 2004). Soil application of Zn is better than foliar spray. Soil application of boron as borax is the common method in field crops. But its availability has been limited due to its immobile nature. The dosage could vary from 3-20 kg ha^{-1} (Prasad, 2007). For field crops and also when B deficiency is detected in a growing crop, foliar application of 0.1-0.5% boric acid solution is recommended.

It is in this context, a holistic study on the comparative evaluation of method of application of nutrients was taken up with following major objectives.

1) To evaluate the efficacy of different methods of secondary and micronutrient application
2) To standardize the quantity and time of application of nutrients
3) 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

Rice requires about seventeen nutrients for normal growth and completion of its life cycle. These nutrients can be grouped as macro and micronutrients. Macro nutrients are required by plants in concentrations exceeding 0.1%, and these include C, H, O, N, P, K, Ca, Mg and S (Havlin *et al.*, 2006). 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 as primary or major nutrients.

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 most yield limiting nutrient in low land rice production. Intensive agricultural production systems have increased the use of nitrogen fertilizer in order to sustain high crop yields (Fageria *et al.*, 2010). Nitrogen Use Efficiency in water logged rice is 30-35% (Yadav, 2012). Low recovery of N is associated with its loss by volatilization, leaching, surface run off, immobilization and denitrification. N is an essential constituent of amino acids, nucleic acids, nucleotides and chlorophyll and is closely related to photosynthetic rate

(Coumaravel *et al.*, 2004). It promotes increased plant height, number of tillers, spikelets per panicle, percentage filled spikelets per panicle and yield (Dobermann and Fairhurst, 2000).

The total N content in soil varies from traces to 1-2% depending upon the C:N ratio of soil OM (Prasad, 2007). The optimum ranges of N content in rice at tillering, flowering and maturity is 2.9-4.2, 2.2-3.0 and 0.6-0.8% respectively. The critical level of deficiency of nitrogen at tillering stage is <2.5% (Dobermann and Fairhurst, 2000). The deficiency of nitrogen leads to yellowing of older leaves and stunted growth. It also results in reduced tillering and grain yield.

N interacts positively with most of the plant nutrients (Aulakh and Malhi, 2005). Lambert *et al.* (2007) and Gupta *et al.* (2007) reported positive NxP, NxK, NPKxZn, NPKxCu and NPKxMn interaction in rice. 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. The combined application of 60 mg N kg^{-1} along with 30 mg K_2O kg^{-1} increased grain and straw yield in rice (Singh *et al.*, 1999). Ca and Mg saturation decreased with increasing N rates by ammonium sulphate and urea fertilizers (Fageria *et al.*, 2010).

Masthanareddy *et al.* (2009) reported that the application of 200 or 250 kg N ha^{-1} significantly increased N content, N uptake and grain yield. Aulakh *et al.* (2010) reported that flooded rice responded to N rates up to 120 kg N ha^{-1} on sandy loam soils in India. The 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}.

Phosphorous

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

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

The optimum ranges of P content in rice at tillering, flowering and maturity is 0.20-0.40, 0.20-0.30 and 0.10-0.15% respectively. The critical level of deficiency of P at tillering stage is <0.10 %. P deficient plants are stunted with reduced tillering. It also leads to reduced number of leaves, panicles and grains per panicle (Dobermann and Fairhurst, 2000). 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). P fertilization increased grain yield significantly up to 60 kg P_2O_5 ha^{-1} (Cong *et al.*, 2011).

Potassium

Among the major plant nutrients, potassium is the most abundant plant nutrient in soils. It constitutes an average of 1.9% of the earth's crust. Potassium is known to exist in structural (mineral) form 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). 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 (Havlin *et al.*, 2006).

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

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

2.2 Secondary nutrients

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

2.2.1 Calcium

Calcium is referred to as 'Liming Element' because it is added to ammend soil pH and plays a greater role in neutralizing the acid forming effects of H^+. Ca makes up to about 3.64 % of earth's crust (Mengel and Kirkby, 1987). It is present in soils as a component of silicate minerals or as carbonate, sulphate or phosphate minerals. Large amount of Ca is present in soil as exchangeable Ca on silicate minerals in soils having pH 6 or above.

Exchangeable Ca in soils can range from < 25mg kg^{-1} to more than 5000 mg kg^{-1} and that in soil solution may range from 68-778 mg kg^{-1} (Prasad and Power, 1997). Critical level of deficiency of neutral normal ammonium acetate extractable Ca in soil for rice is <1.0 c mol (p^+) kg^{-1}. For optimum growth of rice, Ca: Mg ratio should be > 3- 4:1 for exchangeable soil form and 1:1 in soil solution. A Ca: Mg ratio of 1-1.5:1 in rice shoots from tillering to panicle initiation is optimal. The concentration of Ca in soil solution tends to increase after flooding because of the displacement of exchangeable Ca^{+2} by Fe^{+2} (Dobermann and Fairhurst, 2000).

Depletion of exchangeable Ca occurs due to heavy leaching and run off. Weathering or continuous application of acid forming fertilizers also lead to the depletion of exchangeable Ca from soil. Soil acidity affects the availability of not only Ca but almost all plant nutrients and therefore the effects of Ca deficiency due to acidity are compounded with the deficiency and toxicity of other nutrients (Havlin *et al.*, 2006). As the soil acidity increases the proportion of Al increases which lead to Al toxicity and limit the growth and crop production (Foy, 1992). Liming of acidic red and laterite soil not only ameliorate soil acidity related problem but also supply Ca and increased the uptake of Ca (Fox *et al.*, 1991; Samui and Mandal, 2003).

Calcium is absorbed as Ca^{+2} from the soil. Percentage content of calcium in rice ranges from 0.2 – 1.0% (Samui and Mandal, 2003). The Critical level of Ca at tillering stage of rice is <0.15% (Dobermann and Fairhurst, 2000). Ca is necessary for cell division and cell elongation and is present as calcium pectate in middle lamella of cell wall which maintain cell wall integrity. It is an enzyme activator and is required for osmoregulation.

Ca is an immobile nutrient, and hence deficiency symptoms first appear in young leaves and parts of the plants. The first symptom of Ca deficiency in rice is the bleaching, rolling and curling of tip of the youngest leaves. Necrotic tissues may develop along the lateral margin of the leaves, and old leaves eventually turn brown and die. Calcium deficiency also result in impaired root function, and may predispose rice plant to Fe toxicity (Jakobsen, 1993). White tip may occur when Ca: Mg ratio is <1.

Amelioration of soil with lime significantly increased the yield components of rice like number of panicle per ha, grains per panicle and 100 grain weight (Chang and Sung, 2004). Krasaesindhu and Sims (1972) reported increased grain yield, decreased straw weight and markedly increased grain : straw ratio by the application of Ca.

2.2.2 Magnesium

Magnesium in soil is derived from mineral biotite, phlogopite, hornblende, olivine and serpentine. In arid and calcarious soil Mg may be found as epsomite ($MgSO_4\ 7H_2O$) and dolomite ($CaCO_3\ MgCO_3$) respectively. The Mg content in earth's crust is about 2.07 % (Mengel and Kirkby, 1987). The exchangeable form of Mg is about 4-20% of CEC. Magnesium in soil solution may range from 50- 120 mg L^{-1} (Prasad, 2007). The critical level of deficiency of neutral normal ammonium acetate extractable Mg in soil for rice is <1.0 c mol (p^+) kg^{-1}. A Ca: Mg ratio in soil solution greater than 7:1 is considered undesirable (Dobermann and Fairhurst, 2000).

High soil pH, base imbalances, aluminum and manganese toxicity decreases the availability of Mg (Lynch and Clair, 2004). High levels of exchangeable aluminium affect Mg uptake in strongly acidic soil. Continuous use of high amount of liming materials may increase Ca: Mg ratio and induce Mg deficiency. High levels of exchangeable potassium may reduce the Mg availability and K: Mg ratio should be 5:1 for field crops. Competition of ammonium ion and magnesium ion can also lower magnesium availability. The introduction of high yielding varieties and the increased use of nitrogen, phosphorus and potassium fertilizers also induced magnesium deficiency (Ding *et al.*, 2006).

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

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

Mg is fairly mobile in plants and highly reactive. Deficiency of magnesium in rice is a widespread problem, affecting productivity and quality of rice (Hermans *et al.*, 2004). The first symptom of Mg deficiency in rice is the development of orange- yellow interveinal chlorosis on older leaves. Later on chlorosis leads to yellowing and finally necrosis in older leaves. Mg deficient leaves are wavy and droopy due to an expansion in angle between leaf sheath and leaf blade. Deficiency also causes reduced number of spikelets, thousand grain weight, grain yield and quality (Dobermann and Fairhurst, 2000). Mg deficiency in rice (less than 1.1 mg g^{-1} dry weight in the shoot) resulted in significant reduction in shoot biomass, total chlorophyll concentration and net photosynthetic rate (Ding *et al.*, 2006).

Magnesium fertilization significantly increases fertilizer N uptake and recovery % of fertilizer N (Choudhury and Khanif, 2001). If soluble salts of Mg is applied with urea, it prevents the volatilization of NH_3, by forming ammonium chloride or nitrate (Fenn *et al.*, 1981). Choudhury and Khanif (2001) reported that grain yield of rice increased signifcantly due to the application of 20 kg Mg ha^{-1}. Mg application signifcantly increased total Mg uptake both at10 and 20 kg Mg ha^{-1}.

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

Magnesium alone and in combination with silicon increased the productive factors such as tillering, height of the plant, leaf width, root weight and spread as well as the test weight of grain (Padmaja and Verghese, 1966). Mg is involved in the protection of rice plants against grain discolouration and its application increased grain yield by an average of 34% (Yamauchi and Winslow, 1989). The foliar application of Mg as epsom salt at 3.2 and 6.4 kg ha^{-1}MgO significantly increased the chlorophyll concentration and grain yield in soyabean (Teklic *et al.*, 2009).

2.2.3 Sulphur

Sulphur is regarded as the 4^{th} 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). 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). T he 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. Tandon (1991) reported that sulphur deficient soils are found in all the districts of Kerala ranging from 20-55%.

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

Sulphur is mobile in soil system and it moves down in the lower layers of soil due to heavy rain and excess irrigation. The intensive tillage and consequent over exposure of soil to higher temperature accelerate organic matter loss which can seriously impair sulphur supplying power of soil. Greater sulphur removal from soil occurs as a result of an increase in agricultural production by increasing fertilizer use, intensifying cropping systems, promoting high yield crop varieties, improving irrigation, adding less sulphur to soil due to the increasing proportions of high analysis sulphur free fertilizers, crop removals, organic matter depletion *etc.* (Katyal *et al.*, 1997; John *et al.*, 2006).

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

The interaction between N and S is generally positive or synergistic since these two nutrients increase the concentration and uptake of each other in the plants. The nature of P- S interactions depends on their rate of application. The PxS interactions is synergistic at low- medium levels and antagonistic at higher levels for field crops. In the case of Mg & S, both synergistic and antagonistic effects have been reported. The antagonism between Mg & S was more when K was also applied (Tiwari, 1997). A significant ZnxS interaction in rice was also reported by Singh and Singh (2002).

In field condition, sulphur is found to be absorbed by the rice crop in amounts equal to phosphorus and is considered essential for the attainment of 90% of optimum yield (Sheela *et al.*, 2006). The application of 45 kg S ha^{-1} significantly increased the grain and straw yield of rice to the tune of 4490 and 6490 kg ha^{-1} respectively in laterite soil, while control treatment recorded 3820 and 5420 kg ha^{-1} respectively (John *et al.*, 2004). It also improves the sulphur uptake by crop and highest crop uptake was noticed at 45 kg S ha^{-1} (15.92 kg ha^{-1}) compared to control (7.58 kg ha^{-1}). The residual effect increases with increasing level of sulphur (John *et al.*, 2006). Rathish (2010) reported that combined application of nitrogen and sulphur increase the grain yield of rice. Maximum yield is obtained by the combined application of nitrogen at 90 kg and sulphur at 30 kg ha^{-1}(6557 kg ha^{-1}).

The application of gypsum @ 30 kg S ha^{-1} considerably increased the available sulphur status of the laterite soil. 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}).

Rathish (2010) reported that the incorporation of straw at 10 t ha^{-1} is a better source of sulphur in soil than cow dung.

2.3 Micronutrients

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

2.3.1 Iron

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

Fe toxicity is mainly experienced in rice which is grown on acid sulfate soils, ultisols and sandy soils with a low CEC, moderate to high acidity, active Fe, and low to moderately high in organic matter (Benckiser *et al.*, 1984). The iron toxicity inducing factors are release of iron from parent material to soil solution, reduction in oxidation reduction potential, increase in ionic strength, low soil fertility, low soil pH, soil organic matter content, high reactivity and content of Fe (III) oxide hydrates, increased salts content, microbial activities, interaction with other nutrients and plant genetic variability (Fageria *et al.*, 2008). Range of oxidation-reduction potential values at which reduction of Fe^{3+} to Fe^{2+} occur is +180 to +150 (Patrick, 1966).

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

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

Critical level of toxicity of Fe in rice at tillering stage is 300-500 mg kg^{-1} (Samui and Mandal, 2003). Fe is not very mobile in plants. Fe toxicity symptoms are generally manifested as tiny brown spots starting from the tips and spreading towards the bases of the lower leaves. Excessive Fe uptake results in increased polyphenol oxidase activity, leading to the production of oxidized polyphenols, which cause leaf bronzing (Dobermann and Fairhurst, 2000). With increased Fe toxicity, the entire leaf looks purplish brown followed by drying of the leaves. The roots of the plants become scanty, coarse, short and blunted, and dark brown in colour (Sahrawat, 2004). The other effects include stunted plant growth, decreased tillering and high spikelet sterility (Mohapatra, 2011).

Cultural practices such as planting date, ridge planting, water management, and pre submergence of soil can be manipulated to reduce Fe toxicity in rice (Abu *et al.*, 1989). Effective measures to ameliorate Fe^{2+} toxicity include periodic surface drainage to oxidize reduced Fe^{2+}, liming of acid soils, use of adequate amounts of essential nutrients and planting of iron toxicity tolerent cultivars or genotypes. The application of Zn @ 10 kg ha^{-1} as ZnO along with NPK decreased iron toxicity and also increased yield in rice (Audeberta and Sahrawata, 2000). The shoot biomass, plant height and chlorophyll content decreased at 10 mg L^{-1} of Fe concentration (Panda *et al.*, 2012).

2.3.2 Zinc

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

Soil chemical properties *i.e.* pH, redox potential, organic matter, pedogenic oxide and soil sulfur contents have strong influence on the adsorption-desorption reactions of Zn and play a critical role in regulating Zn solubility. The forms of Zn include soluble Zn present in soil solution (water soluble), adsorbed on exchange sites (exchangeable), associated with organic matter, co-precipitated as secondary minerals or associated with sesquioxides and as structural part of primary minerals (Alloway, 2003; Rehman *et al.*, 2012). The interactions of Zn with macronutrients, as P in soil or N within the plant could interfere with uptake, root-shoot transport and seed deposition of Zn (Cakmak and Hoffland, 2012, Gupta and Gupta, 2005).

Zn is a divalent cation and has a strong tendency to form tetrahedral complexes in plant cells. It is an essential metallic component for enzymes such as dehydrogenases, oxidase, anhydrases, peroxidases *etc.* (Katyal *et al.*, 2004). Zinc 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 the utilization of phosphorous and nitrogen (Ponnusamy, 2006).

The critical level in soil for occurrence of Zn deficiency is 2 mg kg^{-1} of 0.1 N HCl extractable Zn. The critical level for deficiency of Zn is <20 mg kg^{-1} in younger leaves of rice at tillering stage (Dobermann and Fairhurst, 2000). Deficiency of Zn may either be primary due to low total content of Zn or secondary caused by soil factors reducing its availability to plants (Patel, 2011). In rice, visual symptoms of zinc deficiency appear about 2-3 weeks after transplanting. Reddish brown specks are formed on the margins of fully grown third or fourth leaf from the top of the plants. These specks enlarge, coalesce and become necrotic. The deficient plant develop a rusty appearance known as Khaira disease and remain dwarf and less vigorous (Ponnusamy, 2006). Zinc deficiency not only reduces yield, but also delays crop maturity. During flooded condition, rice plant is unable to support root system respiration due to zinc deficiency (Slanton *et al.*, 2001).

Source, rate, time and method of application of fertilizer influence the availability of zinc (Hegde *et al.*, 2007). The sources of zinc include inorganic, synthetic chelates, natural organic complexes and inorganic complexes. The inorganic sources are sulphate, chloride, carbonate and oxides of zinc. Zn-EDTA is the widely used synthetic chelate. Zn-humate and Zn-fulvate are the natural organic complexes (Patel, 2011). Water solubility of zinc fertilizer is the primary factor that affects Zn uptake and availability to plants (Gangloff *et al.*, 2002).

Zinc sulphate is the most common and reliable fertilizer used in India (Gupta and Gupta, 2005; Gangloff *et al.*, 2006). Increased use of Zn sulphate by the farmers in recent years has resulted in an increase of available Zn contents in soils in many areas (Sidhu and Sharma, 2010). Zn deficiency is mainly corrected by soil and foliar application of zinc fertilizer. When zinc sulphate is applied to the soil, utilization by crops seldom exceeds 5%, most of the added Zn remains unutilized (Hegde *et al.*, 2007). This may either lead to toxicity or impart residual effect.

Time of fertilizer application may considerably influence crop response to fertilizer. A number of factors like nature of the crop, its growth stages and nutrient requirements or crop needs, soil conditions, nature of the fertilizer *etc.* affect the time of fertilizer application (Ravichandran and Sriramachandrasekharan, 2011).

The best time of application of Zn to most field crops is prior to seeding or transplanting. Zinc application to rice by splitting half the dose as basal and half at the tillering stage was equivalent to full basal application (Patel, 2011). Zn sources can be applied in nursery, seedling stage, maximum tillering and panicle initiation. Zn fertilizer fails to prevent deficiency when applied to the soil surface shortly before flooding (Slaton *et al.*, 2005).

There are different methods of Zn application *viz.*, soil, foliar, dusting seed with Zn powder or soaking in Zn solution, swabbing foliage with Zn paste and seedling dip. The application rates of 25 to 50 kg $ZnSO_4.7H_2O$ ha^{-1} are mainly recommended. 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 (Katyal *et al.*, 2004). A soil was rated responsive to Zn fertilization if it produced more than 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).

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). There was an increase in growth, yield attributes, grain and straw yield as well as system productivity, when rice received 100% recommended dose of NPK on the basis of soil test data along with Zn at 20 kg $ZnSO_4$ ha^{-1} (Pal *et al.*, 2008).

The application of $ZnSO_4$ @ 45kg ha^{-1} recorded higher 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 (3.4 Mg ha^{-1}) and straw (4.8 Mg ha^{-1}) yield. The soil application $ZnSO_4$ @ 45kg ha^{-1} was superior than foliar application $ZnSO_4$ @ 0.75%. Zn uptake by plant significantly varied with different methods and doses of $ZnSO_4$ application (Kumar and Kumar, 2009). Koruth (2010) reported that basal application of 25 kg $ZnSO_4$ ha^{-1} is sufficient to correct Zn deficiency. Residual effect of Zn will be there for 10 rice seasons (5 years) by the application of 25 kg $ZnSO_4$ ha^{-1}. Further application should be needed only after 5 years. Arif *et al.* (2012) reported that soil application of 15 kg Zn ha^{-1}as zinc sulphate produced higher plant height (100.65 cm), productive tiller/m^2 (234.00) and 1000 grain weight (20.00 g) compared to control. It also recorded higher straw (8.20 t ha^{-1}) and grain yield (3.45 t ha^{-1}). The treatment recorded 1.47 mg g^{-1} of chlorophyll a, 0.52 mg g^{-1} of chlorophyll b and 1.96 mg g^{-1} which were higher than control.

The application of $ZnSO_4$ at 25 kg ha^{-1} along with 5t FYM increased the yield of rice over recommended dose of NPK. The Zn uptake (262.78 g ha^{-1}) was also higher in the above treatment. The uptake of NPK is maximum in Zn+ FYM treatment (Husain *et al.*, 2009). Hence with the use of organic manure the optimum level of Zn can be reduced to about 50% (Gupta and Handore, 2009).

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). Number of spikelets per panicle, 1000 grain weight and grain yield increased with the application of 5. 7.5 &10 kg Zn ha^{-1} than the control but 5 kg Zn ha^{-1} showed higher values. The plant height is decreased with the increasing order of Zn application (Shehu *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. The foliar application of Zn increased the yield of rice significantly over control (Katyal *et al.*, 2004). The foliar application of 0.1% Zn as $ZnSO_4$ $7H_2O$ 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, 0.1 and 0.2%. It is also superior than the application of 0.1% Zn as $ZnSO_4$ $7H_2O$ at maximum tillering (Das *et al.*, 2004). 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). The highest yield, N and Zn uptake in Basmati rice was recorded with 2% ZEU (Zinc enriched urea) followed by 0.2% foliar spray of $ZnSO_4$ (Pooniya *et al.*, 2011).

2.3.3 Boron

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

Rice, when grown on a wide range of soil types such as calcareous, clayey laterite, acid, *etc.* with varying soil pH levels, boron availability, uptake and mobilization become limiting and leads to reduced productivity and poor rice yields (Rao *et al.*, 2013).

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

Boron primarily occurs in the soil as H_3BO_3. Available B is derived from decomposition of organic matter and release from clay minerals. The H_3BO_3 form of B is highly mobile in the soil (Dunn *et al.*, 2005). Soil application of boron leads to fixation and unavailability (Rao *et al.*, 2013). Boron is immobile in plant. Deficiency symptoms of B in rice begin with a whitish discoloration and twisting of new leaves. Severe deficiency symptoms in rice include thinner stems, shorter and fewer tillers, death of growing point and failure to produce viable seeds (Dunn *et al.*, 2005). The application of boron through different sources either through soil or foliar spray was found to be beneficial in simulating plant growth and in increasing yield of rice (Sakal *et al.*, 2002).

Rice receiving soil applied boron produced significantly greater yields than rice with foliar applied B. Since the soil applied treatments were made at planting as compared to foliar treatments at early tiller stage, soil applied B may have helped early vegetative growth and promoted tillering (Dunn *et al.*, 2005). General soil application rate of B is 1–1.5 kg B ha^{-1} as borax.

B application at very low rate substantially improved seedling emergence, tillering, chlorophyll, water relations and yield related traits resulting in better yield and grain B contents. Boron application at higher level adversely affected chlorophyll pigments (Rehman *et al.*, 2012). Debnath *et al.* (2009) reported that the application of 1.5 kg B ha^{-1} increased the plant height, number of tillers, dry weight and spikelet sterility. The dry matter yield decreases at higher B levels may be ascribed to B toxicity because a slight increase in B levels markedly increased the B concentration in shoots (Debnath and Ghosh, 2012).

Grain yield of wheat increased significantly from 3.6 t ha^{-1} in control to 3.8 t ha^{-1} at 10 kg B ha^{-1} level. Beyond this level reduction in yield was recorded. Similar trend was observed in straw yield also. This reduction in yield may be attributed to injurious effect of high concentration of boron in grain as well as straw. Increasing levels of B up to 10 kg borax ha^{-1} significantly increased its content in grain (27.3 mg kg^{-1}) and straw (43.1 mg kg^{-1}) over control 19.3 mg kg^{-1} & 33 mg kg^{-1}). A positive interaction exist between P and B when boron was applied at higher dose (Gaur and Singh, 2010). Significant increase in straw yield was obtained by the application of boron in red loam soils of Kerala (Sreedharan and George, 1969).

The application of 0.4 ppm B at anthesis decreases the number of unfilled spikelets compared to control. The application 0.4 ppm B recorded higher yield compared to 0.8 ppm (Rao *et al.*, 2013).

2.3.4 Manganese

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

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). Large concentrations of Mn in the medium can induce Mg deficiency in the plant (Heenan and Campbell, 1981). 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.

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).

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).

2.3.5 Copper

Among the heavy metals, copper is an essential micronutrient for plant growth and various biochemical processes. Slightly higher concentration of Cu from the optimal level induces toxicity to the plant. 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).

Copper is more strongly bound by clays and humus than other cations, and high aluminum content in soil, as low as 0.1 mg kg^{-1} markedly reduces total copper uptake by plants. The acidity of the soil has no effect on copper absorption by plants (Herawati *et al.*, 1998). A gradual decrease in shoot and root elongation was observed with the increase in Cu concentration from 10 to 100 μM (Thounaojam *et al.*, 2012).

2.4 Factors affecting nutrient availability

The factors that affect availability of secondary and micronutrients are soil pH, soil texture, soil reaction, organic matter, calcium carbonate content, cultural and management practices, nutrient interactions and status of micronutrients in the soil (Zayed *et al.*, 2011; Muralidharan and Jose, 1994). The climate, farm management, and crop variety also play an important role in the uptake of micronutrients (Pirzadeh *et al.*, 2010).

2.4.1 Soil pH

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). Soil pH had positive effects on Cu in grain and soil and Mn in grain (Lin *et al.*, 2009). A significant and negative correlation was observed between soil pH and available contents of Mn and Fe (Sidhu and Sharma, 2010). 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, Chandel *et al.*, 2010, Ponnusamy, 2006).

Extractable Cu, and Zn were increased up to about pH 5.5 and then decreased in a quadratic mode with increasing soil pH. The high pH has a negative effect on soil boron availability to rice (Dunn *et al.*, 2005). The low pH causes low availability of calcium and favours the increased availability of P (Papadopoulos *et al.*, 2009).

2.4.2 Organic matter

Organic C markedly controlled the distribution of available forms of all the micronutrients. Organic C has a positive effect on available Zn, Cu, Mn, Fe, B and Mg (Katyal and Sharma 1991, Chandel *et al.*, 2010). DTPA Zn decreased with increased clay content of the soils (Sidhu and Sharma, 2010). 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).

Cu and Mn both in grain and soil decreased as SOM increased, whereas Fe in soil was positively correlated with SOM (Lin *et al.*, 2009). Organic matter is the main reservoir of available Cu in soils and its content was found to increase with increase in clay and organic-matter content, particularly in soils initially low in organic matter (Sidhu and Sharma, 2010). The available B was found to be positively and significantly correlated with organic carbon (Debnath and Ghosh, 2012).

2.4.3 Calcium carbonate content

$CaCO_3$ has a negative effect on the available forms of Zn, Cu, Mn, and Fe micronutrients (Shuman 1986). 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).

2.4.4 Nutrient interactions and Status of micronutrients in soil

The Zn availability depend 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).

2.4.5 Climate and Management practices

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 grains of rice (Hao *et al.*, 2007).

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. 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

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). 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).

