SECONDARY AND MICRONUTRIENT MANAGEMENT FOR ENHANCING SOIL HEALTH AND PRODUCTIVITY IN UPLAND RICE

by

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Secondary and micronutrient management for enhancing soil health and productivity in upland rice"**, 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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SHAMSIDA P.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

%	Per cent
₹	Indian rupee (s)
@	At the rate of
°C	Degree Celsius
°E	Degree East
°N	Degree North
B	Boron
B:C	Benefit cost
Ca	Calcium
CEC	Cation Exchange Capacity
CD	Critical difference
cm	centimeter
cm^3	Cubic centimeter
c mol kg^{-1}	centi mol per kilogram
Cu	Copper
DAS	Days after sowing
ds m^{-1}	deci Siemens per meter
DTPA	Diethylene triamine penta acetic acid
EC	Electrical Conductivity
et al.	and other co workers
Fe	Iron
FYM	Farmyard manure
Fig.	Figure
g	gram
ha	Hectare

i.e.	That is
K	Potassium
kg	kilogram
kg ha^{-1}	kilogram per hectare
L	litre
m	metre
mm	millimeter
Mg	Magnesium
Mg m^{-3}	Mega gram per cubic metre
Mn	Manganese
Mo	Molybdinum
m^{-2}	Per square meter
mg kg^{-1}	milli gram per kilogram
N	Nitrogen
No.	Number
NS	Non-significant
P	Phosphorus
pH	Negative logarithm of hydrogen ions
ppm	Parts per million
RBD	Randomized Block Design
m^2	Square metre
t ha^{-1}	tonnes per hactare
viz.	Namely
Zn	Zinc

INTRODUCTION

1. INTRODUCTION

Rice (*Oryza sativa* L.), is the most important food crop of the world, relied upon by more than half of the global population. Though rise in population and increased consumer preference has escalated the demand for rice, global production does not meet the ever increasing demand mainly due to the twin threats of declining productivity and shrinking area of wet land paddy.

There has been a drastic decline in the area of wet land rice in Kerala, over the years, mainly due to conversion of rice fields for urbanization and for the cultivation of more remunerative crops. But the demand for rice is increasing, with an estimated requirement of 35- 40 tonnes per annum. The area under rice, which was 1.97 lakh ha with a production of 5.08 lakh tones during 2015-16 (GoK, 2016) has dropped to 1.71 lakh ha and 4.3 lakh tones, respectively during 2017- 18 (GoK, 2018). Thus the deficit in rice production is increasing year after year due to a reduction in area and decline in productivity.

The most effective means of attaining sustainable rice production is to increase the productivity at the farm level. But there are several factors limiting yield under wet land conditions. Indiscriminate and imbalanced use of high analysis fertilizers has not only deteriorated soil physico-chemical properties, but also caused considerable pollution of soils and waters. Hence crop response to applied fertilizers has declined with a corresponding decrease in fertilizer use efficiency (Nair, 2012). Moreover, indiscriminate use of chemical fertilizers along with reduced use of organic manures has led to widespread micronutrient deficiencies thereby aggravating the productivity decline in rice (Singh *et al.,* 2009).

The limited wetland area available for rice cultivation with minimum scope for expansion coupled with scarcity of water resources, has forced rice farmers to search for alternative methods of cultivation, to meet the increasing demand. Since rice thrives reasonably well under diverse soil and climatic conditions, more thrust has been recently laid upon upland rice technology.

Upland rice is grown under aerobic conditions in soils which are unflooded for a major part of the growing season wherein, the crop which is naturally adapted to semi aquatic conditions, has to regulate to dry conditions. This results in unstable yields, chiefly due to water scarcity and resulting nutrient uptake problems. The other major constraints faced by upland rice farmers are unreliable and uneven distribution of rainfall and low soil fertility which hinders nutrient uptake, leading to a reduction in reproductive growth (Wade *et al*., 1999).

Upland rice cultivation has been in vogue in Kerala since time immemorial, using traditional varieties. Generally soils put to upland rice are highly acidic, low in CEC and encounter mineral stresses like low exchangeable bases, toxicity of micronutrients like Fe, Al and Mn and deficiency of K, Ca, Mg, Zn and B. Occurrence of such mineral stress during the critical growth stages adversely affect the growth and productivity of the crop.

But rice when grown under dry condition responds well to management practices like adequate fertilization, organic manure addition and management of acidity through the application of liming materials. Liming along with the addition of organic manure and micronutrients increases the base saturation of soil, provide balanced nutrition, sustain soil fertility, improve nutrient availability and produce better crop yields under upland conditions.

A survey of soils of Kerala by the Kerala State Planning Board (2013) has identified extensive deficiencies of secondary nutrients *viz.* Ca and Mg with 40 and 75 %, respectively and the micronutrient boron with 60 % deficiency. Zinc deficiency was also found in 12 % of the soils sampled. This necessitates judicious application of secondary and micronutrients to these soils to obtain optimum rice yields under upland conditions. The range in deficiency and toxicity limit of micronutrients being very narrow; chances of over dose are high (Katyal *et al.,* 2004). In addition, the difficulty in application of individual macro and micronutrients, the time factor involved, the increased cost of application and the poor use efficiency of applied nutrients make farmers slip away from secondary and micronutrient application. Hence combined application of nutrients as foliar spray is a viable alternative. This will also overcome the problems related to low nutrient availability due to water stress during critical growth stages, negative effect of soil pH, nutrient interactions and losses, and accumulation of nutrients to toxic levels.

Since nutrients are delivered to roots mainly by mass flow and diffusion, the availability is decreased as moisture stress increases under upland conditions. Hence foliar fertilization can be considered more efficient for supplementing nutrients to the crop. It also facilitates easy and quick absorption of nutrients and better utilization by plants (Gooding and Davis, 1992).