Soil application of Zn is prophylactic treatment and has a relatively long residual effect. General application rate of Zn is 5-11 kg Zn kg ha^{-1} as $ZnSO_4$ (Rattan *et al.*, 2008). 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). Basal application of $ZnSO_4$ at 25 kg ha^{-1} increased grain yield to 6137 kg ha^{-1} compared to control (Stalin *et al.*, 2011). Kumar and Kumar (2009) reported that the soil application of $ZnSO_4$ @ 45kg ha^{-1} is superior than 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).

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).

2.6.2 Foliar application of nutrients

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. Foliar application is one of the most effective and safest approaches to enrich essential micronutrients in crop grain (Fang *et al.*, 2008). Micronutrients are required in small amounts and foliar application of these nutrients is more uniform compared to soil application (Fageria *et al.*, 2009). Foliar spray of different micronutrients has been reported to be equally or more effective than soil application because of higher uptake efficiency (Jin *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. Correction of deficiency symptoms usually occurs 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 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 ensures adequate supply at critical stages of development (Brown and Shelp, 1997). The dry matter production was more efficient when boron fertilizer is 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).

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).

Materials & Methods

III. MATERIALS AND METHODS

The present study entitled "Relative efficiency of soil and foliar applied nutrients in irrigated rice of Palakkad" was carried out in the farmer's field, Thathamangalam, Palakkad during *Mundakan* season October 2011- February 2012. The materials used and the methodology adopted for the study is described in this chapter.

3.1 General details

3.1.1 Location

Palakkad district is situated in the South West Coast of India, bounded on the North by Malappuram, in the East by Coimbatore of TamilNadu, in the South by Thrissur and in the West by Thrissur and Malappuram districts. The experiment field, Pudunagaram lies between $10^{\circ}68'$ N latitude and $76^{\circ}70'$ E longitude and at an altitude of 67.2 m above MSL.

3.1.2 Weather and Climate

The area enjoys tropical humid climate. The temperature of the district varies from $20^{\circ}C$ to $40^{\circ}C$. The maximum and minimum temperature during the cropping period was $35.1^{\circ}C$ and $21.9^{\circ}C$ respectively. The mean monthly averages of important meteorological parameters observed during the experimental period are presented in Appendix I.

3.1.3 Soil

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

3.1.4 Crop and Variety

The rice cv. Uma (MO-16), a red kernelled, medium duration variety was used for the experiment. The variety is suitable for all the three seasons,

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

Properties	Value
a. Physical properties	
Bulk density (g cm^{-3})	1.42
Particle density (g cm^{-3})	2.46
Porosity (%)	42.00
Water holding capacity (%)	45.60
Particle size composition	
Sand (%)	53.30
Silt (%)	12.90
Clay (%)	33.60
Texture	Sandy clay loam
b. Chemical properties	
Soil reaction (pH)	5.95
Electrical conductivity (ds m^{-1})	0.07
Organic carbon (%)	0.98
Available N (kg ha^{-1})	267.00
Available P_2O_5 (kg ha^{-1})	38.79
Available K_2O (kg ha^{-1})	104.60
Available Ca (mg kg^{-1})	1152.00
Available Mg (mg kg^{-1})	25.00*
Available S (mg kg^{-1})	6.18
Available Fe (mg kg^{-1})	364.00
Available Zn (mg kg^{-1})	1.77
Available B (mg kg^{-1})	0.13*
Available Cu (mg kg^{-1})	2.50
Available Mn (mg kg^{-1})	75.40

* Deficient

medium tillering, resistant to BPH and capable of producing a yield of over 5 t ha^{-1} under favourable situations.

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) during 2^{nd} crop season (*Mundakan*) from October 2011 to February 2012. The experimental design was RBD with 3 replications. The plot size was 5.0 m x 4.0 m and the spacing adopted was 20 cm x 10 cm. The layout of the experiment is depicted in Fig. 1. The treatment details for the crop are given in Table 3.2.

3.2.1 Treatment details

Table 3.2 Treatment details

	Treatments
T_0	Absolute control
T_1	Soil test based all nutrient package inclusive of FYM
T_2	Existing POP
T_3	POP NPK alone
T_4	POP NPK + $MgSO_4$ 40 kg ha^{-1}
T_5	POP NPK + $MgSO_4$ 80 kg ha^{-1}
T_6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}
T_7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}
T_8	POP NPK + Borax 10 kg ha^{-1}
T_9	POP NPK + Borax 20 kg ha^{-1}
T_{10}	POP NPK + $MgSO_4$ foliar - 0.50%
T_{11}	POP NPK + $MgSO_4$ foliar - 1.00%
T_{12}	POP NPK + $ZnSO_4$ foliar - 0.50 %
T_{13}	POP NPK + $ZnSO_4$ foliar - 1.00 %
T_{14}	POP NPK + Boron foliar - 0.25 %
T_{15}	POP NPK + Boron foliar - 0.50 %

N

5 m, 4 m

R_1		R_2		R_3	
T_3	T_2	T_{13}	T_8	T_8	T_1
T_{14}	T_6	T_{11}	T_0	T_2	T_3
T_9	T_{13}	T_7	T_3	T_{11}	T_{14}
T_4	T_{10}	T_4	T_5	T_{10}	T_7
T_{15}	T_8	T_{10}	T_{15}	T_4	T_{12}
T_1	T_{12}	T_6	T_9	T_5	T_{15}
T_7	T_5	T_2	T_{14}	T_9	T_{13}
T_{11}	T_0	T_{12}	T_1	T_6	T_0

Fig. 3.1 Lay out of the experimental plot

T_0- Control **T_1**- Soil test based nutrient +FYM, **T_2** – POP NPK+FYM, **T_3** – POP NPK, **T_4** – 40 kg $MgSO_4$, **T_5**-80 kg Mg SO_4, **T_6**- 20 kg Zn SO_4, **T_7**- 30kg Zn SO_4, **T_8**- 10 kg Borax, **T_9**- 20 kg Borax, **T_{10}**- 0.5% Mg SO_4,**T_{11}**- 1.0% Mg SO_4, **T_{12}**- 0.5% Zn SO_4, **T_{13}**- 1.0% Zn SO_4-, **T_{14}**-0.25% Borax, **T_{15}**- 0.5% Borax

* The quantity of sulphur applied in all the treatments will be made uniform by combination of N sources (ammonium sulphate and urea).

T_1 indicate the supply of nutrients based on soil test inclusive of FYM. The NPK recommendation in soil test based nutrient application is 70:37:53 kg N, P_2O_5 & K_2O ha^{-1}. T_2 is the supply of nutrients based on existing POP NPK (90:45:45 kg N, P_2O_5 & K_2O ha^{-1}) inclusive of 5 t FYM ha^{-1}. T_3 is the supply of only POP NPK at 90:45:45 kg N, P_2O_5 & K_2O ha^{-1} without FYM.

3.2.1.1. Fertilizers

Urea, ammonium sulphate, rajphos, muriate of potash, magnesium sulphate, zinc sulphate and borax were used as the sources for different nutrients. The nutrient content of the fertilizer is given in Table 3.3.

Table 3.3 Sources of nutrients

Nutrients	Fertilizer	Nutrient content (%)
Nitrogen	Urea	46
	Ammonium sulphate	21
Phosphorus	Rajphos	18
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 the Kerala Agricultural University (KAU, 2011). Seeds of the variety Uma were obtained from Regional Agricultural Research Station, Patambi. Twenty three 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 @ 2-3 seedlings/ hill. Date of nursery sowing, transplanting and harvesting are given in table 3.4.

Table 3.4 Sowing and harvesting date of crops

Particulars	Date
Sowing (nursery)	11- 10- 2011
Transplanting	03- 11- 2011
Harvesting	27- 02- 2012

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

Mg, Zn and B spray were given at 20 and 40 DAT of rice according to the treatment. Spray volume used was 250 l ha^{-1}.

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 25 EC per ha) and rice bug (Malathion 1000 ml of 50 EC per ha).

3.3.3 Harvesting

The crops were harvested on 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 done manually 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

Height of ten plants was measured in cm from ground level to the tip of the longest leaf at 30 DAT, 60 DAT and at harvest.

3.4.1.2 Tiller count

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

3.4.1.3 Dry matter production

Six plants were taken for dry matter production. They were cleaned, air dried and then oven dried at 80 ± 5^0C and dry weight was recorded in g at 30 days, 60 days and at harvest.

3.4.1.4 Leaf Area Index (LAI)

Leaf area index is the ratio of leaf area to ground area. The leaf area was calculated using Leaf Area Meter (CI-202 Area Meter) from the randomly selected plants at 60 DAT.

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

3.4.1.5 Number of panicles per hill

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

3.4.1.6 Number of spikelets per panicle

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

3.4.1.7 Percentage of filled grain

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

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

3.4.2. Physiological characters

3.4.2.1 Chlorophyll content

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

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

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

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

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

3.4.3. Chemical analysis

3.4.3.1 Soil analysis

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

3.4.3.2 Plant analysis

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

3.4.4 Economics of cultivation

The cost of cultivation, gross returns and benefit: cost ratio (gross return/cost of cultivation) were 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. 17 and 2 per kg respectively. Benefit cost ratio was worked out by dividing the gross return 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 3.5 Method used for soil analysis

No.	Particulars	Method
1.	Particle size analysis	International Pipette Method (Robinson, 1922)
2.	Soil reaction (pH)	Soil water suspension of 1:2.5 and read in a pH meter (Jackson, 1958)
3	Electrical conductivity	Soil water suspension of 1:2.5 and read in a EC meter (Jackson, 1958)
4.	Organic carbon	Walkley and Black method (Walkley and Black, 1934)
5.	Available N	Alkaline permanganate method (Subbiah and Asija, 1956)
6.	Available P_2O_5	Ascorbic acid reduced molybdophosphoric blue colour method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965)
7.	Available K_2O	Neutral normal ammonium acetate extract using flame photometer (Jackson, 1958)
8.	Available Ca	Neutral normal ammonium acetate extract using Atomic Absorption Spectrophotometer
9.	Available Mg	Neutral normal ammonium acetate extract using Atomic Absorption Spectrophotometer
10.	Available S	$CaCl_2$ extract- turbidimetry method (Chesnin and Yien, 1951)
11.	Available Fe, Zn, Mn & Cu	HCl acid extract method using Atomic Absorption Spectrophotometer (Sims and Johnson, 1991)
12.	Available B	Hot water extraction and Azomethine- H method using Spectrophotometer (Berger and Truog, 1939; Gupta, 1972)

Table 3.6 Method used for plant analysis

No.	Nutrients	Method
1.	N	Microkjeldhal digestion and distillation method (Jackson, 1958)
2.	P	Diacid digestion of leaf sample followed by filtration. Vanadomolybdate phosphoric yellow colour in nitric acid system (Piper, 1966)
3.	K	Diacid extract using flame photometer (Piper, 1966)
4.	Ca	Diacid extract using Atomic Absorption Spectrophotometer (Piper, 1966)
5.	Mg	Diacid extract using Atomic Absorption Spectrophotometer (Piper, 1966)
6.	Fe, Zn, Mn & Cu	Diacid extract using Perkin- Elmer Atomic Absorption Spectrophotometer (Piper, 1966)
7.	B	Determined by dry ashing (Gaines and Mitchell, 1979) and Azomethine – H method (Bingham, 1982)

Plate 1. Field preparation and transplanting of rice seedlings

Plate 2. Foliar application of nutrients at 20 DAT

Plate 3. General view of the experimental plot at 30 DAT

Plate 4. General view of the experimental plot at harvest

Results

IV. RESULTS

A field experiment to compare the efficiency of soil and foliar applied nutrients in irrigated rice of Palakkad was conducted during the second crop season of 2011-2012 in farmer's field, Thathamangalam, Palakkad. The data obtained from the experiment are described here with appropriate tables after statistical analysis.

4.1 Crop growth factors

4.1.1 Plant height

The effect of various treatments on height of plants at 30 and 60 DAT and at harvest are given in table 4.1. The height recorded by the treatments at 30 DAT were on par except the control. The height ranged between 41 and 50 cm. The height at 60 DAT also followed similar trend and it ranged from 59.71 (T_0) to 73.54 cm (T_6). At harvest stage, there were some marked differences in height (76.66 to 89.31 cm) due to various treatments and POP NPK+ $MgSO_4$ at 80 kg ha^{-1} (T_5), 20 kg $ZnSO_4$ ha^{-1} (T_6) and $MgSO_4$ at 1% foliar spray (T_{11}) produced the tallest plants.

The application of either $MgSO_4$ (80 kg ha^{-1}) or $ZnSO_4$ (20 kg ha^{-1}) along with POP NPK recorded more height compared to other levels. Application of borax at 10 & 20 kg ha^{-1} did not show any difference. The shortest plants were seen in the control plot (76.66cm).

4.1.2 Tiller count and Tiller decline

The data regarding the effects 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. All the treatments showed significantly similar tiller count at 30 DAT except the control. The application of POP NPK along with FYM (T_2) recorded higher tiller count (13.40) and the lowest was in control (8.03).

Table 4.1 Effect of treatments on plant height (cm)

	Treatments	30DAT	60DAT	Harvest
T0	Absolute control	41.53[b]	59.71[b]	76.66[c]
T1	Soil test based all nutrient package inclusive of FYM	47.96[a]	68.76[a]	85.6[ab]
T2	Existing POP inclusive of FYM	49.30[a]	71.35[a]	85.05[ab]
T3	POP NPK	48.50[a]	69.14[a]	88.26[ab]
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	48.57[a]	70.94[a]	87.28[ab]
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	50.24[a]	72.69[a]	88.46[a]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	50.51[a]	73.54[a]	89.31[a]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	47.38[a]	69.44[a]	84.70[ab]
T8	POP NPK + Borax 10 kg ha^{-1}	47.96[a]	71.67[a]	87.26[ab]
T9	POP NPK + Borax 20 kg ha^{-1}	47.99[a]	69.99[a]	87.49[ab]
T10	POP NPK + $MgSO_4$ foliar - 0.50%	48.14[a]	69.86[a]	86.45[ab]
T11	POP NPK + $MgSO_4$ foliar - 1.00%	47.14[a]	72.08[a]	88.64[a]
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	49.69[a]	69.05[a]	84.94[ab]
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	48.32[a]	68.57[a]	85.95[ab]
T14	POP NPK + Borax foliar - 0.25 %	47.47[a]	70.97[a]	84.07[ab]
T15	POP NPK + Borax foliar - 0.50%	47.10[a]	67.65[a]	82.90[b]

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

Table 4.2 Effect of treatments on tiller count and tiller decline

Treatments		30DAT	60DAT	Harvest	Tiller decline from 60DAT - harvest (%)
T0	Absolute control	8.03[b]	9.13[d]	6.90[d]	23.85[a]
T1	Soil test based all nutrient package inclusive of FYM	12.90[a]	12.03[abc]	10.80[abc]	9.87[def]
T2	Existing POP inclusive of FYM	13.40[a]	12.30[abc]	11.30[ab]	8.06[f]
T3	POP NPK	12.70[a]	12.00[abc]	10.35[bc]	13.78[cd]
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	13.10[a]	12.47[abc]	10.47[abc]	16.09[bc]
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	12.17[a]	13.10[ab]	10.97[abc]	16.30[bc]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	13.13[a]	13.30[a]	11.37[ab]	14.55[cd]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	12.53[a]	11.83[bc]	10.13[bc]	14.40[cd]
T8	POP NPK + Borax 10 kg ha^{-1}	11.87[a]	11.70[bc]	9.50[c]	17.90[b]
T9	POP NPK + Borax 20 kg ha^{-1}	12.30[a]	11.80[bc]	10.43[abc]	11.56[de]
T10	POP NPK + $MgSO_4$ foliar - 0.50%	12.10[a]	11.93[abc]	10.60[abc]	11.05[de]
T11	POP NPK + $MgSO_4$ foliar - 1.00%	12.13[a]	13.10[ab]	11.87[a]	9.42[def]
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	12.07[a]	11.20[c]	10.40[abc]	7.11[f]
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	12.77[a]	12.53[abc]	10.30[bc]	17.60[b]
T14	POP NPK + Borax foliar - 0.25 %	12.20[a]	12.13[abc]	10.43[abc]	13.83[cd]
T15	POP NPK + Borax foliar - 0.50%	11.77[a]	12.43[abc]	10.30[bc]	17.18[b]

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

The tiller count increased from 30 to 60 DAT in some treatments. But it was reduced even when POP inclusive of FYM was applied. The soil application of 20 kg $ZnSO_4$ ha^{-1} showed significantly higher tiller count (13.30) at 60 DAT.

At harvest stage more productive tillers were observed by the foliar application of 1% $MgSO_4$ (11.87), which was on par with 20 kg $ZnSO_4$ ha^{-1} (11.37) and POP NPK + FYM (11.30). The control treatments had the lowest productive tillers (6.9). In all the other treatments the number of productive tillers ranged from 9.50 to 11.87.

The tiller decline from 60 DAT to harvest was very high in control plot compared to other treatments. It was the least in T_{12} (POP NPK+ 0.5% $ZnSO_4$) and T_2 (POP NPK +FYM).

4.1.3 Leaf area index (LAI)

The data on LAI are given in table 4.3. All the treatments showed similar LAI except the control at 60 DAT. The soil application of 10 kg borax ha^{-1} showed relatively higher LAI (4.86) followed by soil test based nutrient application (T_1) and POP NPK +FYM (T_2) and the least was in control treatment (3.26).

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. The soil application of 20 kg borax ha^{-1} (T_9) and POP NPK +FYM (T_2) recorded comparatively higher chlorophyll a (2.95 mg kg^{-1}), Chlorophyll b (0.77 mg kg^{-1}) and total chlorophyll (3.67 mg kg^{-1}) and the least was in control treatment (1.91 mg kg^{-1}).

4.1.5 Dry matter production

The dry matter obtained at 30 DAT, 60 DAT and at harvest by the application of various treatments are presented in Table 4.5. The dry matter

Table 4.3 Effect of treatments on LAI

Treatments		LAI
T0	Absolute control	3.26[b]
T1	Soil test based all nutrient package inclusive of FYM	4.65[a]
T2	Existing POP inclusive of FYM	4.64[a]
T3	POP NPK	4.27[a]
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	4.07[a]
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	4.36[a]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	4.08[a]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	4.45[a]
T8	POP NPK + Borax 10 kg ha^{-1}	4.86[a]
T9	POP NPK + Borax 20 kg ha^{-1}	4.26[a]
T10	POP NPK + $MgSO_4$ foliar - 0.50%	4.25[a]
T11	POP NPK + $MgSO_4$ foliar - 1.00%	4.33[a]
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	4.26[a]
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	4.20[a]
T14	POP NPK + Borax foliar - 0.25 %	4.32[a]
T15	POP NPK + Borax foliar - 0.50%	4.82[a]

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

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

Treatments		Chl. a	Chl. b	Total chl.
T0	Absolute control	1.9^{b}	0.42^{b}	2.33^{b}
T1	Soil test based all nutrient package inclusive of FYM	2.67^{a}	0.66^{a}	3.47^{a}
T2	Existing POP inclusive of FYM	2.69^{a}	0.64^{a}	3.44^{a}
T3	POP NPK	2.55^{a}	0.48^{ab}	2.34^{ab}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	2.51^{a}	0.79^{a}	3.29^{a}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	2.56^{a}	0.51^{a}	3.06^{a}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	2.41^{a}	0.51^{a}	2.92^{a}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	2.43^{a}	0.63^{a}	3.05^{a}
T8	POP NPK + Borax 10 kg ha^{-1}	2.02^{ab}	0.48^{ab}	2.49^{ab}
T9	POP NPK + Borax 20 kg ha^{-1}	2.95^{a}	0.77^{a}	3.67^{a}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	2.39^{a}	0.52^{a}	2.89^{a}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	2.44^{a}	0.53^{a}	2.97^{a}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	2.63^{a}	0.58^{a}	3.20^{a}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	2.11^{ab}	0.42^{b}	2.72^{a}
T14	POP NPK + Borax foliar - 0.25 %	2.43^{a}	0.51^{a}	3.04^{a}
T15	POP NPK + Borax foliar - 0.50%	2.68^{a}	0.62^{a}	3.29^{a}

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

produced by the treatments at 30 DAT were on par except the control. The soil applied $MgSO_4$ at 40 kg ha^{-1} produced higher dry matter (1.18 t ha^{-1}) followed by $ZnSO_4$ at 20 kg ha^{-1} and POP NPK +FYM, which were on par. The dry matter obtained by the soil and foliar application of nutrients were on par at 30 DAT. The control treatment produced the least dry matter (0.59 t ha^{-1}).

The application of POP NPK + FYM (T_2) recorded the highest dry matter at 60 DAT and at harvest with 5.21 t ha^{-1} and 16.40 t ha^{-1} respectively. T_{12} also produced high dry matter per hectare. The lowest dry matter was noted in control treatment at all the three stages.

4.2 Yield attributes

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 obtained by the foliar application of 1% $MgSO_4$ (11.87).. However this was on par with 20 kg $ZnSO_4$ ha^{-1}, POP NPK + FYM and soil test based nutrients + FYM. The control treatment resulted in the lowest number of productive tillers (6.9).

4.2.2 Spikelets/panicle

The effect of various treatments on spikelets/panicle is shown in table 4.6. The number of spikelets ranged from 78 to 99. The soil application of $MgSO_4$ at 80 kg ha^{-1} (T_5) recorded significantly higher number of spikelets/ panicle (99.15). The number of spikelets/ panicle by the application of 30 kg $ZnSO_4$ ha^{-1}, 1% $ZnSO_4$ were on par with T_5. The absolute control recorded the lowest number of spikelets/panicle (78.94).

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 was observed with foliar application of 0.25 % borax (93.19%), which was on par with the application of 80 kg $MgSO_4$

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

Treatments		30DAT (t ha^{-1})	60DAT (t ha^{-1})	Harvest (t ha^{-1})
T0	Absolute control	0.59^{b}	3.43^{c}	9.01^{d}
T1	Soil test based all nutrient package inclusive of FYM	1.00^{a}	4.80^{ab}	13.99^{abc}
T2	Existing POP inclusive of FYM	1.08^{a}	5.21^{a}	16.40^{a}
T3	POP NPK	1.11^{a}	4.60^{ab}	14.71^{abc}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	1.18^{a}	4.47^{ab}	14.49^{abc}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	1.13^{a}	4.82^{ab}	15.22^{ab}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	1.15^{a}	4.55^{ab}	14.70^{abc}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	1.02^{a}	4.62^{ab}	13.83^{abc}
T8	POP NPK + Borax 10 kg ha^{-1}	1.07^{a}	4.89^{ab}	15.31^{ab}
T9	POP NPK + Borax 20 kg ha^{-1}	1.02^{a}	4.17^{b}	14.74^{abc}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	0.95^{a}	4.59^{ab}	13.72^{abc}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	0.94^{a}	4.52^{ab}	14.73^{abc}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	1.00^{a}	4.90^{ab}	16.35^{a}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	1.04^{a}	4.74^{ab}	14.83^{abc}
T14	POP NPK + Borax foliar - 0.25 %	1.04^{a}	4.49^{ab}	15.36^{ab}
T15	POP NPK + Borax foliar - 0.50%	0.95^{a}	4.19^{b}	13.08^{bc}

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

Table 4.6 Effect of treatments on yield attributes of rice

Treatments		Panicles /hill	Spikelets/ panicle	Filled grain/ panicle (%)	1000 grain wt.
T0	Absolute control	6.90[d]	78.94[e]	88.38[e]	23.71[e]
T1	Soil test based all nutrient package inclusive of FYM	10.80[abc]	89.43[c]	91.09[cd]	24.32[de]
T2	Existing POP inclusive of FYM	11.30[ab]	93.78[b]	91.74[bcd]	25.36[abc]
T3	POP NPK	10.35[bc]	84.15[d]	90.67[d]	24.03[de]
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	10.47[abc]	89.70[c]	91.49[bcd]	24.74[cd]
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	10.97[abc]	99.15[a]	92.28[abc]	25.78[ab]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	11.37[ab]	95.19[b]	92.42[ab]	25.34[abc]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	10.13[bc]	96.77[ab]	92.30[abc]	25.37[abc]
T8	POP NPK + Borax 10 kg ha^{-1}	9.50[c]	83.97[d]	92.29[abc]	25.74[abc]
T9	POP NPK + Borax 20 kg ha^{-1}	10.43[abc]	86.97[cd]	92.01[abc]	25.84[ab]
T10	POP NPK + $MgSO_4$ foliar - 0.50%	10.60[abc]	88.71[c]	92.45[ab]	26.15[a]
T11	POP NPK + $MgSO_4$ foliar - 1.00%	11.87[a]	86.12[cd]	90.75[d]	26.04[a]
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	10.40[abc]	86.63[cd]	92.39[ab]	25.58[abc]
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	10.30[bc]	97.03[ab]	92.68[ab]	24.23[de]
T14	POP NPK + Borax foliar - 0.25 %	10.43[abc]	89.61[c]	93.19[a]	24.87[bcd]
T15	POP NPK + Borax foliar - 0.50%	10.30[bc]	96.68[ab]	92.16[abc]	25.62[abc]

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

ha^{-1}, 10 kg borax ha^{-1} and 0.5% $ZnSO_4$. The next best treatment was the application of POP NPK+FYM. Foliar application of nutrients recorded comparatively higher percentage of filled grains than soil applied nutrients. The lowest percentage of filled grains was shown by control treatment (88.38%).

4.2.4 Thousand grain weight

The data on thousand weight of grain is shown in table 4.6. The foliar application of 0.5 % $MgSO_4$ recorded significantly higher thousand grain weight (26.15 g), which was on par with 1 % $MgSO_4$. The control treatment resulted in the lowest thousand grain weight (23.71 g).

4.3 Yield

4.3.1 Grain yield

The effect of various treatments on grain yield is shown in table 4.7. The existing POP NPK along with FYM (T_2) application recorded significantly higher yield (7.6 t ha^{-1}), which was on par with the application of 0.50 % $ZnSO_4$, 0.25 % Borax, 10 kg borax ha^{-1} and 1% $MgSO_4$ along with POP NPK. Foliar application of $MgSO_4$ and $ZnSO_4$ recorded higher yield compared to their soil application. Borax at 0.5% foliar application reduced the grain yield compared to 0.25%. Higher level of borax (20 kg ha^{-1}) as soil application also reduced the yield. The lowest yield (4.5 t ha^{-1}) obtained from the absolute control.

4.3.2 Straw yield

The treatment effects on straw yield is shown in table 4.7. The highest straw yield (8.9 t ha^{-1}) was obtained by the foliar application of 0.50 % $ZnSO_4$ along with the POP NPK, which was on par with all other treatments except soil test based nutrient application, 30 kg $ZnSO_4$ ha^{-1} and 0.5% borax and the control. The control plot gave the least grain and straw yield.

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

Treatments		Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	HI
T0	Absolute control	4.50 [d]	4.50 [d]	0.50 [ab]
T1	Soil test based all nutrient package inclusive of FYM	7.11 [ab]	6.88 [c]	0.51 [a]
T2	Existing POP inclusive of FYM	7.63 [a]	8.78 [ab]	0.47 [abc]
T3	POP NPK	6.39 [abc]	8.32 [abc]	0.43 [bc]
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	6.48 [abc]	8.01 [abc]	0.45 [abc]
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	6.93 [ab]	8.29 [abc]	0.45 [abc]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	6.65 [abc]	8.05 [abc]	0.45 [abc]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	6.67 [abc]	7.17 [bc]	0.48 [ab]
T8	POP NPK + Borax 10 kg ha^{-1}	7.22 [ab]	8.09 [abc]	0.47 [ab]
T9	POP NPK + Borax 20 kg ha^{-1}	6.70 [abc]	8.03 [abc]	0.46 [abc]
T10	POP NPK + $MgSO_4$ foliar - 0.50%	6.02 [c]	7.70 [abc]	0.44 [c]
T11	POP NPK + $MgSO_4$ foliar - 1.00%	7.07 [ab]	7.65 [abc]	0.48 [ab]
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	7.37 [a]	8.98 [a]	0.45 [abc]
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	7.11 [ab]	7.72 [abc]	0.48 [ab]
T14	POP NPK + Borax foliar - 0.25 %	7.17 [ab]	8.19 [abc]	0.47 [ab]
T15	POP NPK + Borax foliar - 0.50%	5.97 [bc]	7.11 [bc]	0.46 [abc]

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

4.4 Harvest Index

The effect of various treatments on HI is shown in table 4.7. The application of nutrients based on soil test recorded the highest harvest index (0.51), which was on par with all other treatments except the application of $MgSO_4$ at 40 kg ha^{-1} and 0.5% foliar spray. The foliar spray of $MgSO_4$ at 0.5 % recorded the least harvest index (0.40).

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. Though the N content varied from 2.68% in absolute control to 3.40% in borax application (20 kg ha^{-1}) at 30 DAT the difference was not statistically significant. Similarly the N content of plants varied from 1.91% in absolute control to 2.34% in $ZnSO_4$ @ 1% foliar application at 60 DAT. N content in grain varied significantly due to treatments but in the straw there was not much significant difference.

N content in grain was the highest in foliar applied $MgSO_4$ at 1% with 1.43% (T_{11}), which was on par with soil test based nutrient application (T_1) and 80 kg $MgSO_4$ ha^{-1} (T_5). The absolute control treatment resulted in the lowest N content in grain (0.85%).

4.5.2 Phosphorus

The phosphorus content of plant analyzed at 30 DAT, 60 DAT and at harvest are shown in table 4.9. P content varied from 0.17% to 0.25% at 30 DAT. The highest P content at 30 DAT was observed in soil test based nutrient application (T_1) and 1% foliar applied $MgSO_4$ (T_{11}) with 0.25%. At 60 DAT, P content was highest in soil applied $MgSO_4$ at 40 kg ha^{-1} (0.29%), which was on par with 0.25 % foliar applied borax and POP NPK + FYM.

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

Treatments		30 DAT	60 DAT	Harvest	
				Grain	Straw
T0	Absolute control	2.68 [a]	1.91 [a]	0.85 [f]	0.54 [a]
T1	Soil test based all nutrient package inclusive of FYM	3.00 [a]	2.05 [a]	1.42 [ab]	0.59 [a]
T2	Existing POP inclusive of FYM	2.95 [a]	2.29 [a]	1.32 [c]	0.64 [a]
T3	POP NPK	2.98 [a]	2.04 [a]	1.22 [d]	0.59 [a]
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	3.05 [a]	2.17 [a]	1.22 [d]	0.57 [a]
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	3.07 [a]	2.15 [a]	1.41 [ab]	0.55 [a]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	3.10 [a]	2.37 [a]	1.08 [e]	0.60 [a]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	3.00 [a]	2.08 [a]	1.39 [abc]	0.59 [a]
T8	POP NPK + Borax 10 kg ha^{-1}	3.11 [a]	2.07 [a]	1.34 [bc]	0.57 [a]
T9	POP NPK + Borax 20 kg ha^{-1}	3.40 [a]	2.29 [a]	1.23 [d]	0.60 [a]
T10	POP NPK + $MgSO_4$ foliar - 0.50%	2.68 [a]	1.99 [a]	1.16 [d]	0.56 [a]
T11	POP NPK + $MgSO_4$ foliar - 1.00%	3.17 [a]	2.25 [a]	1.43 [a]	0.52 [a]
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	3.37 [a]	2.06 [a]	1.04 [e]	0.60 [a]
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	3.18 [a]	2.34 [a]	1.16 [d]	0.61 [a]
T14	POP NPK + Borax foliar - 0.25 %	3.25 [a]	1.99 [a]	1.17 [d]	0.56 [a]
T15	POP NPK + Borax foliar - 0.50%	2.94 [a]	2.10 [a]	1.23 [d]	0.64 [a]

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

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

Treatments		30DAT	60DAT	Harvest	
				Grain	Straw
T0	Absolute control	0.17 d	0.17 h	0.21 e	0.12 e
T1	Soil test based all nutrient package inclusive of FYM	0.25 a	0.23 cde	0.22 de	0.17 cd
T2	Existing POP inclusive of FYM	0.21 abc	0.27 abc	0.25 cde	0.18 bcd
T3	POP NPK	0.22 abc	0.21 defg	0.27 bcde	0.21 ab
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	0.21 abc	0.29 a	0.34 a	0.15 d
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	0.19 cd	0.22 defg	0.25 cde	0.15 d
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	0.24 ab	0.23 cde	0.29 abc	0.19 abc
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	0.21 abc	0.24 cde	0.27 bcde	0.20 abc
T8	POP NPK + Borax 10 kg ha^{-1}	0.23 ab	0.21 defg	0.32 ab	0.15 d
T9	POP NPK + Borax 20 kg ha^{-1}	0.21 abc	0.19 fgh	0.28 bcd	0.18 bcd
T10	POP NPK + $MgSO_4$ foliar - 0.50%	0.22 abc	0.20 efgh	0.32 ab	0.17 bcd
T11	POP NPK + $MgSO_4$ foliar - 1.00%	0.25 a	0.25 bcd	0.25 cde	0.21 ab
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	0.21 abc	0.25 bcd	0.26 bcde	0.19 abc
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	0.21 abc	0.20 efgh	0.23 cde	0.17 cd
T14	POP NPK + Borax foliar - 0.25 %	0.21 abc	0.28 ab	0.28 bcd	0.23 a
T15	POP NPK + Borax foliar - 0.50%	0.21 abc	0.19 gh	0.29 abc	0.23 a

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

The soil applied $MgSO_4$ at 40 kg ha^{-1} showed significantly higher P content in grain (0.34%), which was on par with the application of 10 kg borax ha^{-1} and 0.5% Mg SO_4.

The foliar applied borax at 0.25% and 0.5% recorded the highest P content in straw (0.23%), which was on par with 1% $MgSO_4$ and POP NPK. The control treatment recorded the least P content in all the stages.

4.5.3 Potassium

The potassium content of plant noted in 30 DAT, 60 DAT and at harvest are presented in table 4.10. The application of POP NPK along with FYM (T_2) recorded the highest K content at 30 DAT (2.83 %). It was on par with POP without FYM and POP along with 1% $ZnSO_4$ foliar application.

At 60 DAT, the soil test based nutrient application showed the highest K content (2.20%), which was on par with the application of POP NPK +FYM (T_2), 10 and 20 kg borax ha^{-1} (T_8 & T_9) and 1% $ZnSO_4$ (T_{13}). The foliar applied 0.5% $MgSO_4$ and control treatment recorded the lowest K content 1.65% and 1.74% respectively, which were on par.

The K content in grain was highest in soil test based nutrient application (0.31%), which was on par with the application POP NPK with and without FYM, 20 kg borax ha^{-1} and 0.5% & 1% $ZnSO_4$. The highest K content in straw was noted in foliar application of 1% $ZnSO_4$ (2.08 %), which was on par with POP NPK +FYM (T_2). The lowest K content was shown by control treatment in all the stages.

4.5.4 Calcium

The effect of various treatments on Ca content in plant at 30 DAT, 60 DAT and at harvest are shown in table 4.11. The soil application of 30 kg $ZnSO_4$ ha^{-1} recorded significantly higher Ca content (5798 mg kg^{-1}) at 30 DAT followed by soil test based nutrient application (5248 mg kg^{-1}) . The Ca content

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

Treatments		30DAT	60DAT	Harvest	
				Grain	Straw
T0	Absolute control	2.28[e]	1.74[ef]	0.22[c]	1.52[g]
T1	Soil test based all nutrient package inclusive of FYM	2.27[e]	2.20[a]	0.31[a]	1.57[g]
T2	Existing POP inclusive of FYM	2.83[a]	2.11[ab]	0.27[abc]	2.00[ab]
T3	POP NPK	2.80[ab]	1.98[bcd]	0.27[abc]	1.56[g]
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	2.76[ab]	1.99[bcd]	0.26[abc]	1.74[def]
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	2.58[abcd]	1.87[cde]	0.24[bc]	1.58[fg]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	2.60[abcd]	1.96[bcd]	0.23[bc]	2.04[a]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	2.37[de]	2.04[abcd]	0.25[abc]	1.91[abc]
T8	POP NPK + Borax 10 kg ha^{-1}	2.69[abc]	2.11[ab]	0.25[abc]	1.67[efg]
T9	POP NPK + Borax 20 kg ha^{-1}	2.50[bcde]	2.11[ab]	0.28[abc]	1.74[def]
T10	POP NPK + $MgSO_4$ foliar - 0.50%	2.43[cde]	1.65[f]	0.25[bc]	1.97[ab]
T11	POP NPK + $MgSO_4$ foliar - 1.00%	2.74[ab]	1.87[cde]	0.26[abc]	1.87[bcd]
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	2.59[abcd]	1.83[def]	0.28[abc]	1.85[bcd]
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	2.81[ab]	2.06[abc]	0.28[abc]	2.08[a]
T14	POP NPK + Borax foliar - 0.25 %	2.69[abc]	1.98[bcd]	0.24[bc]	1.76[cde]
T15	POP NPK + Borax foliar - 0.50%	2.74[ab]	1.94[bcde]	0.29[ab]	1.87[bcd]

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

Table 4.11 Effect of treatments on calcium content of rice plant (mg kg^{-1})

Treatments		30DAT	60DAT	Harvest	
				Grain	Straw
T0	Absolute control	4319^{fg}	5018^{f}	96^{g}	4028^{i}
T1	Soil test based all nutrient package inclusive of FYM	5248^{b}	5739^{b}	143^{e}	5378^{b}
T2	Existing POP inclusive of FYM	4423^{e}	5578^{c}	129^{f}	5437^{ab}
T3	POP NPK	4337^{f}	5437^{d}	100^{g}	4615^{d}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	3208^{i}	3571^{k}	143^{e}	3425^{j}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	4374^{ef}	4699^{hi}	148^{d}	4573de
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	3486^{h}	3610^{k}	160^{b}	5411^{ab}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	5798^{a}	5984^{a}	167^{a}	5481^{a}
T8	POP NPK + Borax 10 kg ha^{-1}	4578^{cd}	5324^{e}	130^{f}	4935^{c}
T9	POP NPK + Borax 20 kg ha^{-1}	4553^{d}	4707^{hi}	131^{f}	4624^{d}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	4639^{c}	5638^{c}	154^{c}	4473^{fg}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	4254^{g}	4379^{j}	161^{b}	4388^{h}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	4352^{ef}	4818^{g}	160^{b}	4405^{gh}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	4556^{d}	4685^{hi}	158^{bc}	4621^{d}
T14	POP NPK + Borax foliar - 0.25 %	4576^{cd}	4756^{gh}	133^{f}	4518^{ef}
T15	POP NPK + Borax foliar - 0.50%	4586^{cd}	4658^{i}	132^{f}	4385^{h}

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

was lowest in soil applied $MgSO_4$ at 40 kg ha^{-1}(3208 mg kg^{-1}). The Ca content at 60 DAT followed similar trend. There was a gradual increase in Ca content from 30 to 60 DAT. Here also the soil applied $ZnSO_4$ at 30 kg ha^{-1} recorded the highest Ca content (5984 mg kg^{-1}) and the lowest was in soil applied $MgSO_4$ at 40 kg ha^{-1} (3575 mg kg^{-1}).

The soil applied $ZnSO_4$ at 30 kg ha^{-1} showed the highest Ca content in grain (167 mg kg^{-1}). Application of $ZnSO_4$ either in soil or as foliar noted higher Ca content in grain compared to other treatments. The absolute control recorded the least Ca content (96 mg kg^{-1}) which was comparable to POP NPK application.

Ca content in straw was significantly higher in soil applied $ZnSO_4$ at 30 kg ha^{-1} (5481 mg kg^{-1}), which was on par with 20 kg $ZnSO_4$ and POP NPK along with FYM. Soil applied $MgSO_4$ at 40 kg ha^{-1}recorded the lowest Ca content in straw (3425 mg kg^{-1}) even less than absolute control indicating antagonism between Ca & Mg. Ca content in grain was very much lower than that in straw.

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. Throughout the growth stages application of $MgSO_4$ showed a higher content of Mg in the plant when it was applied as soil or foliar. The highest Mg content was noted in T_5 (POP NPK + $MgSO_4$ @ 80 kg ha^{-1}). During 30 DAT, T_5 recorded 1709 mg kg^{-1} Mg content followed by 1579 mg $kg^{-1}$where 1% $MgSO_4$ (T_{11}) was applied as foliar. At 60 DAT, T_5 recorded 1189 mg kg^{-1} of Mg, which was on par with 1% $MgSO_4$ foliar (T_{11}). Even at harvest the Mg content in the straw was 1338 mg kg^{-1} along with 1085 mg kg^{-1} Mg content in grain. Foliar application of Mg @ 1% also showed higher Mg content along with 0.5% $MgSO_4$ spray. The lowest Mg content was in control treatment in all stages.

Table 4.12 Effect of treatments on Mg content of rice plant (mg kg^{-1})

Treatments		30DAT	60DAT	Harvest	
				Grain	Straw
T0	Absolute control	896^{g}	721^{h}	423^{k}	685^{j}
T1	Soil test based all nutrient package inclusive of FYM	1480^{c}	1056^{bc}	733^{d}	971^{cde}
T2	Existing POP inclusive of FYM	1426^{c}	882^{def}	697^{de}	945^{cdef}
T3	POP NPK	1172^{f}	999^{bc}	613^{fg}	904^{defg}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	1370^{d}	1002^{bc}	837^{c}	1029^{bc}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	1709^{a}	1189^{a}	1085^{a}	1338^{a}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	1362^{d}	949^{cde}	518^{ijh}	836^{fghi}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	1354^{d}	980^{cd}	591^{g}	1001^{bcd}
T8	POP NPK + Borax 10 kg ha^{-1}	1430^{c}	1031^{bc}	663^{ef}	786^{hij}
T9	POP NPK + Borax 20 kg ha^{-1}	1360^{d}	730^{h}	556^{ghi}	801^{ghi}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	1242^{e}	1049^{bc}	1013^{b}	1115^{b}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	1579^{b}	1096^{ab}	978^{b}	1236^{a}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	1218^{ef}	859^{efg}	465^{jk}	881^{efgh}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	1204^{ef}	827^{fgh}	574^{ghi}	1086^{b}
T14	POP NPK + Borax foliar - 0.25 %	1246^{e}	771^{gh}	528^{hij}	763^{ij}
T15	POP NPK + Borax foliar - 0.50%	1198^{ef}	1033^{bc}	810^{c}	1011^{bcd}

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

4.5.6 Iron

The effect of various treatments on Fe content of rice plant at 30DAT, 60 DAT and at harvest are shown in table 4.13. Since rice was grown on acidic soil the content of Fe was very high in the plant at all stages. The highest Fe content was noted in plot where $ZnSO_4$ at 30 kg ha^{-1} (T_7) was applied along with POP NPK application. The soil application of 30 kg $ZnSO_4$ ha^{-1} showed significantly higher plant Fe content. At 30 DAT, T_7 recorded 2445 mg kg^{-1} of Fe and the lowest Fe content was observed in soil applied borax at 10 kg ha^{-1} (591.3 mg kg^{-1}).

At 60 DAT, the Fe content in plant got reduced considerably in all the treatments and there was further reduction in Fe content in straw towards harvest and it was significantly higher in 30 kg $ZnSO_4$ ha^{-1} (831 mg kg^{-1}) at 60 DAT. The lowest Fe content was noticed in 0.5% foliar applied borax (348 mg kg^{-1}).

The Fe content in grain was more than sufficient according to the earlier reported values indicating rich source of Fe inherent in the soil. In the existing POP inclusive of FYM the Fe content in grain was 164 mg kg^{-1} where as in control it was only 138 mg kg^{-1} which was the lowest content.

4.5.7 Manganese

The manganese content of rice plant analyzed at 30 DAT, 60 DAT and at harvest are shown in table 4.14. The Mn content was highest in POP NPK along with FYM (T_2) at all the stages of rice plants including the grain. in all the three stages. The Mn content recorded by T_2 at 30 DAT, 60 DAT and at harvest (grain and straw) was 292.50 mg kg^{-1}, 293.42 mg kg^{-1}, 97.69 and 194.42 mg kg^{-1} respectively. The lowest Mn content was noted in soil applied $MgSO_4$ at 40 kg ha^{-1} at 30 and 60 DAT with 160.96 mg kg^{-1} and 118.61 mg kg^{-1} respectively.

Table 4.13 Effect of treatments on Fe content of rice plant (mg kg^{-1})

Treatments		30DAT	60DAT	Harvest	
				Grain	Straw
T0	Absolute control	1340[e]	773[ab]	138[h]	412[cde]
T1	Soil test based all nutrient package inclusive of FYM	784[k]	481[de]	235[de]	337[ef]
T2	Existing POP inclusive of FYM	1041[ij]	495[de]	164[g]	379[def]
T3	POP NPK	1215[fg]	494[de]	274[c]	328[f]
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	1164[gh]	780[ab]	312[b]	436[cd]
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	692[k]	552[cd]	321[ab]	463[bc]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	1937[b]	461[ef]	310[b]	418[cd]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	2445[a]	831[a]	334[a]	555[a]
T8	POP NPK + Borax 10 kg ha^{-1}	591[l]	490[de]	305[b]	524[bc]
T9	POP NPK + Borax 20 kg ha^{-1}	1478[d]	579[c]	220[ef]	232[g]
T10	POP NPK + $MgSO_4$ foliar - 0.50%	1127[ghi]	469[e]	236[de]	310[f]
T11	POP NPK + $MgSO_4$ foliar - 1.00%	1756[c]	398[fgh]	242[d]	542[a]
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	1078[hij]	756[b]	269[c]	375[def]
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	986[j]	436[efg]	279[c]	374[def]
T14	POP NPK + Borax foliar - 0.25 %	1309[ef]	390[gh]	207[f]	302[fg]
T15	POP NPK + Borax foliar - 0.50%	1052[ij]	348[h]	324[ab]	337[ef]

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

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

Treatments		30DAT	60DAT	Harvest	
				Grain	Straw
T0	Absolute control	277.56^{b}	160.50^{e}	50.58^{g}	149.33^{cd}
T1	Soil test based all nutrient package inclusive of FYM	294.79^{a}	203.64^{bc}	85.64^{b}	105.70^{g}
T2	Existing POP inclusive of FYM	292.50^{a}	293.42^{a}	97.69^{a}	194.42^{a}
T3	POP NPK	173.06^{g}	118.61^{f}	40.38^{h}	98.24^{g}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	160.96^{h}	159.79^{e}	62.53^{f}	98.86^{g}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	188.89^{f}	157.09^{e}	77.86^{bc}	129.85^{ef}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	232.17^{d}	147.54^{e}	78.52^{bc}	139.65 [illegible]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	183.38^{f}	153.70^{ef}	65.21^{ef}	142.14 [illegible]
T8	POP NPK + Borax 10 kg ha^{-1}	190.58^{f}	215.68^{b}	68.23^{def}	178.47^{b}
T9	POP NPK + Borax 20 kg ha^{-1}	276.52^{b}	134.09^{fg}	75.41^{cd}	113.50^{fg}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	171.95^{g}	195.39^{cd}	75.73^{cd}	162.20^{bc}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	190.69^{f}	181.67^{d}	61.85^{f}	160.58^{c}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	231.38^{d}	184.25^{d}	72.78^{cde}	128.34^{ef}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	215.97^{e}	218.28^{b}	74.78^{cd}	139.28^{de}
T14	POP NPK + Borax foliar - 0.25 %	228.10^{d}	191.46^{cd}	62.63^{f}	163.72^{bc}
T15	POP NPK + Borax foliar - 0.50%	240.85^{c}	206.60^{bc}	75.28^{cd}	191.27^{a}

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

It is interesting to note that in the plot which received only POP NPK, the Mn content in plant was less compared to even absolute control towards the later part of the crop growth.

4.5.8 Zinc

The data on Zn content of plant at 30 DAT, 60 DAT and at harvest are shown in table 4.15. At 30 DAT, the application of nutrients based on soil test recorded significantly higher Zn content at 30 DAT (51.89 mg kg^{-1}) followed by 1% foliar spray of $ZnSO_4$ (47.12 mg kg^{-1}).

During 60 DAT, Zn content was highest in 1% foliar spray of (48.60 mg kg^{-1}), which was on par with soil test based nutrient application (T_1). The foliar spray of 1% $ZnSO_4$ recorded the highest Zn content in grain and straw (11.62 & 84.96 mg kg^{-1}). Generally the Zn content in rice plant was higher in foliar application compared to the soil application of $ZnSO_4$. The control treatment showed the least Zn content in grain and straw (6.25 & 25.16 mg kg^{-1}). The application of nutrients increased the Zn content in rice plants compared to control.

4.5.9 Boron

The data on boron content in rice plant at 30 DAT, 60 DAT and at harvest are shown in table 4.16. The soil application of 10 kg borax ha^{-1} (T_8) recorded significantly higher B content at 30 DAT, 60 DAT and at harvest. The B content recorded by T_8 at 30 DAT was 4.88 mg kg^{-1}. The plot received soil test based nutrient application inclusive of FYM also showed high content of B in plants.

There was an increase in boron content from 30 to 60 DAT. The soil test based nutrient application showed significantly higher boron content (7.22 mg kg^{-1}), which was on par with soil applied borax at 10 kg ha^{-1} (6.98 mg kg^{-1}). Soil application of borax recorded relatively higher boron content than foliar at 60 DAT.

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

	Treatments	30DAT	60DAT	Harvest	
				Grain	Straw
T0	Absolute control	14.52[j]	21.74[g]	6.25[f]	25.16[h]
T1	Soil test based all nutrient package inclusive of FYM	51.89[a]	45.92[ab]	6.63[f]	39.50[c]
T2	Existing POP inclusive of FYM	36.13[fg]	24.12[fg]	8.87[d]	36.66[def]
T3	POP NPK	34.99[g]	25.01[f]	9.94[bc]	34.66[f]
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	20.82[i]	24.85[fg]	10.45[b]	36.36[def]
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	21.17[i]	23.24[fg]	9.79[c]	36.54[def]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	40.18[cde]	38.70[c]	10.39[bc]	37.37[cde]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	41.48[cd]	44.19[b]	11.80[a]	39.46[c]
T8	POP NPK + Borax 10 kg ha^{-1}	25.23[h]	30.71[e]	12.08[a]	34.80[ef]
T9	POP NPK + Borax 20 kg ha^{-1}	27.53[h]	25.20[f]	11.56[a]	37.94[cd]
T10	POP NPK + $MgSO_4$ foliar - 0.50%	42.89[c]	33.30[de]	11.65[a]	36.62[def]
T11	POP NPK + $MgSO_4$ foliar - 1.00%	36.56[efg]	35.36[d]	9.79[c]	52.94[b]
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	39.28[cdef]	39.89[c]	11.52[a]	54.20[b]
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	47.12[b]	48.60[a]	11.62[a]	84.96[a]
T14	POP NPK + Borax foliar - 0.25 %	38.02[defg]	30.34[e]	8.87[d]	34.08[f]
T15	POP NPK + Borax foliar - 0.50%	38.97[def]	34.96[d]	7.34[e]	31.60[g]

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

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

Treatments		30DAT	60DAT	Harvest	
				Grain	Straw
T0	Absolute control	2.20[g]	3.64[f]	2.56[h]	4.81[f]
T1	Soil test based all nutrient package inclusive of FYM	4.26[c]	7.22[a]	6.62[a]	9.40[a]
T2	Existing POP inclusive of FYM	3.32[f]	5.29[d]	4.32[fg]	7.97[b]
T3	POP NPK	3.36[f]	4.42[e]	4.06[g]	6.46[cd]
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	3.48[f]	4.57[e]	5.78[bcd]	6.24[cde]
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	3.67[de]	4.80[de]	5.51[de]	5.92[cde]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	3.48[ef]	4.61[e]	4.62[f]	5.60[e]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	3.34[f]	4.44[e]	4.17[g]	6.58[c]
T8	POP NPK + Borax 10 kg ha^{-1}	4.88[a]	6.98[ab]	6.68[a]	9.91[a]
T9	POP NPK + Borax 20 kg ha^{-1}	4.53[b]	6.25[c]	6.06[b]	9.37[a]
T10	POP NPK + $MgSO_4$ foliar - 0.50%	3.56[def]	4.46[e]	5.90[bc]	6.11[cde]
T11	POP NPK + $MgSO_4$ foliar - 1.00%	3.38[f]	4.60[e]	5.26[e]	5.73[de]
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	3.45[ef]	4.40[e]	5.59[cde]	5.89[cde]
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	3.38[f]	4.55[e]	5.63[cd]	5.67[e]
T14	POP NPK + Borax foliar - 0.25 %	3.64[de]	6.11[c]	6.46[a]	8.54[b]
T15	POP NPK + Borax foliar - 0.50%	3.80[d]	6.61[bc]	6.49[a]	9.45[a]

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

The soil application of 10 kg borax ha^{-1} (T_8) showed significantly higher boron content in grain and straw (6.68 &9 .91 mg kg^{-1}). The B content in grain and straw recorded by T_8 was on par with 0.5 % borax and soil test based nutrients. The control treatment recorded the lowest boron content in all the stages.

4.5.10 Copper

The copper content at 30 DAT, 60 DAT and at harvest are presented in table 4.17. The application of POP NPK along with FYM (T_2) recorded significantly higher Cu content at 30 DAT, 60 DAT and at harvest. T_2 recorded Cu content of 7.92 mg kg^{-1} &13.13 mg kg^{-1} at 30 & 60 DAT respectively. The Cu content in plant was more at 60 DAT compared to 30 DAT even when the biomass went on increasing indicating that high rate of absorption of Cu was taking place from the soil. The least was recorded in control treatment (1.80 mg kg^{-1} & 3.84 mg kg^{-1}).

The Cu content in grain was less than that in straw in all the treatments and it was least in the control plot. When $ZnSO_4$ was applied either soil or as foliar, the Cu content in grain is reduced without showing much difference in straw.

4.6 Nutrient uptake

4.6.1 Nitrogen

The data pertaining to nitrogen uptake by the crop at harvest is shown in table 4.18. The foliar spray of 1% $MgSO_4$ showed significantly higher N uptake by grain (101.45 kg ha^{-1}), which was on par with soil test based nutrient application (T_1) and POP NPK along with FYM (T_2). The lowest N uptake in grain was recorded in control treatment (38.41 kg ha^{-1}).

The highest N uptake in straw was observed in POP NPK application along with FYM (55.74 kg ha^{-1}), which was on par with foliar spray of 0.5%

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

	Treatments	30DAT	60DAT	Harvest	
				Grain	Straw
T0	Absolute control	1.88^{i}	3.84^{l}	1.71^{i}	2.78^{c}
T1	Soil test based all nutrient package inclusive of FYM	6.04^{bcd}	4.50^{k}	3.13^{cde}	5.23^{a}
T2	Existing POP inclusive of FYM	7.92^{a}	13.13^{a}	3.75^{a}	5.50^{a}
T3	POP NPK	4.29^{efgh}	9.88^{b}	2.75^{efg}	3.45^{bc}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	5.00^{def}	5.00^{j}	3.00^{def}	4.20^{b}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	3.84^{fgh}	5.88^{gh}	3.29^{abcd}	4.13^{b}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	6.08^{bcd}	6.38^{ef}	2.04^{hi}	4.27^{b}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	3.50^{gh}	5.96^{fgh}	2.34^{gh}	4.07^{b}
T8	POP NPK + Borax 10 kg ha^{-1}	6.21^{bcd}	5.71^{hi}	3.17^{bcde}	5.55^{a}
T9	POP NPK + Borax 20 kg ha^{-1}	3.29^{h}	6.84^{de}	3.00^{def}	5.29^{a}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	4.59^{efg}	5.25^{ij}	3.46^{abcd}	4.25^{b}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	5.09^{efg}	5.67^{hi}	3.67^{ab}	3.47^{bc}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	6.88^{ab}	6.42^{ef}	2.75^{efg}	5.39^{a}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	7.00^{ab}	6.92^{d}	2.54^{fg}	3.83^{b}
T14	POP NPK + Borax foliar - 0.25 %	6.71^{b}	6.34^{fg}	3.54^{abc}	3.85^{b}
T15	POP NPK + Borax foliar - 0.50%	6.29^{bc}	7.92^{c}	3.42^{abcd}	3.90^{b}

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

Table 4.18 Effect of treatments on N uptake by rice (kg ha^{-1})

Treatments		Grain	Straw	Total
T0	Absolute control	38.41^{g}	24.18^{c}	62.58^{e}
T1	Soil test based all nutrient package inclusive of FYM	100.73^{a}	40.49^{b}	141.22^{abc}
T2	Existing POP inclusive of FYM	100.57^{a}	55.74^{a}	156.31^{a}
T3	POP NPK	77.96^{cdef}	48.82^{ab}	126.78^{bcd}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	78.40^{cdef}	45.34^{ab}	123.74^{bcd}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	97.53^{ab}	45.70^{ab}	143.24^{ab}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	71.59^{ef}	48.68^{ab}	120.27^{bcd}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	92.34^{abc}	42.28^{b}	134.63^{abc}
T8	POP NPK + Borax 10 kg ha^{-1}	96.58^{ab}	45.44^{ab}	142.02^{abc}
T9	POP NPK + Borax 20 kg ha^{-1}	82.27^{bcde}	48.56^{ab}	130.83^{bcd}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	64.24^{f}	45.25^{ab}	109.49^{d}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	101.45^{a}	39.85^{b}	141.30^{abc}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	76.39^{def}	54.00^{a}	130.39^{bcd}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	82.40^{bcde}	47.22^{ab}	129.62^{bcd}
T14	POP NPK + Borax foliar - 0.25 %	74.76^{def}	45.97^{ab}	120.73^{bcd}
T15	POP NPK + Borax foliar - 0.50%	73.51^{def}	45.28^{ab}	118.80^{cd}

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

$ZnSO_4$ along with POP NPK. The least N uptake by straw was noticed in control treatment (24.18 kg ha^{-1}). The N uptake in grain was 1.52 to 2 times more than straw. The total uptake of N in absolute control was 62.58 kg ha^{-1} where as it was 160.31 in the case of POP NPK inclusive of FYM.

4.6.2 Phosphorus

The effect of various treatments on P uptake by the crop is presented in table 4.19. The soil application of 10 kg borax ha^{-1} recorded significantly higher P uptake in grain (23.27 kg ha^{-1}), which was on par with $MgSO_4$ at 40 kg ha^{-1} and 0.25 % borax.

P uptake by straw was highest in foliar spray of 0.25 % borax (18.62 kg ha^{-1}), which was on par with foliar spray of $ZnSO_4$ @ 0.5%, $MgSO_4$ @ 1% and POP NPK with or without FYM. The foliar spray of 0.25 % borax recorded significantly higher total P uptake by the rice crop (39.91 kg ha^{-1}) and was on par with the application of POP NPK, POP NPK+FYM, foliar spray of $ZnSO_4$ @ 0.5% and $MgSO_4$ @ 1% . The total uptake of P was least in control (16.96 kg ha^{-1}). The lowest P uptake by crop was noted in control treatment.

4.6.3 Potassium

The effect of treatments on K uptake by the crop is shown in table 4.20. The K uptake by grain was significantly higher in soil test based nutrient application (22.00 kg ha^{-1}), which was on par with POP NPK along with FYM. The control treatment recorded least uptake (12.60 kg ha^{-1}). When $MgSO_4$ was given as 0.5% foliar spray the uptake by grain was very low and it showed a higher uptake by straw. But @ 1% $MgSO_4$ foliar spray it was just the reverse.

The highest K uptake by straw was noticed in 0.5% foliar spray of $ZnSO_4$ (186 kg ha^{-1}), which was on par with the application of $MgSO_4$ at 80 kg ha^{-1} (T_7) and $ZnSO_4$ at 20 kg ha^{-1} (T_6). The lowest was noticed in absolute control (75.1 kg ha^{-1}).

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

Treatments		Grain	Straw	Total
T0	Absolute control	10.50^{f}	4.31^{e}	14.81^{d}
T1	Soil test based all nutrient package inclusive of FYM	16.11^{de}	11.62^{d}	27.72^{c}
T2	Existing POP inclusive of FYM	18.87^{bcde}	15.82^{abcd}	34.69^{abc}
T3	POP NPK	17.25^{cde}	17.77^{ab}	35.02^{abc}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	22.32^{ab}	12.28^{cd}	34.60^{abc}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	17.07^{cde}	12.49^{cd}	29.55^{c}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	19.49^{abcd}	15.08^{abcd}	34.57^{abc}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	18.32^{bcde}	14.40^{abcd}	32.72^{bc}
T8	POP NPK + Borax 10 kg ha^{-1}	23.27^{a}	12.07^{cd}	35.34^{abc}
T9	POP NPK + Borax 20 kg ha^{-1}	18.81^{bcde}	14.51^{abcd}	33.32^{abc}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	17.34^{cde}	14.30^{bcd}	31.64^{bc}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	17.71^{cde}	16.14^{abc}	33.86^{abc}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	19.43^{abcd}	17.55^{ab}	36.99^{ab}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	14.60^{e}	13.53^{bcd}	28.13^{c}
T14	POP NPK + Borax foliar - 0.25 %	20.08^{abc}	18.62^{a}	38.70^{a}
T15	POP NPK + Borax foliar - 0.50%	17.36^{cde}	16.03^{abc}	33.38^{abc}

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

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

Treatments		Grain	Straw	Total
T0	Absolute control	12.60^{e}	75.10^{f}	87.70^{d}
T1	Soil test based all nutrient package inclusive of FYM	22.00^{a}	104.84^{ef}	126.84^{c}
T2	Existing POP inclusive of FYM	20.39^{ab}	139.09^{bcd}	159.48^{bc}
T3	POP NPK	17.25^{abc}	129.73^{cde}	146.98^{bc}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	16.56^{bcde}	139.76^{bcd}	156.32^{bc}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	16.56^{bcde}	165.72^{ab}	182.29^{ab}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	15.63^{cde}	164.06^{abc}	179.69^{ab}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	16.53^{bcde}	137.04^{bcde}	153.56^{bc}
T8	POP NPK + Borax 10 kg ha^{-1}	18.19^{abc}	126.97^{de}	145.16^{bc}
T9	POP NPK + Borax 20 kg ha^{-1}	18.56^{abc}	139.29^{bcd}	157.85^{bc}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	13.72^{de}	160.29^{abcd}	174.01^{ab}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	18.08^{abc}	143.22^{bcd}	161.30^{bc}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	16.32^{bcde}	185.99^{a}	202.31^{a}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	19.97^{ab}	142.76^{bcd}	162.72^{bc}
T14	POP NPK + Borax foliar - 0.25 %	17.21^{abc}	146.09^{bcd}	163.29^{b}
T15	POP NPK + Borax foliar - 0.50%	17.01^{bcd}	132.61^{bcde}	149.62^{bc}

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

The foliar spray of 0.5% $ZnSO_4$ (T_{12}) showed the highest total uptake of K (202.3 kg ha^{-1}), which was on par with 80 kg $MgSO_4$, 20 kg $ZnSO_4$ ha^{-1} and 0.5% $MgSO_4$. Here also, control treatment showed least total uptake of K (87.7 kg ha^{-1}).

4.6.4 Calcium

The data on Ca uptake by the rice crop at harvest is shown in table 4.21. The highest uptake of Ca by grain was observed in the foliar application of 0.5 % $ZnSO_4$ (1.18 kg ha^{-1}) and 1 % $MgSO_4$, which were on par with 30 kg $ZnSO_4$ (T_7). The least uptake was noted in control treatment (0.43 kg ha^{-1}).

The application of POP NPK resulted the highest uptake of Ca by straw (45.24 kg ha^{-1}), which was on par with POP NPK +FYM (T_2) and 0.5% $MgSO_4$ (T_{10}). The control treatment recorded least Ca uptake by straw (19.76 kg ha^{-1}).

The Ca uptake was on par for all the treatments except control and borax 0.5% foliar application. The control treatment showed least total uptake (20.19 kg ha^{-1}). The Ca accumulated in grain was very less compared to total uptake and the calcium left in the straw.

4.6.5 Magnesium

The magnesium uptake by the rice crop at harvest is shown in table 4.22. Mg uptake was more in all the Mg applied plots. The application of nutrients based on soil test recorded significantly higher Mg uptake by grain (7.71 kg ha^{-1}), followed by the foliar spray of $MgSO_4$ at 1% (T_{11}). The table shows that $MgSO_4$ at 1% foliar spray recorded better uptake og Mg in grain and straw. The least uptake was noted in control (1.90 kg ha^{-1}).

Mg uptake by straw was significantly higher in foliar spray of 1% $MgSO_4$ (10.22 kg ha^{-1}), which was on par with 0.5% foliar spray of $MgSO_4$. Foliar application of $MgSO_4$ recorded significantly higher uptake compared to

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

Treatments		Grain	Straw	Total
T0	Absolute control	0.43^{h}	19.76^{f}	20.19^{c}
T1	Soil test based all nutrient package inclusive of FYM	1.02^{abcde}	36.98^{bc}	38.00^{a}
T2	Existing POP inclusive of FYM	0.99^{cdef}	40.50^{abc}	41.48^{a}
T3	POP NPK	0.64^{g}	45.24^{a}	45.88^{a}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	0.93^{cdef}	27.44^{e}	28.37^{b}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	1.03^{abcde}	37.91^{abc}	38.94^{a}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	1.06^{abcd}	36.02^{cd}	37.08^{a}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	1.07^{abc}	35.37^{cd}	36.44^{a}
T8	POP NPK + Borax 10 kg ha^{-1}	0.94^{cdef}	44.34^{ab}	45.28^{a}
T9	POP NPK + Borax 20 kg ha^{-1}	0.88^{defg}	37.14^{bc}	38.02^{a}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	0.85^{efg}	43.99^{ab}	44.85^{a}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	1.18^{a}	33.58^{cde}	34.76^{a}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	1.18^{a}	39.56^{abc}	40.75^{a}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	1.12^{ab}	35.69^{cd}	36.81^{a}
T14	POP NPK + Borax foliar - 0.25 %	0.85^{efg}	36.99^{bc}	37.84^{a}
T15	POP NPK + Borax foliar - 0.50%	0.80^{fg}	28.61^{de}	29.41^{b}

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

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

Treatments		Grain	Straw	Total
T0	Absolute control	1.90^{h}	3.54^{h}	5.44^{g}
T1	Soil test based all nutrient package inclusive of FYM	7.71^{a}	6.67^{efg}	14.39^{bc}
T2	Existing POP inclusive of FYM	5.32^{cd}	8.29^{cde}	13.61^{bcd}
T3	POP NPK	3.92^{efg}	7.52^{def}	11.44^{ef}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	5.43^{c}	8.25^{cde}	13.69^{bcd}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	5.07^{cd}	9.24^{abc}	14.32^{bc}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	3.46^{g}	6.73^{defg}	10.19^{f}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	3.95^{efg}	7.17^{defg}	11.13^{ef}
T8	POP NPK + Borax 10 kg ha^{-1}	4.79^{cde}	5.54^{g}	10.33^{ef}
T9	POP NPK + Borax 20 kg ha^{-1}	3.73^{fg}	6.43^{fg}	10.16^{f}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	5.58^{c}	9.95^{ab}	15.53^{ab}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	6.88^{b}	10.22^{a}	17.10^{a}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	3.43^{g}	7.91^{cdef}	11.34^{ef}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	4.08^{efg}	8.34^{bcd}	12.48^{cde}
T14	POP NPK + Borax foliar - 0.25 %	3.79^{efg}	6.25^{fg}	10.04^{f}
T15	POP NPK + Borax foliar - 0.50%	4.84^{cde}	7.18^{defg}	12.02^{def}

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

soil application. Here also control treatment recorded least uptake of Mg by straw (3.54 kg ha^{-1}).

The total uptake of Mg was higher in foliar spray of 1% $MgSO_4$ (17.10 kg ha^{-1}), followed by 0.5% $MgSO_4$, which were on par. The least Mg uptake was recorded in control treatment (5.44 kg ha^{-1}).

4.6.6 Iron

The effect of various treatments on Fe uptake by the rice crop is shown in table 4.23. The Fe uptake by grain and straw was highest in soil applied 30 kg $ZnSO_4$ ha^{-1} (2.41 kg ha^{-1} & 4.47 kg ha^{-1}), which was on par with the 10 kg borax ha^{-1}. The least uptake by grain and straw were observed in absolute control (0.62 kg ha^{-1} & 1.86 kg ha^{-1}).

The total uptake of Fe by the crop was also highest in 30 kg $ZnSO_4$ ha^{-1} (6.88 kg ha^{-1}), which was on par with10 kg borax ha^{-1} and 20 kg $ZnSO_4$ ha^{-1}. The control treatment showed the lowest uptake of Fe by the crop (2.48 kg ha^{-1}). In those plots where $ZnSO_4$, $MgSO_4$ and borax at lower dose were applied there was better Fe uptake by rice.

4.6.7 Manganese

The uptake of Mn by the application of various treatments are shown in table 4.24. The application of POP NPK + FYM recorded the highest Mn uptake by grain and straw with 0.69 & 1.56 kg ha^{-1} respectively. The control treatment showed the lowest manganese uptake by grain and straw (0.18 kg ha^{-1} & 0.67 kg ha^{-1}).

The highest total uptake of Mn by rice crop was observed in POP NPK + FYM (2.25 kg ha^{-1}), which was on par with soil applied borax at 10 kg ha^{-1}. The control recorded the lowest Mn uptake (0.85 kg ha^{-1}). The table also showed that the Mn uptake was less than Fe uptake.

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

Treatments		Grain	Straw	Total
T0	Absolute control	0.62^{h}	1.86^{f}	2.48^{g}
T1	Soil test based all nutrient package inclusive of FYM	1.67^{cdef}	2.35^{ef}	4.03^{ef}
T2	Existing POP inclusive of FYM	1.26^{g}	3.32^{bcde}	4.58^{cdef}
T3	POP NPK	1.75^{cde}	2.74^{def}	4.49^{cdef}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	2.02^{abc}	3.51^{abcd}	5.53^{abcd}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	2.23^{ab}	3.85^{abc}	6.08^{ab}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	2.06^{abc}	3.00^{cde}	6.53^{a}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	2.41^{a}	4.47^{a}	6.88^{a}
T8	POP NPK + Borax 10 kg ha^{-1}	2.03^{abc}	4.24^{ab}	6.27^{a}
T9	POP NPK + Borax 20 kg ha^{-1}	1.47^{efg}	1.86^{f}	3.33^{fg}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	1.30^{fg}	2.56^{def}	3.86^{ef}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	1.71^{cde}	4.15^{ab}	5.86^{abc}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	1.99^{bc}	3.38^{bcde}	5.37^{abcd}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	1.98^{bc}	2.88^{cdef}	4.87^{bcde}
T14	POP NPK + Borax foliar - 0.25 %	1.48^{efg}	2.48^{def}	3.96^{ef}
T15	POP NPK + Borax foliar - 0.50%	1.95^{bcd}	2.40^{ef}	4.34^{def}

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

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

Treatments		Grain	Straw	Total
T0	Absolute control	0.18^{g}	0.67^{f}	0.85^{g}
T1	Soil test based all nutrient package inclusive of FYM	0.61^{ab}	0.72^{f}	1.33^{ef}
T2	Existing POP inclusive of FYM	0.69^{a}	1.56^{a}	2.25^{a}
T3	POP NPK	0.26^{f}	0.82^{ef}	1.08^{f}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	0.40^{ef}	0.79^{ef}	1.20^{f}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	0.54^{bc}	1.08^{d}	1.62^{cde}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	0.52^{bcde}	1.13^{cd}	1.65^{bcd}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	0.44^{cdef}	1.01^{de}	1.45^{def}
T8	POP NPK + Borax 10 kg ha^{-1}	0.49^{bcdef}	1.44^{ab}	1.93^{ab}
T9	POP NPK + Borax 20 kg ha^{-1}	0.51^{bcde}	0.99^{de}	1.50^{def}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	0.42^{def}	1.33^{abc}	1.75^{bcd}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	0.47^{cdef}	1.23^{bcd}	1.70^{bcd}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	0.54^{bcd}	1.15^{cd}	1.68^{bcd}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	0.53^{bcd}	1.07^{d}	1.61^{cde}
T14	POP NPK + Borax foliar - 0.25 %	0.45^{cdef}	1.33^{abc}	1.78^{abc}
T15	POP NPK + Borax foliar - 0.50%	0.45^{cdef}	1.36^{abc}	1.81^{abc}

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

4.6.8 Zinc

The effect of various treatments on the uptake of Zn by rice crop is given in table 4.25. The Zn uptake by grain varied from 0.03 to 0.09 kg ha^{-1} and it varied from 0.11 to 0.76 kg ha^{-1} in straw. The total Zn uptake was only 0.14 to 0.85 kg ha^{-1} indicating that Zn is needed only in minute quantities. The highest Zn uptake by grain (0.09 kg ha^{-1}) was obtained when $ZnSO_4$ was applied as 0.5% spray (T_{12}) and it was comparable with 30 kg $ZnSO_4$ ha^{-1} application in the soil. The Zn uptake by straw was also more in T_{12} (0.76 kg ha^{-1}) resulting in a total uptake of 0.85 kg ha^{-1}. There was a decrease in Zn uptake when 1% spray was given compared to 0.5% spray.

4.6.9 Boron

The data on B uptake by the crop is presented in table 4.26. The foliar spray of 0.25% borax showed significantly higher B uptake by grain (0.05 kg ha^{-1}) and straw (0.07 kg ha^{-1}) which was on par with 10 and 20 kg borax ha^{-1}. The least uptake was noted in control treatment (0.01 kg ha^{-1} & 0.02 kg ha^{-1}).

The foliar spray of 0.25% borax recorded significantly higher total B uptake by crop (0.12 kg ha^{-1}), which was on par with 10 & 20 kg borax ha^{-1}. The least uptake was noted in control treatment (0.03 kg ha^{-1}).

4.6.10 Copper

The uptake of Cu by rice crop due to the application of various treatments is given in table 4.27. There were no significant differences between the treatments in the case of Cu uptake by grain and it varied from 0.1 to 0.03 kg ha^{-1}.

The foliar spray of 0.5% $ZnSO_4$ showed significantly higher Cu uptake by straw (0.05 kg ha^{-1}) and total uptake (0.07 kg ha^{-1}) which were on par with all other treatments except the control. The least uptake of Cu by the crop was recorded in control treatment.

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

Treatments		Grain	Straw	Total
T0	Absolute control	0.03^{e}	0.11^{f}	0.14^{h}
T1	Soil test based all nutrient package inclusive of FYM	0.05^{d}	0.27^{c}	0.32^{ef}
T2	Existing POP inclusive of FYM	0.07^{abc}	0.32^{c}	0.39^{cd}
T3	POP NPK	0.06^{c}	0.29^{d}	0.35^{def}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	0.07^{abc}	0.29^{cde}	0.36^{def}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	0.07^{abc}	0.30^{cd}	0.37^{def}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	0.07^{abc}	0.30^{cd}	0.37^{def}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	0.08^{ab}	0.28^{c}	0.36^{def}
T8	POP NPK + Borax 10 kg ha^{-1}	0.09^{a}	0.28^{cd}	0.37^{def}
T9	POP NPK + Borax 20 kg ha^{-1}	0.08^{ab}	0.30^{cd}	0.38^{cd}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	0.06^{c}	0.30^{de}	0.36^{def}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	0.07^{abc}	0.41^{b}	0.47^{bc}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	0.09^{a}	0.76^{a}	0.85^{a}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	0.08^{ab}	0.42^{b}	0.50^{b}
T14	POP NPK + Borax foliar - 0.25 %	0.06^{c}	0.28^{cd}	0.34^{def}
T15	POP NPK + Borax foliar - 0.50%	0.04^{d}	0.22^{e}	0.27^{g}

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

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

Treatments		Grain	Straw	Total
T0	Absolute control	0.01^{d}	0.02^{e}	0.03^{d}
T1	Soil test based all nutrient package inclusive of FYM	0.05^{a}	0.06^{bc}	0.11^{ab}
T2	Existing POP inclusive of FYM	0.03^{bc}	0.07^{ab}	0.10^{abc}
T3	POP NPK	0.02^{bc}	0.05^{cd}	0.07^{bc}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	0.04^{abc}	0.05^{cd}	0.09^{bc}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	0.04^{abc}	0.05^{cd}	0.09^{bc}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	0.03^{bc}	0.05^{cd}	0.08^{bc}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	0.03^{bc}	0.05^{cd}	0.08^{bc}
T8	POP NPK + Borax 10 kg ha^{-1}	0.04^{abc}	0.08^{a}	0.12^{a}
T9	POP NPK + Borax 20 kg ha^{-1}	0.04^{abc}	0.08^{a}	0.12^{a}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	0.03^{bc}	0.05^{cd}	0.08^{bc}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	0.04^{abc}	0.04^{d}	0.08^{bc}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	0.04^{abc}	0.05^{cd}	0.09^{bc}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	0.04^{abc}	0.04^{d}	0.08^{bc}
T14	POP NPK + Borax foliar - 0.25 %	0.05^{a}	0.07^{ab}	0.12^{a}
T15	POP NPK + Borax foliar - 0.50%	0.04^{abc}	0.07^{ab}	0.11^{abc}

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

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

Treatments		Grain	Straw	Total
T0	Absolute control	0.01 ^{a}	0.01 ^{b}	0.02 ^{b}
T1	Soil test based all nutrient package inclusive of FYM	0.02 ^{a}	0.04 ^{ab}	0.06 ^{a}
T2	Existing POP inclusive of FYM	0.02 ^{a}	0.03 ^{ab}	0.05 ^{a}
T3	POP NPK	0.02 ^{a}	0.03 ^{ab}	0.05 ^{ab}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	0.02 ^{a}	0.03 ^{ab}	0.05 ^{ab}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	0.02 ^{a}	0.03 ^{ab}	0.05 ^{ab}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	0.01 ^{a}	0.03 ^{ab}	0.04 ^{ab}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	0.02 ^{a}	0.03 ^{ab}	0.05 ^{ab}
T8	POP NPK + Borax 10 kg ha^{-1}	0.02 ^{a}	0.04 ^{ab}	0.06 ^{a}
T9	POP NPK + Borax 20 kg ha^{-1}	0.03 ^{a}	0.04 ^{ab}	0.07 ^{a}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	0.02 ^{a}	0.03 ^{ab}	0.05 ^{ab}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	0.03 ^{a}	0.03 ^{ab}	0.06 ^{a}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	0.02 ^{a}	0.05 ^{a}	0.07 ^{a}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	0.02 ^{a}	0.04 ^{ab}	0.06 ^{a}
T14	POP NPK + Borax foliar - 0.25 %	0.03 ^{a}	0.03 ^{ab}	0.06 ^{a}
T15	POP NPK + Borax foliar - 0.50%	0.02 ^{a}	0.03 ^{ab}	0.05 ^{ab}

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

4.7 Soil characteristics

4.7.1 pH

The effect of various treatments on pH of soil after harvesting of rice crop is presented in table 4.28. The pH of soil after harvesting of rice crop was decreased compared to the initial value (5.95) and was in the acidic region. The highest pH was shown by control treatment (5.3), which was on par with soil test based nutrient application, 30 kg $ZnSO_4$ ha^{-1}, 1% $ZnSO_4$ and 0.5% borax. The lowest pH was observed in the application of POP NPK, 10 & 20 kg borax ha^{-1}, 0.5% $ZnSO_4$ and 0.25 % borax (4.98). It was noted that pH was less in plots where borax was applied.

4.7.2 EC

The effect of various treatments on EC of soil after harvesting is shown in table 4.28. The EC of soil increased after the experiment in all the treatments compared to the initial value (0.07 ds m^{-1}). The electrical conductivity varied from 0.11 to 0.25 ds m^{-1} and it was lower in absolute control. The EC was more in 0.5% foliar applied $ZnSO_4$ (0.25 ds m^{-1}), which was on par with the application of 80 kg $MgSO_4$ ha^{-1} and 30 kg $ZnSO_4$ ha^{-1}. The control treatment showed the least EC (0.11 ds m^{-1}).

4.7.3 Organic carbon

The organic carbon content of soil after harvesting of rice crop is given in table 4.28. The organic carbon content of soil after harvesting of the crop varied from 0.50 to 0.87%. The organic carbon content was reduced compared to the initial value (0.98%). The application of POP NPK+FYM recorded the highest organic carbon content (0.87%) followed by soil test based nutrient application, which were on par. The lowest was in control treatment (0.50%).

Table 4.28 Effect of treatments on pH, EC and OC content of soil after the experiment

Treatments		pH	EC (ds m^{-1})	OC (%)
T0	Absolute control	5.33^{a}	0.11^{h}	0.50^{h}
T1	Soil test based all nutrient package inclusive of FYM	5.23^{abc}	0.22^{abcd}	0.85^{ab}
T2	Existing POP inclusive of FYM	5.00^{e}	0.19^{bcdef}	0.87^{a}
T3	POP NPK	4.98^{e}	0.13^{gh}	0.69^{cdef}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	5.10^{de}	0.14^{fgh}	0.59^{fgh}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	5.10^{de}	0.24^{ab}	0.75^{bcd}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	5.20^{bcd}	0.14^{efgh}	0.71^{cde}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	5.27^{ab}	0.22^{abc}	0.78^{abc}
T8	POP NPK + Borax 10 kg ha^{-1}	4.98^{e}	0.19^{bcdefg}	0.62^{efgh}
T9	POP NPK + Borax 20 kg ha^{-1}	4.98^{e}	0.17^{cdefgh}	0.77^{abc}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	5.12^{cde}	0.17^{cdefgh}	0.75^{bcd}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	5.12^{cde}	0.20^{abcde}	0.64^{defg}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	4.98^{e}	0.25^{a}	0.67^{cdef}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	5.25^{ab}	0.19^{bcdef}	0.60^{efgh}
T14	POP NPK + Borax foliar - 0.25 %	5.00^{e}	0.19^{bcdef}	0.54^{gh}
T15	POP NPK + Borax foliar - 0.50%	5.27^{ab}	0.16^{defgh}	0.51^{h}

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

4.7.4 Available N

The data on available N in soil is shown in table 4.29. The available N status in soil after harvesting was almost steady compared to initial value (267 kg ha^{-1}). The soil application of POP NPK +FYM recorded significantly higher available N in soil (305.2 kg ha^{-1}), which was on par with 20 kg borax ha^{-1}. The absolute control recorded the lowest available N in soil after harvest (213.4 kg ha^{-1}).

4.7.5 Available P_2O_5

The data on available P_2O_5 in soil is shown in table 4.29. There was a decrease in P_2O_5 after the harvesting of the crop compared to the initial value (38.79 kg ha^{-1}). Foliar applied Zn at 0.5% recorded higher P_2O_5 content in soil after harvest (16.40 kg ha^{-1}) followed by foliar spray of 1% $MgSO_4$. Soil test based nutrient application recorded least available P_2O_5 (6.08 kg ha^{-1}) which was on par with control treatment (6.25 kg ha^{-1}).

4.7.6 Available K_2O

The effect of various treatments on available K_2O after harvesting of rice crop is shown in table 4.29. Though available K_2O varied from 73.90 – 123.20 kg ha^{-1}, there were no significant difference between treatments and it become more or less constant compared to the initial value (104.60 kg ha^{-1}). However, the soil application of 20 kg borax ha^{-1} showed comparatively higher available K_2O and was lower in the application of $MgSO_4$.

4.7.7 Available Ca

The available Ca content in soil after harvesting of rice crop is presented in table 4.30. The available Ca content in soil after harvesting of rice crop was decreased compared to initial value (1152 mg kg^{-1}). The application of POP NPK+FYM recorded significantly higher available Ca in soil (646.71 mg kg^{-1}), which was on par with the application of 30 kg $ZnSO_4$, 20 kg borax $ha^{-1}$and

Table 4.29 Effect of treatments on available N, P_2O_5 and K_2O (kg ha^{-1}) of soil after the experimen

Treatments		Available N	Available P_2O_5	Available K_2O
T0	Absolute control	213.37^{f}	6.25^{h}	73.90^{a}
T1	Soil test based all nutrient package inclusive of FYM	246.70^{bcdef}	6.08^{h}	107.89^{a}
T2	Existing POP inclusive of FYM	305.24^{a}	6.21^{h}	97.07^{a}
T3	POP NPK	280.15^{abc}	7.69^{g}	115.73^{a}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	267.61^{abcde}	10.85^{cd}	104.16^{a}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	275.97^{abc}	7.94^{fg}	93.71^{a}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	238.34^{cdef}	11.33^{c}	108.27^{a}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	271.79^{abcd}	11.08^{c}	102.67^{a}
T8	POP NPK + Borax 10 kg ha^{-1}	280.15^{abc}	9.48^{e}	101.17^{a}
T9	POP NPK + Borax 20 kg ha^{-1}	293.70^{ab}	9.86^{de}	123.20^{a}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	221.61^{def}	9.01^{ef}	103.04^{a}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	267.61^{abcde}	13.39^{b}	103.04^{a}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	217.43^{ef}	16.40^{a}	101.55^{a}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	284.33^{abc}	8.96^{ef}	113.68^{a}
T14	POP NPK + Borax foliar - 0.25 %	255.06^{abcdef}	11.19^{c}	92.21^{a}
T15	POP NPK + Borax foliar - 0.50%	242.52^{bcdef}	11.31^{c}	88.11^{a}

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

0.25 % borax. The least available Ca was observed in foliar spray of 1% $MgSO_4$ (555.06 mg kg^{-1}) even less than that of control.

4.7.8 Available Mg

The available Mg content in soil after harvesting of rice crop is given in table 4.30. The available Mg content in soil after the experiment showed a steady value compared to the initial value (25 mg kg^{-1}). There were no significant differences between the treatments on available Mg content in soil after harvesting. However, soil test based nutrient application resulted in 25.13 mg kg^{-1} available Mg whereas it was only 22.65 mg kg^{-1} in absolute control.

4.7.9 Available S

The effect of treatments on available S content of soil is shown in table 4.30. The available S content in soil after the harvesting of the crop increased compared to the initial value (6.18 mg kg^{-1}). The available S content was significantly higher in soil applied $ZnSO_4$ at 30 kg ha^{-1} (21.91 mg kg^{-1}), which was on par with nutrient application based on soil test and soil applied $MgSO_4$ at 80 kg ha^{-1}. The control treatment noted the lowest S content (7.96 mg kg^{-1}).

4.7.10 Available Fe

The available Fe content in soil after the harvest of rice crop is presented in table 4.31. The control treatment showed the highest available Fe (1453 mg kg^{-1}), which was on par with POP NPK alone (1427 mg kg^{-1}). The lowest available Fe content was observed in foliar spray of 0.5% $ZnSO_4$ (989 mg kg^{-1}) and 1% $MgSO_4$.

4.7.11 Available Mn

The available Mn content in soil after the harvest of rice crop is given in table 4.31. There were no significant differences between treatments on available Mn content. However, the application of 10 kg borax recorded comparatively higher available Mn (98.02 mg kg^{-1}) followed by $MgSO_4$ 80 kg.

Table 4.30 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 ($mg\ kg^{-1}$)
T0	Absolute control	598.25^{abcd}	22.65^{a}	7.96^{i}
T1	Soil test based all nutrient package inclusive of FYM	591.19^{bcd}	25.11^{a}	21.42^{ab}
T2	Existing POP inclusive of FYM	646.71^{a}	23.86^{a}	14.09^{f}
T3	POP NPK	597.72^{abcd}	23.85^{a}	13.68^{g}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	576.78^{cd}	24.55^{a}	17.33^{de}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	582.83^{cd}	23.33^{a}	21.4[illegible]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	567.58^{cd}	23.65^{a}	16.0[illegible] [illegible]f
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	642.23^{ab}	24.21^{a}	21.91^{a}
T8	POP NPK + Borax 10 kg ha^{-1}	586.32^{cd}	24.12^{a}	18.31^{cd}
T9	POP NPK + Borax 20 kg ha^{-1}	614.45^{abc}	25.03^{a}	14.48^{fg}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	586.57^{cd}	24.11^{a}	11.06^{h}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	555.06^{d}	24.54^{a}	18.44^{cd}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	561.14^{cd}	24.02^{a}	17.51^{de}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	576.57^{cd}	24.80^{a}	19.85^{bc}
T14	POP NPK + Borax foliar - 0.25 %	615.71^{abc}	23.99^{a}	13.46^{g}
T15	POP NPK + Borax foliar - 0.50%	599.87^{abcd}	23.80^{a}	14.35^{fg}

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

4.7.12 Available Zn

The effect of treatments on available Zn content in soil is presented in table 4.31. The available Zn in soil after the experiment increased compared to the initial value (1.77 mg kg^{-1}). The highest available Zn content in soil was observed in soil test based nutrient application (4.85 mg kg^{-1}), which was on par with soil applied 30 kg $ZnSO_4$ ha^{-1} and 1% foliar spray of $ZnSO_4$. The control treatment recorded the lowest available Zn content after harvest of the crop (2.28 mg kg^{-1}).

4.7.13 Available B

The effect of various treatments on soil available B is shown in table 4.32. Soil test based nutrient application recorded significantly higher available B (1.75 mg kg^{-1}), which was on par with soil application of 10 kg borax ha^{-1} (1.59 mg kg^{-1}). The available B was least in control treatment (0.29 mg kg^{-1}). B was deficient only in control.

4.7.14 Available Cu

The effect of various treatments on soil available Cu is shown in table 4.32. There were no significant differences between treatments on available Cu. The absolute control recorded comparatively higher available Cu (8.69 mg kg^{-1}).

4.8 Economics of cultivation

The effect of treatments on economics of cultivation is presented in table 4.33. The foliar application of 0.5% of $ZnSO_4$ and 0.25% of borax resulted in higher BC ratios, followed by 1% $MgSO_4$. Similar or higher BC ratios were observed for secondary or micronutrients applied treatments than POP recommendation. The BC ratios were markedly increased when these nutrients were foliar applied at desired concentrations.

Table 4.31 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})
T0	Absolute control	1453^{a}	82.12^{a}	2.28^{g}
T1	Soil test based all nutrient package inclusive of FYM	1273^{c}	84.81^{a}	4.85^{a}
T2	Existing POP inclusive of FYM	1349^{b}	81.93^{a}	3.82^{bcdef}
T3	POP NPK	1427^{a}	79.04^{a}	3.78^{cdef}
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	1101^{ef}	83.71^{a}	3.64^{def}
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	1240^{c}	88.65^{a}	3.62^{def}
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	1035^{gh}	82.02^{a}	4.51^{abcd}
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	1095^{ef}	74.34^{a}	4.80^{ab}
T8	POP NPK + Borax 10 kg ha^{-1}	1152de	98.02^{a}	3.89^{abcdef}
T9	POP NPK + Borax 20 kg ha^{-1}	1172^{d}	77.76^{a}	3.31^{ef}
T10	POP NPK + $MgSO_4$ foliar - 0.50%	1255^{c}	85.53^{a}	3.65^{def}
T11	POP NPK + $MgSO_4$ foliar - 1.00%	999^{h}	76.01^{a}	4.16^{abcde}
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	989^{h}	85.09^{a}	3.92^{abcdef}
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	1090^{fg}	82.43^{a}	4.74^{abc}
T14	POP NPK + Borax foliar - 0.25 %	1002^{h}	82.45^{a}	3.74^{cdef}
T15	POP NPK + Borax foliar - 0.50%	1026^{h}	71.25^{a}	2.89^{fg}

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

Table 4.32 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})
T0	Absolute control	0.29 [c]	8.69 [a]
T1	Soil test based all nutrient package inclusive of FYM	1.75 [a]	8.16 [a]
T2	Existing POP inclusive of FYM	0.95 [b]	8.13 [a]
T3	POP NPK	0.86 [b]	8.56 [a]
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	1.02 [b]	8.44 [a]
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	0.91 [b]	8.31 [a]
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	0.87 [b]	7.86 [a]
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	0.83 [b]	7.85 [a]
T8	POP NPK + Borax 10 kg ha^{-1}	1.59 [a]	8.54 [a]
T9	POP NPK + Borax 20 kg ha^{-1}	1.02 [b]	7.56 [a]
T10	POP NPK + $MgSO_4$ foliar - 0.50%	0.84 [b]	8.73 [a]
T11	POP NPK + $MgSO_4$ foliar - 1.00%	0.95 [b]	7.86 [a]
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	0.79 [b]	8.01 [a]
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	0.83 [b]	8.40 [a]
T14	POP NPK + Borax foliar - 0.25 %	0.85 [b]	8.21 [a]
T15	POP NPK + Borax foliar - 0.50%	0.82 [b]	7.95 [a]

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

Table 4.33 Effect of treatments on economics of cultivation (Rs./ha)

Treatments		Cost of cultivation	Gross return	BC ratio
T0	Absolute control	51,825/-	83,259/-	1.61
T1	Soil test based all nutrient package inclusive of FYM	78,765/-	1,31,204/-	1.67
T2	Existing POP inclusive of FYM	76,138/-	1,42,866/-	1.88
T3	POP NPK	69,138/-	1,25,270/-	1.81
T4	POP NPK + $MgSO_4$ 40 kg ha^{-1}	62,780/-	1,22,203/-	1.95
T5	POP NPK + $MgSO_4$ 80 kg ha^{-1}	66,780/-	1,30,176/-	1.95
T6	POP NPK + $ZnSO_4$ 20 kg ha^{-1}	64,650/-	1,25,098/-	1.94
T7	POP NPK + $ZnSO_4$ 30 kg ha^{-1}	66,310/-	1,24,083/-	1.87
T8	POP NPK + Borax 10 kg ha^{-1}	67,900/-	1,34,912/-	1.99
T9	POP NPK + Borax 20 kg ha^{-1}	71,900/-	1,26,012/-	1.75
T10	POP NPK + $MgSO_4$ foliar - 0.50%	60,713/-	1,06,325/-	1.75
T11	POP NPK + $MgSO_4$ foliar - 1.00%	64,738/-	1,31,736/-	2.03
T12	POP NPK + $ZnSO_4$ foliar - 0.50 %	65,810/-	1,38,768/-	2.11
T13	POP NPK + $ZnSO_4$ foliar - 1.00 %	65,930/-	1,32,473/-	2.01
T14	POP NPK + Borax foliar - 0.25 %	66,300/-	1,38,270/-	2.08
T15	POP NPK + Borax foliar - 0.50%	66,700/-	1,12,184/-	1.68

Discussion

V. DISCUSSION

An experiment was conducted on "Relative efficiency of soil and foliar applied nutrients in irrigated rice of Palakkad" in farmer's field, Thathamangalam, Palakkad during the *Mundakan* season October 2011 – February 2012 for comparing the efficiency of soil and foliar applied secondary and micronutrients 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

5.1.1 Plant height

The height recorded by the treatments at 30 & 60 DAT were on par except the control. The soil application of 20 kg $ZnSO_4$ produced the tallest plants at all the stages (Fig. 5.1). Kumar and Kumar (2009) and Pal *et al.* (2008) reported that Zn application increased growth of rice due to its role in cell multiplication and photosynthesis. However, the plant height was decreased when the dose of Zn increased beyond a limit. Shehu *et al.* (2011) reported the decreasing height of rice at higher levels of Zn.

The soil and foliar application of $MgSO_4$ at 40 or 80 kg ha^{-1} or at 1% level gave similar plant height at vegetative stages. However, soil application @ 80 kg ha^{-1} produced significantly taller plants at harvest. Padmaja and Verghese (1966) and Obatolu (1999) also reported similar results. The increased height may be due to the increased chlorophyll production and photosynthetic rate as a result of higher dose of Mg application.

With respect to the plant height at harvest, soil application of borax at 10 or 20 kg ha^{-1} was found better than foliar application. The higher dose at 0.5% foliar spray reduced the plant height at harvest. Rehman *et al.* (2012) and Patil *et al.* (2008) reported increased height due to borax application. However, only small amount of B is required to regulate the meristematic growth, cell elongation and division (Khan *et al.* 2006). Initially there was deficiency of boron in soil and later on soil application of borax could maintain sufficient concentration in soil solution for the absorption by the plants. The control treatment without any secondary or micronutrients application gave the lowest plant height. Similar result was also cited by Zayed *et al.* (2011).

5.1.2 Tiller count and Tiller decline

All the treatments showed similar tiller count except the control at 30 DAT. At earlier stages of growth the application of POP NPK with FYM, $ZnSO_4$ (20 kg ha^{-1}) and $MgSO_4$ (40 kg ha^{-1}) produced relatively higher number of tiller (Fig. 5.2). The decomposition of FYM could maintain sufficient nutrient in soil solution at earlier stages which resulted increased number of tiller. The tiller count increased from 30 DAT to 60 DAT. But it was reduced even when POP NPK along with FYM was applied due to the limited supply of nutrients from FYM during later stages.

The soil application of $ZnSO_4$ at 20 kg ha^{-1} produced more number of tillers compared to foliar application at 60 DAT. It also recorded higher productive tiller at harvest. Shehu *et al.* (2011) reported the increased tiller count due to the $ZnSO_4$ application. Higher level of Zn application leads to the decreased number of tillers. Zinc plays an important role in regulation of the nitrogen metabolism, cell multiplication, photosynthesis and auxin concentration in plants and leads to increased number of tillers.

At the earlier stages also 1% $MgSO_4$ produced relatively higher number of tillers but the effect was more prominent at the harvest. There were several reports about the increased and stronger tillers due to the Mg application compared to untreated plants (Sadaphal and Das, 1961; Varughese and Jose, 1993). During the earlier growth stages, soil application resulted in higher number of tillers compared to foliar application. This may be due to the build up of Mg in soil as a result of soil application. At 60 DAT, soil application of 80 kg $MgSO_4$ and 1% foliar spray were on par. At harvest stage, the highest number of productive tillers were observed by the foliar application of 1% $MgSO_4$. The $MgSO_4$ spray was given twice which resulted in increased concentration of Mg

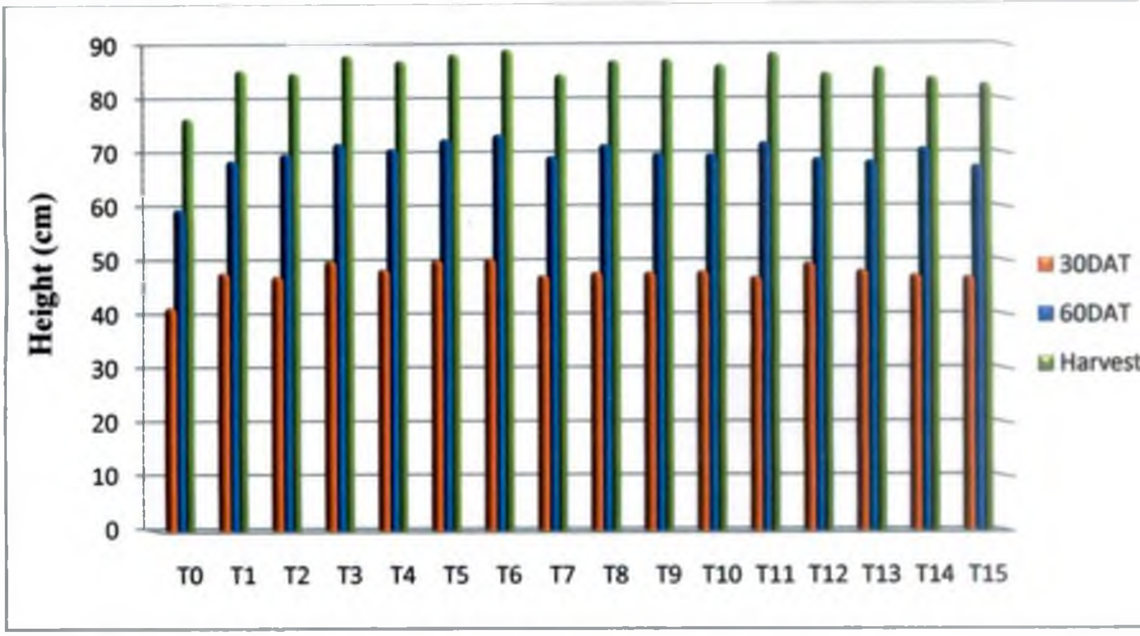

Fig. 5.1 Effect of treatments on height of plant (cm) at 30, 60DAT & harvest

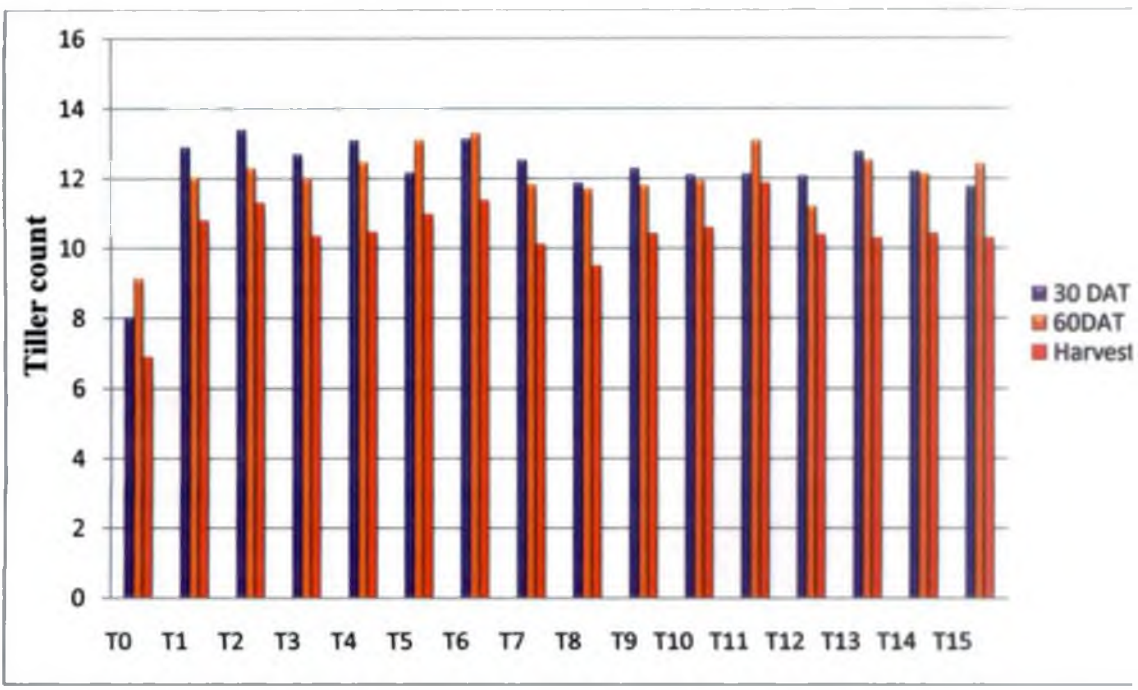

Fig.5.2 Effect of treatments on tiller count at 30, 60DAT & harvest

on the foliage. The increased tiller count is due to the increased rate of photosynthesis as Mg is an integral part of chlorophyll.

The foliar spray of 0.25% borax also recorded more number of tillers. Debnath *et al.* (2009) reported that the application of 1.5 kg B ha^{-1} increased the number of tiller in rice. The increased number of tiller is due to the role of B in metabolic activity which resulted in higher cell division and elongation.

All the vegetative tillers produced may not be productive. Only some of them will be converted to productive tiller and some may die, known as tiller decline. Tiller decline was lower by the foliar spray of 0.5% $ZnSO_4$ and POP NPK + FYM and it was very severe in control plot. The control treatment showed highest tiller decline (23.85%) compared to other treatments due to the inadequate supply of nutrients.

5.1.3 Leaf area index (LAI)

There were no marked difference in Leaf Area Index between the treatments except the control. The soil application of borax at 10 kg ha^{-1} recorded highest LAI and it was on par with 0.5% foliar spray (Table 4.3). Patil *et al.* (2008) reported similar results. The photosynthesis was enhanced in the presence of B and lead to higher leaf width and area. The application of FYM along with soil test based nutrients and POP NPK also resulted in higher LAI due to the steady supply of nutrients.

The soil application of 80 kg $MgSO_4$ ha^{-1} recorded higher LAI compared to foliar treatment of $MgSO_4$. The higher level of Mg application resulted in better photosynthesis and caused increased leaf width (Varughese and Jose, 1993). Borax 10 kg ha^{-1} and 0.5% foliar application gave better LAI even though it was on par. The control treatment without any micronutrients application gave the lowest values of LAI (Zayed *et al.*, 2011).

5.1.4 Chlorophyll content

Even though there were no marked difference between the treatments on chlorophyll content, the soil application of 20 kg borax ha^{-1} followed by POP NPK +FYM resulted in higher content of chlorophyll (Fig. 5.3). B application significantly improved the chlorophyll concentrations in rice leaves (Rehman *et al.*, 2012). Boron is a component of ferrodoxin and electron transport and also associated with chloroplast.

The application of $ZnSO_4$ and $MgSO_4$ also had response on chlorophyll content compared to POP NPK alone. The control treatment without any micronutrients application gave the lowest values of chlorophyll content (Zayed *et al.*, 2011).

5.1.5 Dry matter production

There were no marked difference on dry matter production during 30 DAT except the control. The application of NPK + FYM recorded significantly higher dry matter at 30, 60 DAT and at harvest (Fig. 5.4). Chandrapala *et al.* (2010) reported similar result. The decomposition of FYM resulted in supply of nutrients to the plant. There was an increase in dry matter mainly due to increase in height, number of tiller, leaves and its size, higher photosynthsis and increased leaf area due to the application of nutrients.

The foliar application of $ZnSO_4$ @ 0.5% produced significantly higher dry matter at 30, 60 DAT and at harvest compared to soil application. Kumar and Kumar (2009) also reported increased dry matter production due to Zn application. The direct spray of Zn improves the chlorophyll development and photosynthetic rate which ultimately increased the vegetative growth.

The soil application of borax at 10 kg ha^{-1} significantly recorded higher dry matter at 30, 60 DAT compared to foliar application. The photosynthesis enhanced in the presence of B due to the activation of synthesis of tryptophan and precursor of indole acetic acid (IAA) which is responsible for stimulation of plant growth and accumulation of biomass (Patil *et al.*, 2008). At higher levels of B

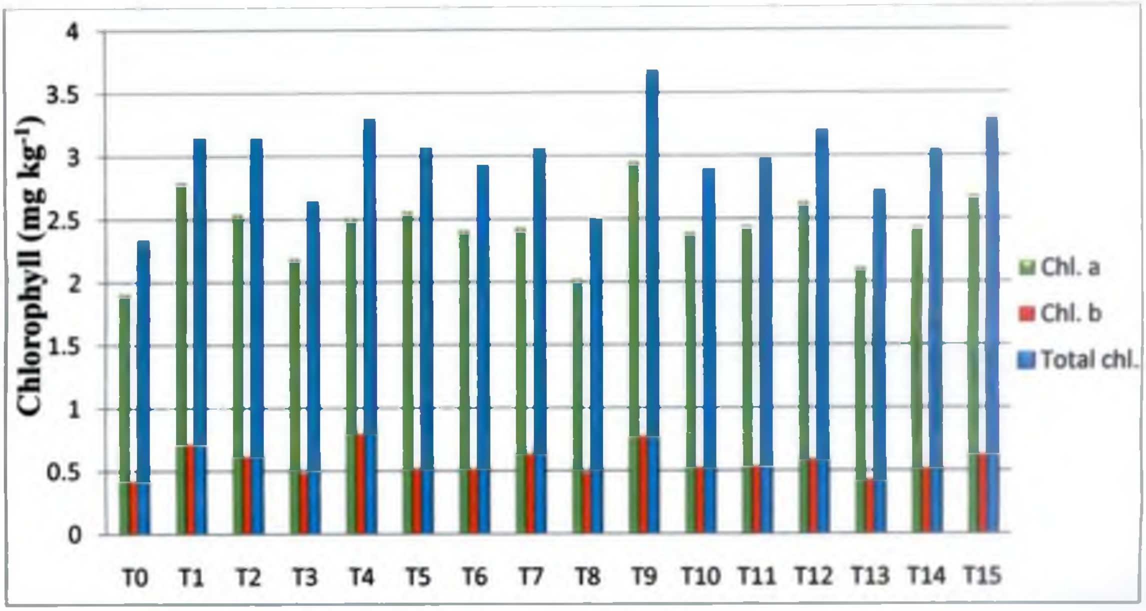

Fig. 5.3 Effect of treatments on chlorophyll content (mg kg^{-1})

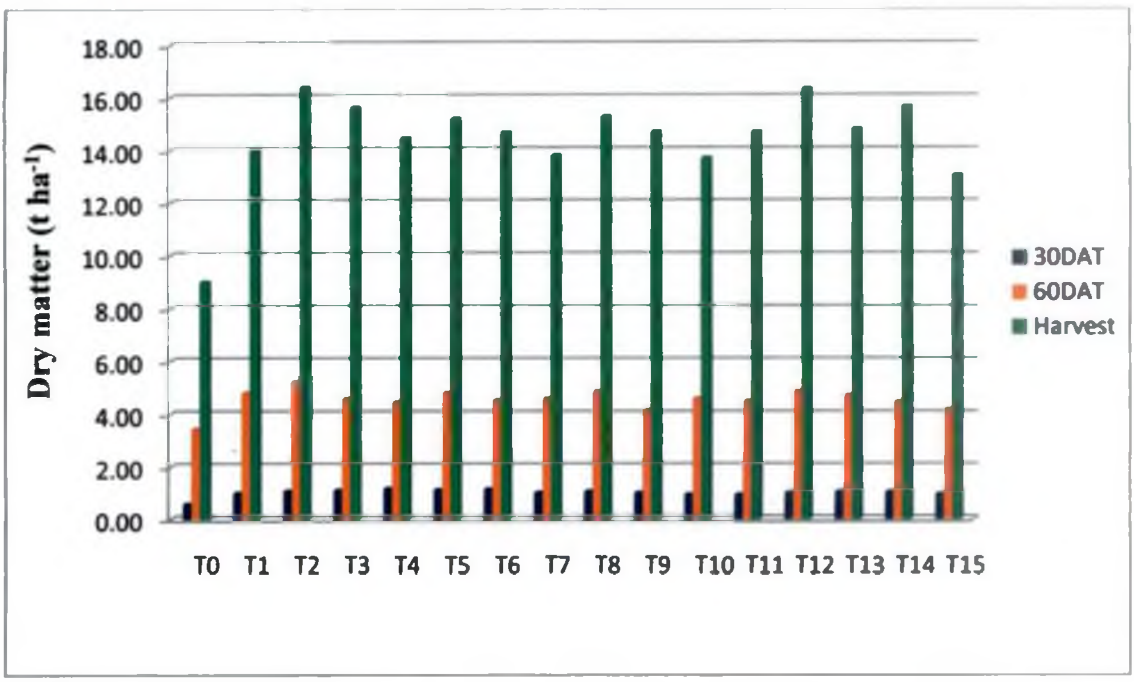

Fig. 5.4 Effect of treatments on dry matter production (t ha^{-1}) at 30, 60DAT & harvest

there was a decrease in dry matter yield due to B toxicity because a slight increase in B levels markedly increased B concentration in plants (Rashid *et al.*, 2004).

The soil application of $MgSO_4$ at 80 kg ha^{-1} recorded higher dry matter compared to foliar application. Bose and Mishra (2001) reported increased dry matter by the application of $MgSO_4$ as Mg is a constituent of chlorophyll resulting in high photosynthetic rates and higher dry matter accumulation. The control treatment without any nutrient application gave the lowest values of dry matter per hill due to the poor nutrient supply.

5.2 Yield attributes

5.2.1 Panicles/hill

The foliar spray of $MgSO_4$ @ 1% increased the number of panicles/hill (Table 4.6). The foliar spray of $MgSO_4$ resulted in higher uptake of Mg which was utilized at reproductive stage for the production of panicles. The application of 20 kg $ZnSO_4$ ha^{-1} was better than its foliar application. The soil application of 20 kg borax ha^{-1} and foliar spray of 0.25% borax recorded similar number of panicles/hill. The application of $MgSO_4$, $ZnSO_4$ and borax have response on panicles/hill and recorded higher number of panicles/hill compared to POP NPK alone. Chapale and Badole (1999) and Kumar and Kumar (2009) reported higher number of panicles/m^2 by the application of Zn along with POP NPK. The foliar application of 1% $ZnSO_4$ was better than soil application. The foliar application resulted in higher uptake of Zn which led to higher production of panicles. The higher uptake of nutrients resulted in better panicles production. The number of panicles/hill was lowest in control plot.

5.2.2 Spikelets/panicle

The application of $MgSO_4$, $ZnSO_4$ and borax had significant effect on spikelets per panicle and recoded comparatively higher number of spikelets compared to POP NPK alone. The application of 80 kg $MgSO_4$ ha^{-1} recorded the highest number of spikelets/panicle (Table 4.6). The uptake of nitrogen at panicle initiation was higher by the application of 80 kg $MgSO_4$ ha^{-1} which resulted in increased number of spikelets/panicle. This is in line with the reports of De Datta (1981) and Singh and Singh (2005). The foliar spray of borax recorded higher number of spikelets/panicle compared to its soil application. There were reports that the foliar application of boron was effective to enhance number of spikelets (Rao *et al.*, 2013).

5.2.3 Filled grains/ panicle

The application of $MgSO_4$, $ZnSO_4$ and borax along with POP NPK recorded higher percentage of filled grains compared to POP NPK alone. The highest percentage of filled grains was noted by the foliar spray of 0.25% borax (Table 4.6). This may be due to the decreased spikelet sterility due to the borax application as reported by Rao *et al.* (2013) and Zayed *et al.* (2011). The application of $MgSO_4$ at 80 kg ha^{-1} and 0.5% also recorded higher percentage of filled grains as reported by Sadaphal and Das (1961) and Singh and Singh (2005). This may be due to the increased N uptake at panicle initiation which contributed to higher percentage of filled grain.

5.2.4 Thousand grain weight

The application of $MgSO_4$, $ZnSO_4$ and borax recorded higher 1000 grain weight compared to control and POP NPK alone. The foliar spray of 0.5% $ZnSO_4$ resulted in higher 1000 grain weight compared to its soil application (Table 4.6). This may be due to the increased transportation of photosynthates from source to zinc due to zinc application as reported by Sriramchandra and Mathan (1988).

In the case of $MgSO_4$, 1% foliar spray resulted in higher thousand grain weight compared to its soil application. Mg application leads to early completion of flowering, which helps in uniform ripening of grain, thereby increasing the grain weight. This is in line with study of Sadaphal and Das (1961). The soil application of 10 kg borax ha^{-1} was superior than its foliar application. This may be due to the role of B in production of bold grains.

5.3 Yield

5.3.1 Grain yield

The application of nutrients generally increased the grain yield compared to the control. Comparatively higher nutrient content in the plant and soil especially N, P, K, Ca, Mg *etc.* gave excellent crop stand and higher yield. The application of FYM along with POP NPK recorded the highest grain yield (Fig. 5.5). 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 application of 0.25% borax resulted in higher grain yield which was comparable with the application of 10 kg borax. A higher boron uptake together with higher number of panicles/hill and percentage of filled grain might contributed to the higher grain yield. Boron has role in flower production, retention, pollen tube elongation, germination and grain development. This is in line with the reports of Ali *et al.* (2011), Debnath and Ghosh (2012) and Rao *et al.* (2013). The production of higher total drymatter by the application of 0.25% borax also resulted in higher yield as reported by Fageria (2004). A higher level of boron application recorded lower yield. The range between the level of soil boron resulting in deficiency and that causing toxicity in plant is relatively small and the reduction in yield may be due to the injurious effect of higher concentration. Gaur and Singh (2010) reported similar result.

The foliar spray of 0.5% $ZnSO_4$ along with POP NPK recorded higher yield compared to the soil application. The foliar application of 0.5% increased uptake of Zn by grain, number of panicle/hill, percentage filled grain and thousand grain weight which led to the higher yield. This is in line with the reports of Gupta and Handore (2009).

In the case of Mg the foliar spray of 1% $MgSO_4$ recorded higher grain yield compared to the soil application. A higher Mg uptake, total dry matter and HI resulted in higher yield in grain. The yield increase may also be due to the increased number of panicles/hill and thousand grain weight. Mg has important role in grain nutrition which lead to higher yield.

5.3.2 Straw yield

All the treatments showed a better straw yield except soil test based nutrient application, 30 kg $ZnSO_4$, 0.5% borax and the control. The application of nutrients resulted in the increased growth of plants which leads to higher total dry matter and straw yield. The foliar spray of 0.5% $ZnSO_4$ along with POP NPK recorded the highest straw yield (Fig. 5.6). The direct spray of $ZnSO_4$ to the foliage increased the photosynthetic rate and vegetative growth as Zn has role in N metabolism and chlorophyll synthesis. Mg application also recorded higher straw yield due to the increased uptake of Mg by crop which resulted in higher plant height, leaf width and number of tiller as Mg is an integral constituent of chlorophyll which leads to higher photosynthetic rate. This is in line with study of Varughese and Jose (1993). The foliar application of 0.25% borax along with POP NPK also resulted in higher straw yield compared to the soil application. This may be due to the increased uptake of B by straw. Increase in straw yield due to boron application was also reported by Gaur and Singh (2010).

5.4 Harvest Index

All the treatments showed higher HI except the foliar application of $MgSO_4$ at 0.5% (Table 4.7). The soil test based nutrient application recorded the highest HI. This may be due to the higher biological yield and grain yield due to the adequate supply of nutrients to the plants. The application of $ZnSO_4$ at 30 kg ha^{-1} and 1% resulted in higher HI. The higher grain yield and straw yield may contribute to the higher HI. Pooniya and Shivay (2011) and Fageria *et al.* (2011) reported the highest harvest index of rice with the application of $ZnSO_4$. The HI shown by control treatment was comparable with other treatments. High HI

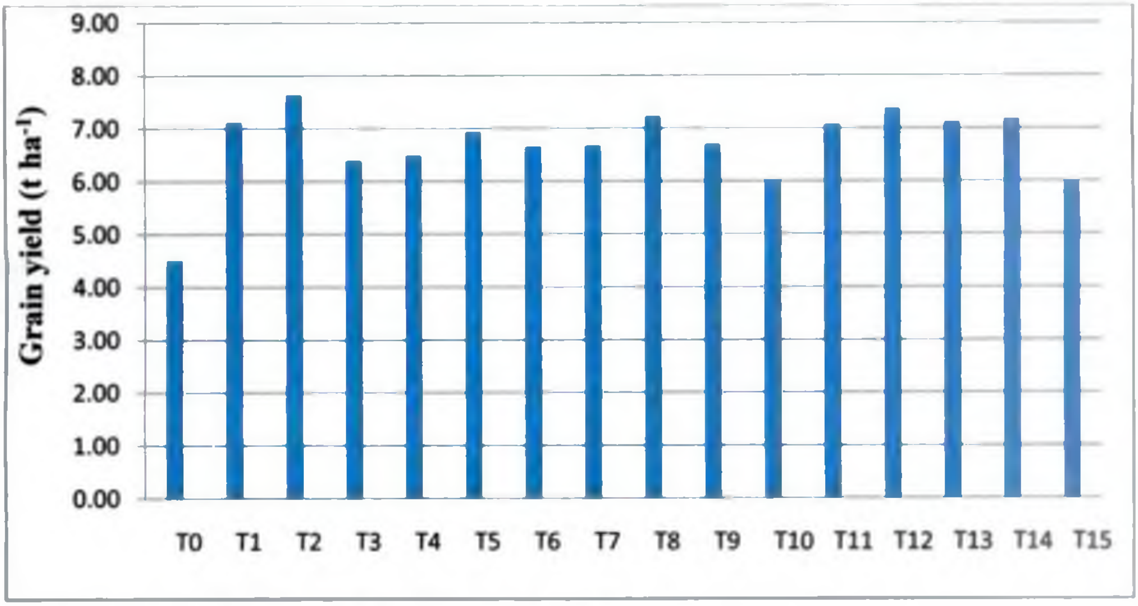

Fig. 5.5 Effect of treatments on grain yield (t ha^{-1})

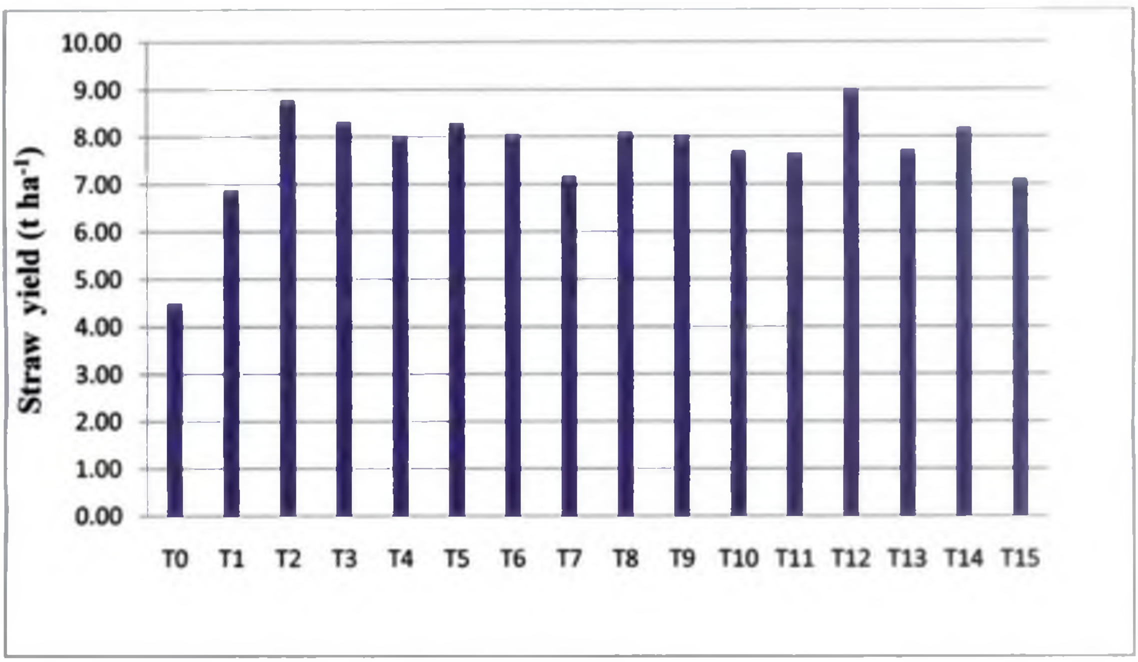

Fig. 5.6 Effect of treatments on straw yield (t ha^{-1})

alone does not mean that it is a high yielder. High HI together with high total yield will result in high yield. There is response for $MgSO_4$, $ZnSO_4$ and borax on HI when it is applied as foliar compared to POP NPK alone.

5.5 Nutrient content

5.5.1 Nitrogen

The treatments did not show significant difference in N% of rice plants at 30, 60 DAT and in straw (Fig. 5.7). The application of N, P, K, Mg, Zn and B has no effect on N content of rice plants because the N status of the soil is sufficient to supply nitrogen to the plant. The N content in rice plant reduced according to the growth stages due to the dilution effect. But there is a clear cut translocation of N to grains at reproductive phase which is evident from the higher N content in grains compared to straw. The foliar application of $MgSO_4$ at 1% recorded significantly higher N content in grain, followed by soil test based nutrient application and 80 kg $MgSO_4$ ha^{-1}. The N content was comparatively higher in Mg treated plot. Choudhury and Khanif (2001) reported increased N content by magnesium application due to increased N uptake by rice plant. The application of soluble salts of Mg reduced NH_3 volatilization loss from surface applied urea.

5.5.2 Phosphorus

The foliar spray of 1% $MgSO_4$ recorded significantly higher P content, which was on par with soil application of 40 kg $MgSO_4$ ha^{-1} at 30 DAT (Fig. 5.8). Mg is a carrier of P in plants. It promotes the uptake and translocation of P and helps in more P content in plants as reported by Varghese and Money (1965). There were reports that at higher dose of Mg there was a decrease in P content in rice (Kumar *et al.*, 1981). The foliar application of borax at 0.25% recorded the highest P content at 60 DAT and in straw due to the positive interaction of B on the P content in rice. This is in line with study of Gaur and Singh (2010). In grain, the soil application of 40 kg $MgSO_4$ ha^{-1} recorded higher P content in grain, because of the increased absorption and translocation of P in the presence of Mg.

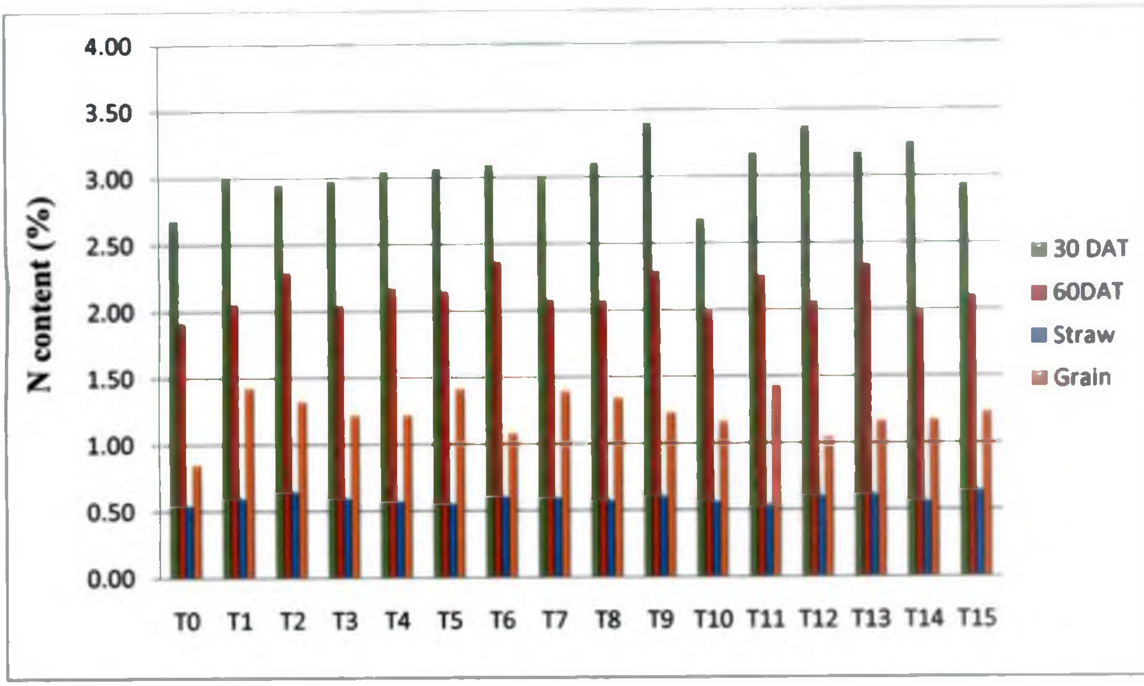

Fig. 5.7 Effect of treatments on nitrogen content of rice plant (%) at 30, 60DAT & harvest

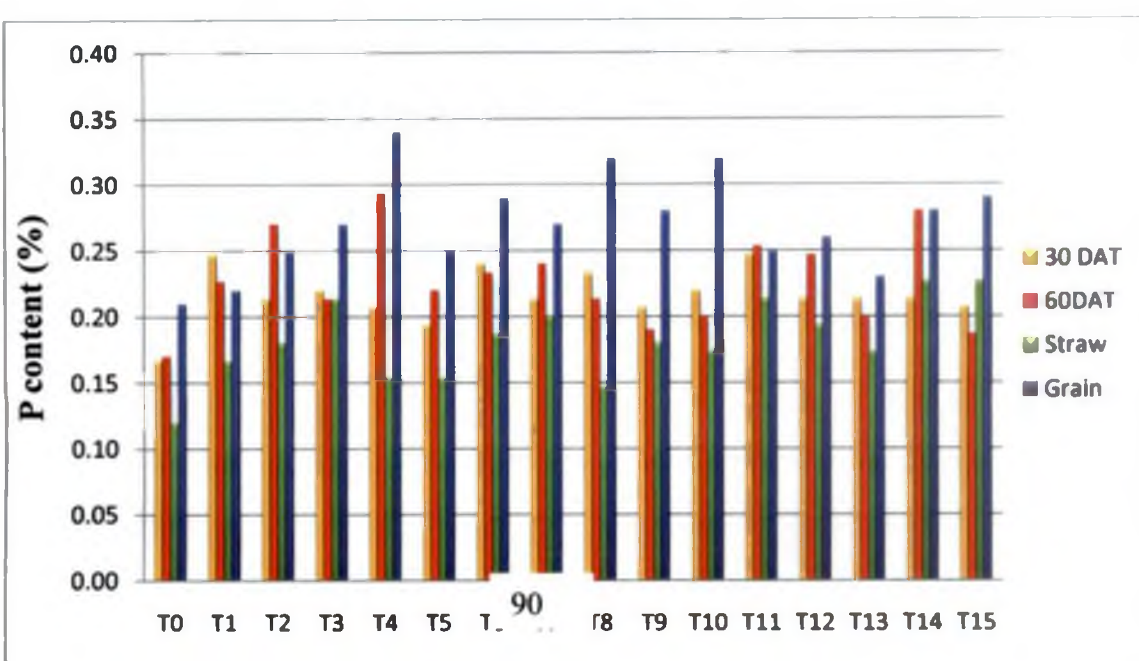

Fig. 5.8 Effect of treatments on phosphorus content of rice plant (%) at 30, 60 DAT & harvest

5.5.3 Potassium

There was a gradual reduction in potassium content according to the growth stages and the highest at 30 DAT due to the active absorption. The application of POP NPK along with FYM recorded the highest K content at 30 DAT (Fig. 5.9). This may be due to the integrated use of FYM with fertilizers, which supply higher K for the absorption by plants. Similar results were reported by Chandrapala *et al.* (2010). The application of POP NPK without FYM and with $ZnSO_4$ @ 1% also resulted in higher K content in rice plant due to the higher availability of K from the soil for the absorption by plants. There were reports that K concentration gets improved with the foliar application of Zn (Singh *et al.*, 2013).

The soil application of 10 & 20 kg borax ha^{-1} increased the K content at 60 DAT, in grain and straw. The micronutrient B acts as catalyst in the uptake of K which leads to the increased K content in plants as reported by Arif *et al.* (2012). The foliar spray of 0.5 % $MgSO_4$ recorded lowest value of K at 60 DAT. There is an antagonistic effect between K and Mg, which may lead to the decreased K content (Ananthanarayana and Rao, 1979).

5.5.4 Calcium

The soil application of $ZnSO_4$ at 30 kg ha^{-1} recorded the highest calcium content at all the stages (Table 4.11). There were reports that the application of Zn increased the calcium content compared to the control (Singh and Singh, 2005). There was a decline in Ca content of plant from 30 to 60 DAT due to dilution effect.

The soil application of $MgSO_4$ at 40 kg ha^{-1} recorded the lowest calcium content at 30 and 60 DAT. This may be due to the antagonistic effect between Ca and Mg. This is in line with the report of Kumar *et al.* (1981). The calcium content of straw was significantly higher in soil applied 10 kg borax ha^{-1} because B application facilitates increased calcium content as reported by Muralidharan (1992). Boron is involved in a variety of physiological activities and synthesis of amino acids and proteins which necessitates uptake of Ca. Ca content in grain was very much lower than that in the straw. Generally the uptake and translocation of Ca is less may be due to the inhibiting action by Fe.

5.5.5 Magnesium

The soil application of 80 kg $MgSO_4$ ha^{-1} recorded the highest Mg content at all the growth stages of rice followed by 1% foliar spray (Fig. 5.10). Muralidharan (1992) and Choudhury and Khanif (2001) reported that the application of $MgSO_4$ resulted in higher Mg content at tillering stage of rice. There was a marked increase in the content of Mg by straw and grain in foliar application of $MgSO_4$ compared to soil application. Sometimes relatively lower pH in laterite soil led to slow dissolution and release of Mg, when applied in soil (Varughese and Jose, 1993). At this situation foliar spray is a better way.

5.5.6 Iron

Since rice was grown on acidic soil the content of Fe was very high in the plant at all stages. The soil application of 30 kg $ZnSO_4$ ha^{-1} showed significantly higher plant Fe content (Table 4.13). Fang *et al.* (2008) reported that Zn fertilizer application had a significant effect on Fe concentration of rice. Even at low concentration of Zn, the Fe concentration in wheat grain got increased. There was a higher Fe content at tillering due to increased availability at submergence. The continuous flooding of the soil and increase in biomass production of rice caused a dilution effect in the availability of Fe from the toxic level. The foliar spray of 1% $MgSO_4$ also recorded significantly higher Fe content in straw. Sahrawat *et al.* (1999) reported that the application of Mg generally improved the content of Fe in plant. The application of borax resulted in lower Fe content at 60 DAT and in straw. This is in line with the study of Santhosh (2013).

5.5.7 Manganese

The application of POP NPK along with FYM recorded the highest Mn content at all the stages (Table 4.14). There was decline in Mn content with the advancement of plant age as reported by Fageria (2004). 1 t of FYM may add

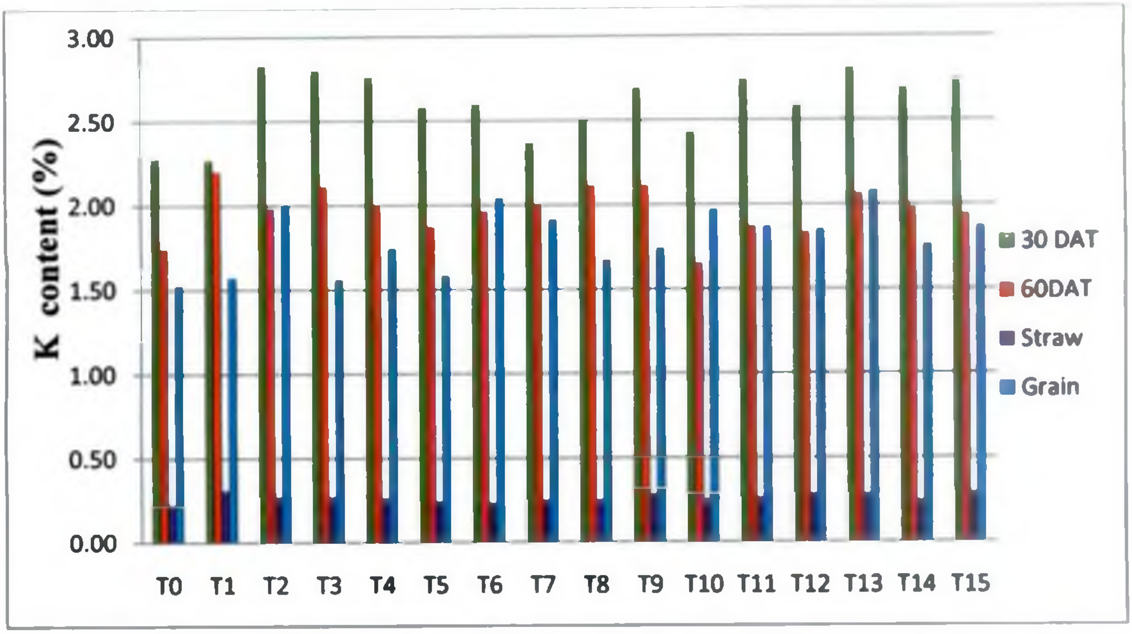

Fig. 5.9 Effect of treatments on potassium content of rice plant (%) at 30, 60 DAT & harve

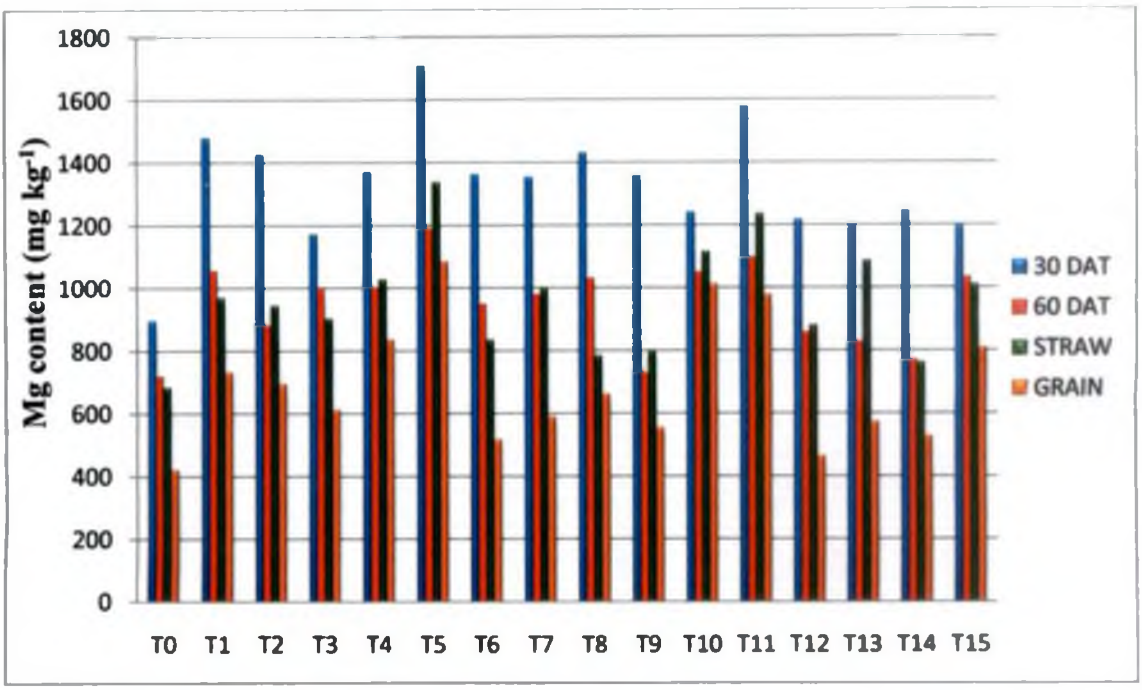

Fig. 5.10 Effect of treatments on magnesium content of rice plant (%) at 30, 60 DAT & ha

1.32 kg Mn depending upon its source (Kumar and Singh, 2010). So the application of FYM may lead to increased availability of Mn in soil solution for the absorption by plant which in turn increased its content in pant.

5.5.8 Zinc

The Zn content recorded by the foliar spray of $ZnSO_4$ @ 1% and soil test based nutrient application was on par at 30 & 60 DAT (Fig. 5.11). During the harvest Zn content in straw @1% foliar application was more than double than the soil application of Zn @ 20 & 30 kg ha^{-1}, where as in the grain it was comparable. Increasing the Zn concentration of foliar application could significantly enhance the Zn level in rice rice plant. There is a rapid rate of absorption when Zn was applied as foliar. This was in line with the reports of Fang *et al.* (2008) and Yilmaz *et al.* (1997).

When $ZnSO_4$ $7H_2O$ applied in soil, it interacts with various soil components like clay, organic manures, sesquioxides *etc.* and form its insoluble complexes which ultimately decreased the availability of Zn in soils and also uptake by the plants.

5.5.9 Boron

The application of borax either as soil or as foliar increased the content of B in rice plant compared to the POP NPK alone. The soil application of 10 kg borax ha^{-1} recorded the highest B content at all the growth stages (Fig. 5.12). Gaur and Singh (2010) reported that increasing levels of B up to 10 kg borax ha^{-1} significantly increased its content in plants over control. In plots, which received soil test based nutrients inclusive of FYM, there was a high content of B in plant.

5.5.10 Copper

The application of POP NPK along with FYM (T_2) recorded significantly higher Cu content at 30 DAT, 60 DAT and at harvest (Table 4.17). 1 t of FYM may add 0.43 kg Cu depending upon its source (Kumar and Singh, 2010). So the application of FYM may lead to increased availability of Cu in soil solution for the absorption by plant which in turn increased its content in pant. The Cu

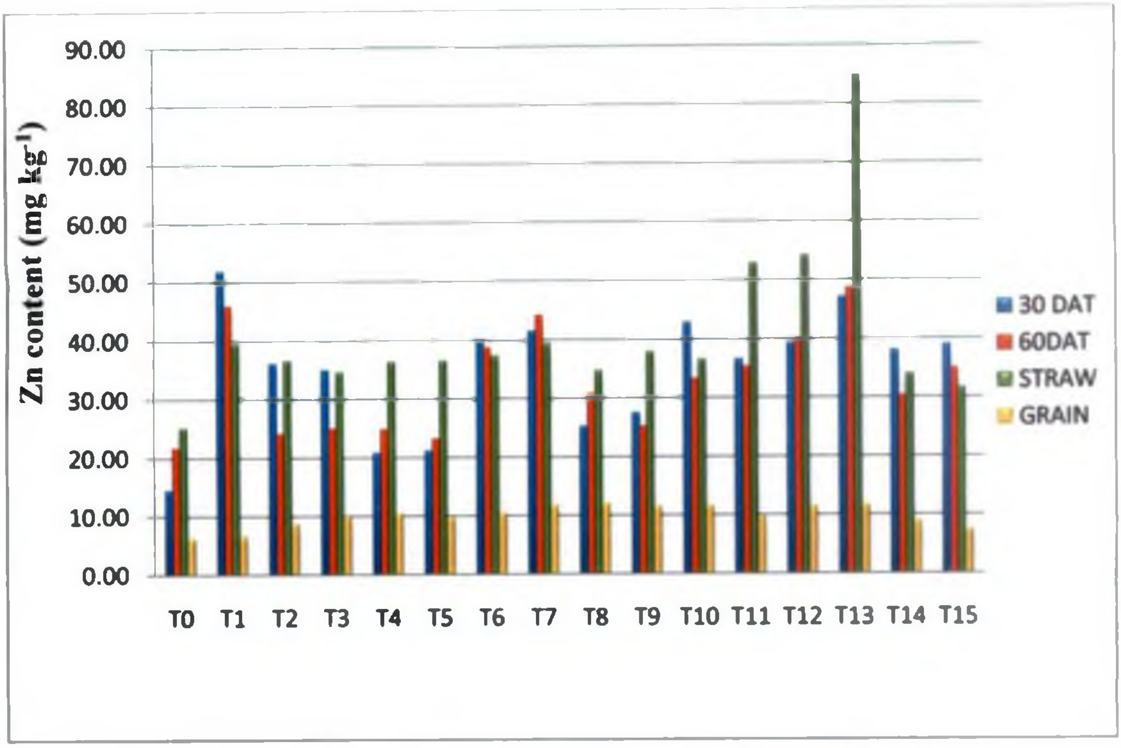

Fig. 5.11 Effect of treatments on zinc content of rice plant (%) at 30, 60 DAT & harvest

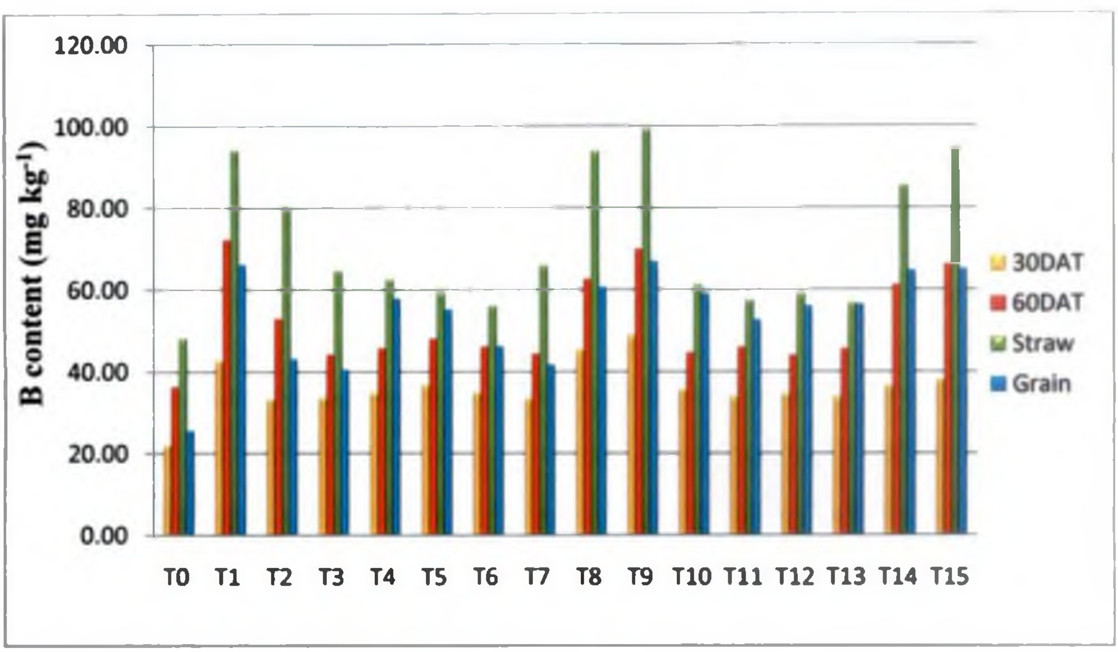

Fig. 5.12 Effect of treatments on boron content of rice plant (%) at 30, 60 DAT & harvest

content in plant was more at 60 DAT compared to 30 DAT even when the biomass 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.

When $ZnSO_4$ was applied either to soil or as foliar, the Cu content in grain is reduced without showing much difference in straw. Zinc decreased copper concentrations mainly by inhibiting copper absorption. This was in line with the study of Chaudhry and Loneragan (1970).

5.6 Nutrient uptake

5.6.1 Nitrogen

The uptake is a factor of content of nutrients and dry matter yield produced. The foliar spray of $MgSO_4$ @ 1% recorded the highest N uptake by grain (Table 4.18). This may be due to the higher content of N in grain and yield due to its application. The straw and total uptake of N was higher in POP NPK + FYM due to the higher content and yield. This may be due to favourable effect of physical and chemical environment of soil with FYM manure application which causes continuous supply of nutrients. It was also reported by Chandrapala *et al.* (2010) and Singh (2006). The foliar spray of $ZnSO_4$ at 0.5% also showed higher uptake of N by straw. The highest uptake of K with the application of Zn along with FYM was also reported by Husain *et al.* (2009).

5.6.2 Phosphorus

The application of 10 kg borax ha^{-1} resulted in the highest P uptake by grain which was comparable with that of $MgSO_4$ at 40 kg ha^{-1} and 0.25% foliar application of borax (Table 4.19). The foliar spray of 0.25% borax recorded the highest uptake of P by straw and crop. The B application had significant effect on phosphorus uptake by grain and straw due to the positive interaction between P and B when it applied at higher dose. The P uptake increased with the application of 10 kg borax ha^{-1}. This is in line with study of Gaur and Singh (2010). The foliar application of $MgSO_4$ at 1% also had significant effect on P uptake because

Mg act as a carrier of P in plants which increased the uptake and translocation of P. This was also reported by Varghese and Money (1965).

5.6.3 Potassium

The application of foliar spray of $ZnSO_4$ at 0.5% recorded the highest K uptake by grain, straw and crop (Table 4.20). The application of Zn increased the accumulation of K in leaf tissues which may lead to the increased uptake. This is in line with the study of Singh and Singh (2005). The application of NPK +FYM also recorded higher K uptake by grain due to the increased supply in the soil for absorption by plants. This may lead to increased content and uptake as reported by Chandrapala *et al.* (2010). The K uptake by the application of 0.5% foliar spray was very low indicating antagonistic effect between K and Mg.

5.6.4 Calcium

The highest Ca uptake by grain was observed by the application of 0.5% $ZnSO_4$ (Table 4.21). The application of Zn increased the calcium content which led to the higher uptake. The total uptake of Ca by the crop was higher when 10 kg borax ha^{-1} was applied in soil along with POP NPK because B application facilitates increased calcium content in plant which caused an increase in uptake. This is in line with the study of Muralidharan (1992). Singh and Singh (2005) reported that the application of Mg also increased the accumulation of K in leaf tissues.

5.6.5 Magnesium

In all the Mg applied plots, Mg uptake was more. The foliar spray of $MgSO_4$ at 1% showed better uptake of Mg by grain, straw and crop (Table 4.22). This may be due to the increased Mg content and yield by the application of $MgSO_4$. The direct spray of Mg on the foliage increased the concentration of Mg together with high yield leading to increased uptake of Mg. This is in line with the study of and Varughese and Jose (1993) and Choudhury and Khanif (2001).

5.6.6 Iron

The soil application of 30 kg $ZnSO_4$ ha^{-1} recorded the highest Fe uptake by the grain, straw and crop (Table 4.23). Fang *et al.* (2008) reported that Zn fertilizer application had a significant effect on Fe concentration of rice which led to higher uptake. The Fe uptake was comparatively higher due to the increased content of Fe in grain and straw. This might be due to the higher availability of Fe in soil.

5.6.7 Manganese

The application of POP NPK + FYM resulted in the highest uptake of Mn by grain and straw due to the increased concentration and yield (Table 4.24). The application of FYM may lead to increased availability of Mn in soil and subsequent absorption by plants. The uptake of Mn was less than the Fe uptake. This may be due to the antagonistic interaction between Fe and Mn as reported by (Olsen and Watanabe, 1979).

5.6.8 Zinc

The highest Zn uptake was obtained when $ZnSO_4$ was applied as 0.5% spray and it was comparable with 30 kg $ZnSO_4$ ha^{-1} (Table 4.25). The Zn uptake by grain and straw increased by the foliar application due to the increased content and yield. This was also reported by Das *et al.* (2004). Concentration and uptake of Zn were significantly influenced by Zn application . This sharp increase in Zn uptake at a greater Zn level may be related to greater increase in Zn concentration in soil solution at this Zn level (Fageria *et al.*, 2011). The uptake of Zn progressively increased with increasing level of Zn (Gupta and Handore, 2009).

5.6.9 Boron

The foliar spray of 0.25% B recorded the highest B uptake by grain and straw. It was comparable with the soil application of 10 & 20 kg borax ha^{-1} (Table 4.26). The foliar application of 0.25% borax increased the concentration of B which led to the higher uptake. The uptake by crops is closely related to B concentration in soil or soil solution. The application of B in soil increased the concentration of boron in soil solution. This led to the increased availability of B and consequently resulted in greater uptake by crop. This is in line with the report of Niaz *et al.* (2013).

5.6.10 Copper

There were no significant difference between the treatments on Cu uptake by the grain and straw. However, the foliar spray of $ZnSO_4$ at 0.5% recorded the highest Cu uptake by the crop (Table 4.27).

5.7 Soil characteristics

5.7.1 pH

The soil pH got reduced after the harvesting of crop compared to initial value (Table 4.28). The application of fertilizers has significant influence on soil pH changes. The application of N through ammonium sulphate and urea led to decreasing pH which is in agreement with the findings of Fageria *et al.* (2010). The results also showed that the soil application of 10 & 20 kg borax ha^{-1} also reduced the pH of the soil after harvesting of the crop due to the negative correlation of B with pH. Dunn *et al.* (2005) reported the same result.

5.7.2 EC

The EC of soil increased after the experiment in all the treatments compared to the initial value (Table 4.28). This may be due to the increased total soluble salts in the soil due to the application of nutrients especially $MgSO_4$, $ZnSO_4$ and borax.

5.7.3 Organic carbon

The organic carbon content of the soil after the experiment got reduced compared to the initial value in all the treatments. The application of FYM along with soil test based nutrients and POP NPK recorded higher organic carbon content (Table 4.28). The decomposition of FYM increased the organic carbon content in soil. Similar results were reported by Dash *et al.* (2000) and Kumar and Singh (2010).

5.7.4 Available N

NPK+ FYM application to rice crop recorded significantly higher quantity of available N content after the harvesting of crops (Fig. 5.13). Kumar and Sing (2010) reported that the application of NPK along with FYM gave significantly higher available N. This may be due to the increased addition of N from fertilizer and FYM (Chandrapala *et al.*, 2010).

There was a decrease in available nitrogen content from the initial value after the harvesting of crops in some treatments (T_1, T_4, T_6, T_{10}, T_{12}, T_{14}, & T_{15}). The decrease in soil N might be associated with crop uptake, immobilization of fertilizer N and its leaching under submerged condition (Yadav and Kumar, 2009).

Rathore *et al.* (1995) observed that residual soil fertility of available nutrients increased under FYM manure application. The continuous application of 120 kg N ha^{-1} every year failed to maintain the initial level of mineralized soil N.

5.7.5 Available P_2O_5

The status of available phosphorus content after the harvesting of rice crop decreased from the initial value (Fig. 5.14). This may be due to low pH and dominance of Fe in soil which leads to the fixation of phosphorus (Dixit, 2006). Generally there is an antagonistic interaction between Zn and P. But the foliar spray of 0.5% $ZnSO_4$ recorded significantly higher available P after the harvesting of crop. This may be due to the less build up of Zn in soil through foliar application. 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 line with the reports of Santhosh (2013) and Gaur and Singh (2010).

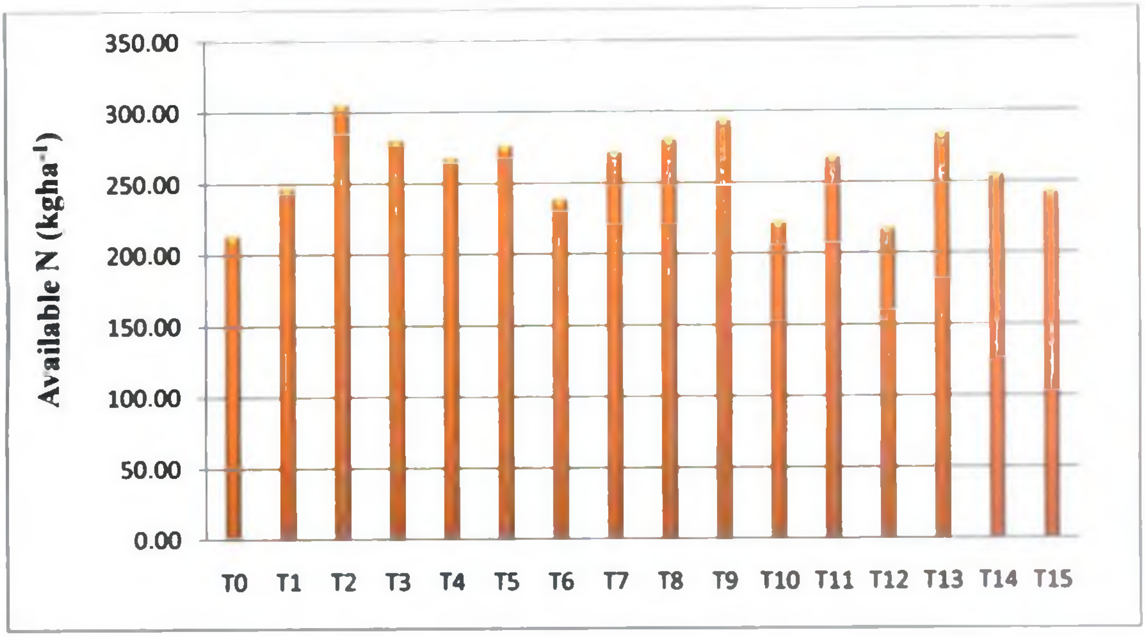

Fig. 5.13 Effect of treatments on available N (kg ha^{-1}) of soil after the experiment

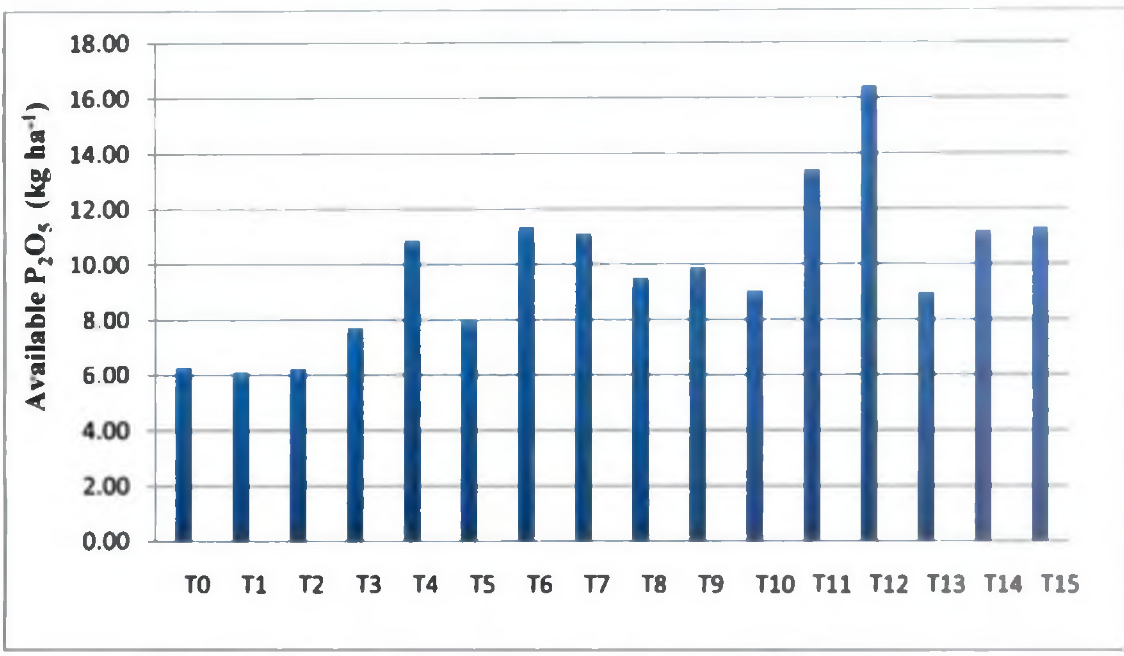

Fig. 5.14 Effect of treatments on available P_2O_5 (kg ha^{-1}) of soil after the experiment

5.7.6 Available K_2O

The content of available K_2O in soil after the experiment remained almost steady compared to initial value (Fig. 5.15). The application of nutrients did not have any effect on available K_2O. The status of available K_2O in soil was sufficient to supply adequate K. There is an antagonistic effect between K and Mg which resulted in reduced available K_2O (Ananthanarayana and Rao, 1979).

5.7.7 Available Ca

The available Ca content in soil was decreased after the experiment compared to the initial value. The application of POP NPK along with FYM recorded significantly higher Ca content (Table 4.30). Addition of Mg decreased the availability of calcium due to the calcium magnesium antagonism (Kumar *et al.*, 1981)

5.7.8 Available Mg

The available Mg content in soil after the experiment showed a steady value compared to the initial value (Fig. 5.16). The dissolution and release of Mg from Mg fertilizer taken place very slowly in laterite soil due to low pH (Varughese and Jose, 1993).

5.7.9 Available S

The available S content in soil after the harvesting of the crop increased compared to the initial value (Table 4.30). The application of $ZnSO_4$ and $MgSO_4$ increased the available S content due to residual effect. This was also reported by Chandrapala *et al.* (2010).

5.7.10 Available Fe

The available Fe content of soil increased compared to the initial value (Table 4.31). The continuous flooding of the soil increased the availability of Fe

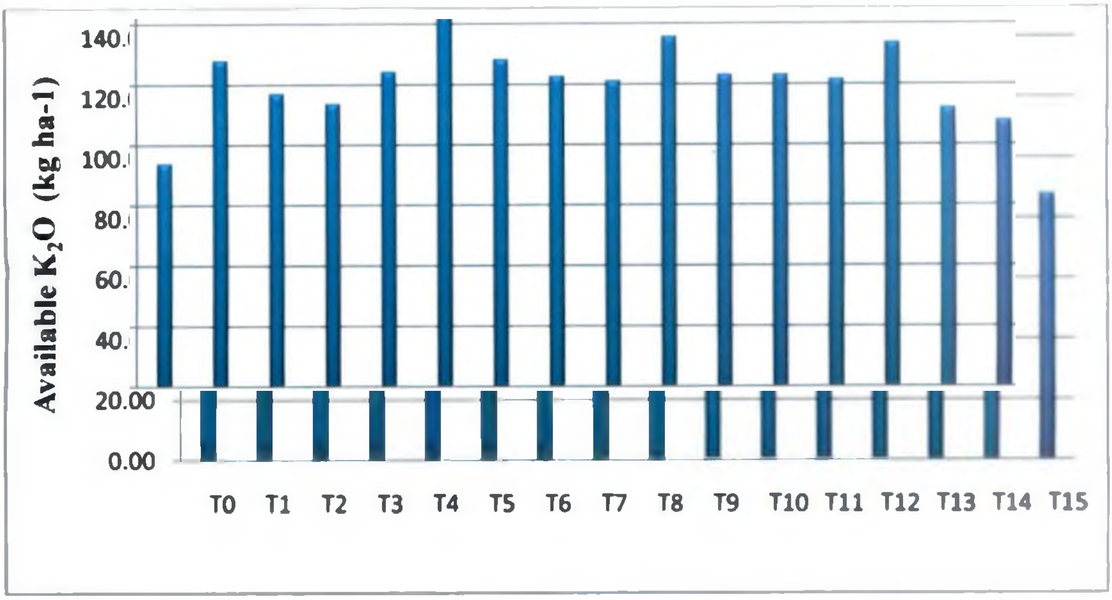

Fig. 5.15 Effect of treatments on available K_2O (kg ha^{-1}) of soil after the experiment

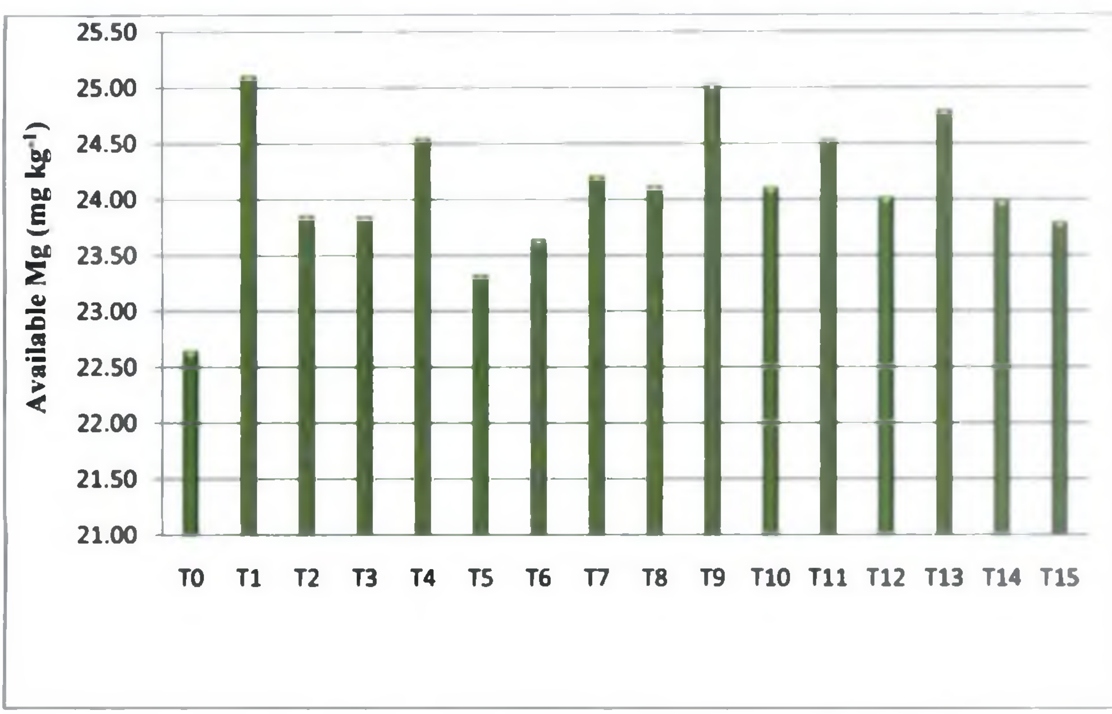

Fig. 5.16 Effect of treatments on available Mg (kg ha^{-1}) of soil after the experiment

in soil (Ponnamperuma, 1978). The control treatment recorded the highest available Fe content in soil.

5.7.11 Available Mn

The availability of Mn increased after the experiment. This may be due to the continuous flooding of soil (Table 4.31). The pH was decreased after the experiment which resulted in relatively higher concentration of Mn as it had a significant negative correlation with pH (Papadopoulos *et al.*, 2009). The application of NPK + FYM 5.0 t ha^{-1} also recorded higher Mn content. This is in line with the result of Kumar and Singh (2010).

5.7.12 Available Zn

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 (Fig. 5.17). Similar result was reported by Husain *et al.* (2009). Zinc being comparatively mobile in soil results in accumulation due to the application. The availability of zinc decreased in control plots due to the continuous uptake and non supplement of this nutrient.

5.7.13 Available B

Initially there was a deficiency of boron which might be due to the high status of Fe. The application of boron in deficient soil increased the concentration of boron in soil solution as reported by Gaur and Singh (2010). Soil test based all nutrient package inclusive of FYM showed greater B content after the experiment due to the supply of B (Fig. 5.18).

5.7.14 Available Cu

The available copper content increased after the experiment compared to the initial value (Table 4.32). The status of available Cu in soil was sufficient enough to supply this nutrient in soil solution.

5.8 Economics of cultivation

Even though the highest grain yield was noted by the application of POP NPK+FYM, the foliar application of 0.5% of $ZnSO_4$ and 0.25% of borax resulted

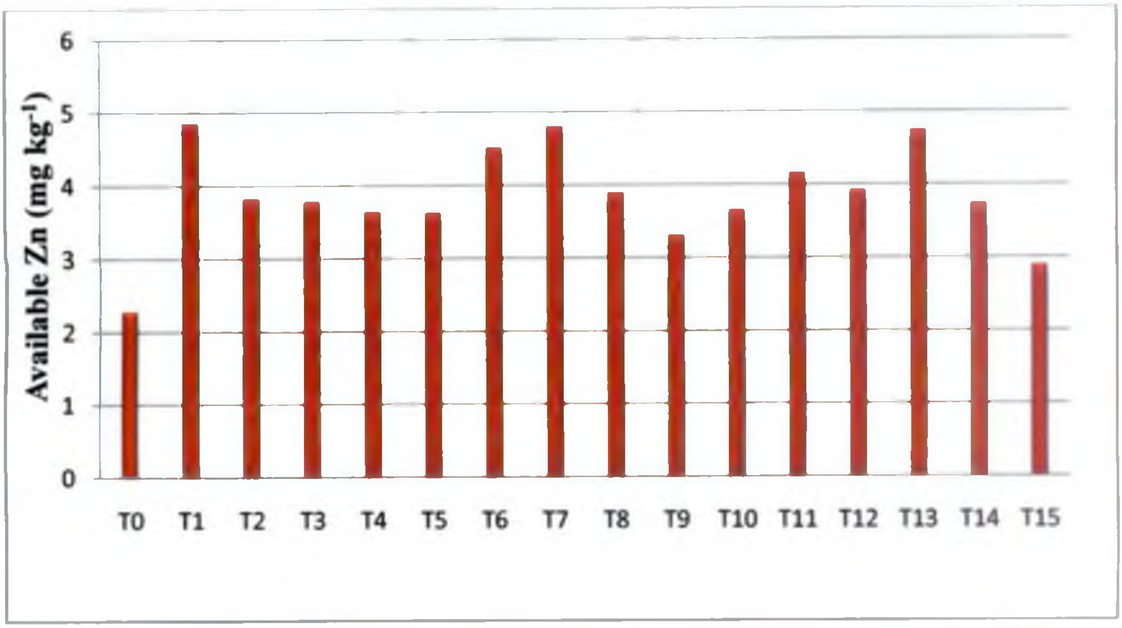

Fig. 5.17 Effect of treatments on available Zn (kg ha^{-1}) of soil after the experiment

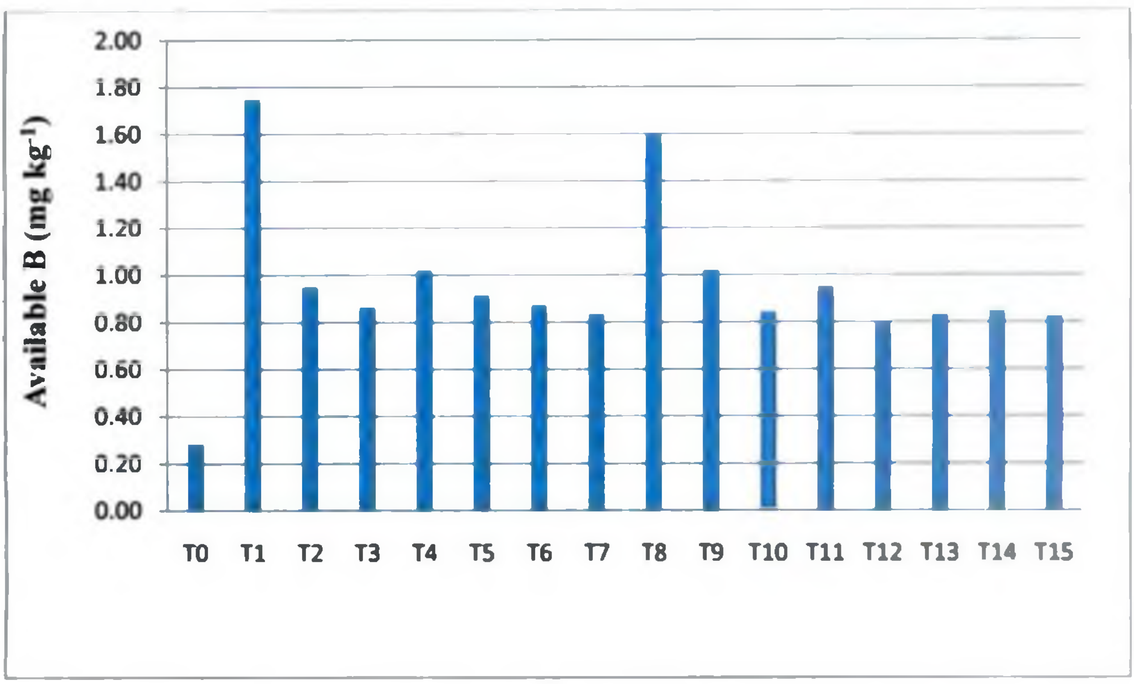

Fig. 5.18 Effect of treatments on available B (kg ha^{-1}) of soil after the experiment

in higher BC ratios, followed by 1% $MgSO_4$ (Table 4.33). This might be due to the higher cost of FYM. Similar or higher BC ratios were observed for secondary or micronutrients applied treatments than POP recommendation. The BC ratios were markedly increased when these nutrients were foliar applied at desired concentrations due the lower quantity of fertilizer required for foliar spray and also higher yield.

Discussion summerised

The application of specific secondary (Mg) or micronutrients (Zn & B) together with POP NPK improved the growth characters of rice especially plant height, tiller count, dry matter production, LAI *etc* compared to POP NPK alone. The height of plant, number of tillers and dry matter production were higher in the treatments where secondary or micronutrients were applied along with POP NPK than in soil test based nutrient application. The N recommendation in soil test based nutrient application was only based on organic carbon content of soil not on mineral N content. So the recommendation of N in soil test based nutrient application became 70 kg ha^{-1} which was less than the existing POP (90 kg ha^{-1}). The application of secondary and micronutrients also have significant effect on nutrient content in rice and uptake by the crop.

Nutrient application with or without FYM enhanced the rice yield considerably. The yield in unfertilized treatment was 2.30 t less than that of the mean yield of 6.8 t ha^{-1} in the fertilized treatments (T_1 to T_{15}) treatments. The highest yield among the fertilized treatments was recorded for the existing POP recommendation of 5 t FYM + NPK at 90: 45: 45 kg ha^{-1}. The application of NPK alone could produce only 6.39 t ha^{-1}, which was 1.24 t less than NPK +FYM treatment. It was evident from the data that application of specific secondary and micronutrients together with NPK could increase the yield. It also implied that such nutrients contained in the FYM was sufficient to produce higher yield. The treatment which received FYM + soil test based NPK application resulted in a half ton reduced yield than that of POP, mainly due to a decreased quantity of N (70 kg ha^{-1}). The N recommendation in soil test based nutrient application was made on the basis of organic carbon content in the soil and not on mineral N content, and the mineralization rate of N from organic matter might have influenced the estimated quantity of N to be supplied.

Supply of additional nutrients other than NPK, either soil applied or as foliar spray, resulted in higher yield than NPK alone except with the lower dose of Mg and higher dose of B, when both were applied as foliar. Rice has responded similarly to soil application of $MgSO_4$ @ 80 kg ha^{-1} or the same as 1% foliar spray in enhancing yield over the one with NPK+FYM, however its 0.5% was not effective. With regard to zinc, foliar application at the lower level of 0.5% was significantly superior to its higher dose (1%) or the soil application at either 20 or 30 kg ha^{-1}. Soil application of borax @ 10 kg ha^{-1} or foliar spray at 0.25% resulted in more than 7 t yield per ha. In the case of boron, application of higher doses either as 20 kg ha^{-1} soil application or as 0.5% foliar spray were found to be not effective and foliar application at this concentration markedly reduced the yield.

Grain yield in transplanted crop is a function of planting density (hills per unit area) productive tillers (panicles/hill), number of spikelets/panicle, fertility percentage and the test weight of grains. The rice was transplanted at 50 hills/m^2 as per the POP recommendation, to give an optimum plant stand and subsequently higher yield. A perusal of the data (Table 4.6) brings about the importance of FYM as a multi nutrient source which positively influenced all the yield attributing characters. It is to be noted that all the yield attributing characters have recorded significantly lower values for the treatment which received NPK alone than others which received FYM or secondary or micronutrients. $MgSO_4$ application either as soil or as foliar has significantly influenced the panicles/hill, spikelets/panicle and 1000 grain weight. Lower doses of zinc (either soil application or foliar) also positively influenced all the yield attributing characters. Borax at lower dose of foliar spray resulted in the highest percentage of filled grains. Other characters were also positively influenced by the lower dose of borax, irrespective of method of application. Higher dry matter production and HI were observed for treatments when FYM was applied or fertilized with secondary or micronutrients, which implied a reduction in the production of secondary metabolites and translocation of photosynthates to the grain in the absence of specific nutrients.

Summary

VI. SUMMARY AND CONCLUSION

The present study entitled "Relative efficiency of soil and foliar applied nutrients in irrigated rice of Palakkad" was carried out in the farmer's field, Thathamangalam, Palakkad during *Mundakan* season October 2011- February 2012 to compare the efficacy of soil and foliar applied nutrients especially magnesium, zinc and boron. 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. Soil application of Mg, Zn and B were done as basal according to the treatments. Mg, Zn and B as 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. The application of $MgSO_4$ either as soil applied @ 80 kg ha^{-1} or as 1% foliar spray and soil application of $ZnSO_4$ at 20 kg ha^{-1} along with POP NPK recorded significantly more height at harvest. However, POP NPK + FYM @ 5 t ha^{-1} was also at par with these treatments. Application of borax at 10 & 20 kg ha^{-1} did not show any difference.
2. The application of POP NPK along with FYM recorded the highest tiller count at 30 DAT. The tiller count increased from 30 to 60 DAT in some treatments and it was higher in the soil application of 20 kg $ZnSO_4$ ha^{-1} at 60 DAT. At harvest stage more productive tillers were observed by the foliar application of 1% $MgSO_4$, 20 kg $ZnSO_4$ ha^{-1} and POP NPK + FYM. The tiller decline from 60 DAT to harvest was very severe in control plot compared to other treatments and was lower in POP NPK+ 0.5% $ZnSO_4$ and POP NPK +FYM.

3. The soil application of 10 kg borax ha^{-1} showed the highest LAI followed by soil test based nutrient application and POP NPK +FYM and was lowest in control treatment.
4. The soil application of 20 kg borax ha^{-1} and POP NPK +FYM recorded comparatively higher chlorophyll a, Chlorophyll b and total chlorophyll and the lowest was in the control treatment. Foliar spray of 0.5% was effective than its spray @ 1% or soil application at 20 & 30 kg ha^{-1}.
5. The soil applied $MgSO_4$ at 40 kg ha^{-1} produced higher dry matter followed by $ZnSO_4$ at 20 kg ha^{-1} and POP NPK +FYM at 30 DAT. At 60 DAT and at harvest, the application of POP NPK + FYM recorded the highest dry matter.
6. $MgSO_4$ application either as soil or as foliar spray has significantly influenced the panicles/hill, spikelets/panicle and 1000 grain weight. Lower dose of Zn (either soil applied or foliar) also positively influenced all the yield attributing characters. Borax at lower level of foliar spray resulted in the highest percentage of filled grain. The application of POP NPK +FYM positively influenced all the yield attributing characters.
7. The application of POP NPK +FYM recorded the highest grain yield which was comparable with the application of 0.50 % $ZnSO_4$, 0.25 % Borax, 10 kg borax ha^{-1} and 1% $MgSO_4$ along with POP NPK. Borax at 0.5% foliar application and soil application at 20 kg ha^{-1} reduced the yield. The highest straw yield was obt y the foliar application of 0.50 % $ZnSO_4$ along with the POP followed by POP NPK +FYM. The HI was higher in treatments where specific secondary and micronutrients were applied and also in FYM application along with POP NPK
8. The BC ratio was higher in foliar application of 0.50 % $ZnSO_4$, 0.25 % Borax, 1% $MgSO_4$ and soil application of 10 kg borax ha^{-1} compared to the POP NPK +FYM.
9. There was no significant difference on N content of plant between the treatments. N content in grain was the highest in foliar applied $MgSO_4$ at

1%. The foliar applied $MgSO_4$ at 1% could produce significant effect on N uptake.

10. The highest P content at 30 DAT was observed in soil test based nutrient application and 1% foliar applied $MgSO_4$. At 60 DAT and in grain, P content was highest in soil applied $MgSO_4$ at 40 kg ha^{-1}. The foliar applied borax at 0.25% and 0.5% recorded the highest P content in straw. The foliar applied borax at 0.25% influenced the uptake of P.
11. The application of POP NPK + FYM recorded the highest K content at 30 DAT. At 60 DAT and in grain, the soil test based nutrient application showed the highest K content. The highest K content in straw was noted in foliar application of 1% $ZnSO_4$ and could produce significant effect on K uptake.
12. The soil application of 30 kg $ZnSO_4$ ha^{-1} recorded higher Ca content at all the stages. The application of 0.5 % $ZnSO_4$, 1 % $MgSO_4$, POP NPK and POP NPK +FYM influenced the uptake of Ca.
13. Throughout the growth stages application of $MgSO_4$ showed a higher content of Mg in the plant when it was applied as soil or foliar. The highest Mg content was noted in POP NPK + $MgSO_4$ @ 80 kg ha^{-1} followed by 1% $MgSO_4$ foliar and could produce significant effect on Mg uptake.
14. The highest Fe content was noted in plot where $ZnSO_4$ at 30 kg ha^{-1} was applied along with POP NPK application and it also recorded the highest Fe uptake.

15. The Mn content was highest by the application of POP NPK along with FYM at all the stages. The higher uptake was also noted in POP NPK + FYM.
16. Zn content was higher in 1% foliar spray of $ZnSO_4$ at various stages of growth. The application of $ZnSO_4$ either as soil or as foliar significantly influenced the uptake of Zn.

17. The soil application of 10 kg borax ha^{-1} recorded significantly higher B content at 30 DAT, 60 DAT and at harvest. The foliar application of 0.25 % borax resulted in significantly higher B uptake.
18. The application of POP NPK along with FYM recorded significantly higher Cu content at 30 DAT, 60 DAT and at harvest. There was not much difference on uptake of Cu between the treatments.
19. The application of $MgSO_4$, $ZnSO_4$ and borax significantly influenced the pH, EC, OC and available nutrient status of soil after the experiment. The application $ZnSO_4$ and borax increased the status of Zn and B of soil after the experiment.
20. The application of secondary and micronutrients must be location and variety specific.

CONCLUSION

- FYM application increased the growth and yield of rice significantly
- Soil test based nutrient application resulted in lower yield than Package of Practice recommendation. It may be due to the lower quantity of N estimated based on soil organic carbon content
- Application of $MgSO_4$ @ 80 kg ha^{-1} or $ZnSO_4$ @ 30 kg ha^{-1} and borax @ 10 kg ha^{-1} resulted in similar yield as that of POP recommendation even in the absence of FYM application
- Foliar spray of 1% $MgSO_4$, 0.5% $ZnSO_4$ and 0.25% borax were equally or more effective than its soil application at 80 kg $MgSO_4$, 30 kg $ZnSO_4$ and 10 kg borax ha^{-1} respectively
- Higher rate of borax with more than 10 kg ha^{-1} or 0.25% foliar spray significantly reduced the yield
- Similar or higher BC ratios were observed for secondary or micronutrients applied treatments than POP recommendation
- The BC ratios were markedly increased when these nutrients were foliar applied at desired concentrations

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* Originals not seen

Appendices

Appendix – 1

Monthly weather data during the crop period

Month	Temperature (^{0}c)		RH (%)		Rainfall (mm)	Rainy days	Mean evaporation (mm)	Sunshine hrs
	Maximum	Minimum	Morning	Evening				
October	31.1	23.5	91	65	193	9	109.1	190.4
November	31.4	22.9	79	57	240	9	114.2	188.9
December	31.9	21.9	75	49	2.4	-	151.1	226.6
January	32.8	21.3	75	40	0	-	158.2	294.0
February	35.1	22.1	75	33	0	-	168.8	265.4

Appendix – 2

Details of cost of cultivation

Sl.No.	Particulars	Men/acre (Rs.400/day)	Women/acre (Rs.250/day)	Amount (Rs./ha)
	Field operations			
1	Ploughing	-	-	2750/-
2	Nursery & Transplanting (Machine)	-	-	7500/-
3	Fertilizer application	4	-	4000/-
4	Weeding (Twice)	-	10	6250/-
5	Water management	2	-	2000/-
6	Foliar spraying of fertilizer	2	-	2000/-
7	Plant protection chemical spraying	2	-	2000/-
8	Harvesting (Machine)	-	-	5000/-
9	Post harvesting	-	6	3750/-

Appendix – 3

Details of cost of inputs

Sl No.	Particulars	Amount (Rs./kg)
1	Seed	20/-
2	FYM	2/-
3	Lime	10/-
4	Urea	7/-
5	Ammonium sulphate	11/-
6	Rajphos	6/-
7	MOP	18/-
8	Magnesium sulphate	12/-
9	Zinc sulphate	52/-
10	Borax	55/-

Abstract

RELATIVE EFFICIENCY OF SOIL AND FOLIAR APPLIED NUTRIENTS IN IRRIGATED RICE OF PALAKKAD

by

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ABSTRACT OF THE THESIS

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ABSTRACT

The research programme entitled "Relative efficiency of soil and foliar applied nutrients in irrigated rice of Palakkad" was conducted in the farmer's field, Thathamangalam, Palakkad during *Mundakan* season October 2011-February 2012 to compare the efficacy of soil and foliar applied nutrients especially magnesium, zinc and boron. The treatments included package of practices recommendation for rice manuring (POP NPK+FYM), NPK alone as in the package of practices recommendation (POP NPK), soil test based nutrient application +FYM, soil application of $MgSO_4$ @ 40 & 80 kg ha^{-1}, $ZnSO_4$ @ 20 & 30 kg ha^{-1}, Borax @ 10 & 20 kg ha^{-1}; foliar spray of $MgSO_4$ @ 0.5 & 1%, $ZnSO_4$ @ 0.5 & 1% and Borax @ 0.25 & 0.5% and an absolute control. Soil application of Mg, Zn and B were done as basal and foliar application 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 improved by the application of $MgSO_4$, $ZnSO_4$ and borax along with POP NPK treatment. The application of POP NPK inclusive of FYM also resulted in noticeable improvement in growth characters. The height, number of tillers and dry matter production were low in the treatments which received soil test based nutrient application. The foliar application of 1% $MgSO_4$ resulted in higher number of productive tillers. The higher level of borax either as soil application or as foliar spray had depressing effect on crop growth characters. The application of $MgSO_4$, $ZnSO_4$ and borax showed significant increase in chlorophyll content at 60 DAT.

$MgSO_4$ application either as soil or as foliar spray has significantly influenced the panicles/hill, spikelets/panicle and 1000 grain weight. Lower dose of Zn (either soil applied or foliar) also positively influenced all the yield attributing characters. Borax at lower level of foliar spray resulted in the highest percentage of filled grain. The application of POP NPK +FYM

positively influenced all the yield attributing characters. The soil application of $MgSO_4$ at 80 kg ha^{-1} or at 1% foliar spray resulted in an increased yield over the POP NPK alone. With regard to zinc, foliar spray at the lower level of 0.5% was significantly superior to its higher concentration (1%) or its soil application @ 20 or 30 kg ha^{-1}. The soil application of borax at 10 kg ha^{-1} or foliar spray at 0.25% concentration resulted in more than 7 t yield per ha. Higher dose of B (20 kg ha^{-1}) either as soil application or as 0.5% foliar spray was found to be not effective and reduced the yield. Soil test based nutrient application together with FYM resulted in an almost 1 t less grain yield than that of POP recommendation possibly due to the application of an estimated lower N rate. Similar or higher BC ratios were observed for secondary or micronutrients applied treatments than POP recommendation. The BC ratios were markedly increased when these nutrients were foliar applied at desired concentrations.

The nutrient contents of rice plants were also influenced by the application of $MgSO_4$, $ZnSO_4$ and borax along with POP NPK. The soil application of $MgSO_4$ @ 80 kg ha^{-1} and foliar spray @1% increased the content and uptake of Mg. The Zn content was higher in 1% foliar spray of $ZnSO_4$ and the application of $ZnSO_4$ either as soil or as foliar significantly influenced the uptake of Zn. In the case of B, the soil application of 10 kg borax ha^{-1} recorded significantly higher B content and the foliar application of 0.25 % borax improved the B uptake. A higher content of nutrients together with higher yield contributed to the higher uptake of nutrients. The application of POP NPK+FYM also recorded significantly high content of nutrients and uptake.

The application of $MgSO_4$, $ZnSO_4$ and borax along with POP NPK significantly influenced the pH, EC, OC and available nutrients of soil after the experiment. The status of available N and K_2O remained almost constant after the experiment. But the P_2O_5 content got reduced. The application of $ZnSO_4$ and borax increased the status of Zn and B in soil. Available Mg was more or less similar after the experiment, compared to the initial content.

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