Organic manure application incorporates essential nutrients to the soil matrix, and allows the soil to act as a reservoir of nutrients, which will be released gradually, for uptake by the plants. Several research have been conducted on organic and inorganic nutrient management approaches in lowland rice, but little has been documented on the response of upland rice to different nutrient management practices including secondary and micronutrient application in Kerala.

Hence there is an urgent need for production technologies involving organic and inorganic nutrient management that will help increase upland rice yields. Therefore this study entitled "Secondary and micronutrient management for enhancing soil health and productivity in upland rice" was carried out at College of Agriculture, Vellayani and at farmer's field in Venganoor, Thiruvananthapuram during 2016-'18 using the medium duration rice variety Uma, with the objective of assessing the effect of secondary and micronutrient application on the productivity of upland rice under organic and integrated nutrient management practices and its effect on soil health.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Rice is the second most widely grown cereal crop globally and the staple food for majority of the world population. Adoption of intensive cultivation practices using high yielding varieties, indiscriminate use of high analysis fertilizers without supplementing secondary and micronutrients, insufficient liming of acid soils and reduced use of organic manures have accelerated the productivity decline of rice (Ray, 2011).

The possibility for expanding areas under rice, for a sustainable increase in rice production is very limited because of scarcity of water resources and the expansion of urban and industrial sectors at the cost of wetlands. This has necessitated a shift from wetland to upland rice cultivation, by utilizing the homesteads and interspaces in coconut gardens. But rice being adapted to semiaquatic conditions, give poor and unstable yields under upland conditions mainly due to soil acidity, low base status, water stress and associated nutrient uptake problems. There is scope for increasing the productivity of upland rice since it responds well to appropriate management efforts like fertilization, liming and organic manuring.

A brief review of related literature on rice and rice nutrition with special emphasis on the role of secondary and micronutrients in enhancing the growth and yield of upland rice is presented in this chapter.

2.1 RICE CROP

Rice (*Oryza sativa* L.) is the staple food of a large section of humankind, and occupies the second position in production and consumption in the world (FAO, 2009). Rice, that has been cultivated in Asia since time immemorial, belongs to three sub species; Indica, Japonica and Javanica (Gupta and O'Toole, 1986).

The rice plant, belonging to the grass family Poaceae, is a short day crop adapted to semi–aquatic conditions. Unlike other crops, rice possess some structural adaptations which enables it to tolerate submergence. This is achieved by the longitudinal interconnections called aerenchyma which are air spaces enabling internal aeration within the rice plant, thus supplying oxygen from the aerial parts down to the roots (Yoshida, 1981, and Setter *et al.,* 2009). The crop has been cultivated in all regions having abundant moisture and sufficient temperature for optimum growth. Climate and soil conditions like temperature, rainfall, relative humidity, solar radiation, soil type and nutrient status affect the development and performance of rice (De Datta, 1981; FAO, 2009).

2.2 SOIL AND NUTRIENT REQUIREMENT OF RICE

Rice crop can be cultivated under varying soil conditions, from the coarser sandy loam to heavy clays but heavy soils are more preferred. Flooding improves nutrient availability and reduces the effects of very alkaline or acidic soil conditions on plant growth that occurs under aerobic conditions (Nwilene *et al.,* 2008). Though nitrogen, phosphorus and potassium are the major elements that limit rice production, the role of secondary and micronutrients in improving productivity has been well established (Mghase *et al.,* 2010).

2.3 ROLE OF SECONDARY NUTRIENTS

2.3.1 Functions of Secondary Nutrients in Plants

Calcium is involved in cell division and elongation and plays an important role in the maintenance of cell membrane integrity. It also helps to maintain the nutrient balance in plant tissues and to ameliorate heavy metal toxicity (Fageria *et al.,* 1997).

Magnesium is required for grana stacking and formation of light-harvesting chlorophyll a/b complexes (Obatolu, 1999). It is involved in CO_2 assimilation and protein synthesis and 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).

2.3.2. Effect of Secondary Nutrients on Growth and Yield of Rice

Krasaesindhu and Sims (1972) reported that application of Ca increased grain yield decreased straw yield and markedly increased grain: straw ratio in rice. Soil application of magnesium as basal dose in the form of $MgSO_4$ (16% MgO) or dolomite (10% MgO) @ 20kg MgO ha^{-1} was also found to be effective in producing a significant increase in grain and straw yields of rice (KAU, 2016).

Significant increase in grain and straw yields of rice was achieved by the application of Mg in the form of $MgSO_4$, magnesite or dolomite in Mg deficient soils (Biswas *et al.*, 2013). The harvest index of rice decreased due to the application of Mg as magnesium carbonate at the rate of 50 kg ha^{-1}.

In rice, application of Ca and Mg alone or in combination had a non-significant increase in yield (Preman, 2015). Application of dolomite to lowland rice fields affected with Fe^{2+} toxicity also increased grain yield, plant height and shoot and root dry weights (Suriyagoda *et al.*, 2016). Application of Ca and Mg supplemented with phosphorus significantly increased the grain and straw yields, agronomic and physiological P efficiencies and improved harvest index of upland rice grown on an ultisol (Sahrawat *et al.*, 1999).

Amelioration of an acid soil with lime significantly increased the yield components of rice like number of panicle bearing tillers, grains per panicle and 1000 grain weight (Chang and Sung, 2004). Liming at the rate of 1 t ha^{-1} significantly influenced all the plant parameters viz. plant height, panicle length, number of panicles per hill, grains per panicle and grain yield of rice over the unlimed plot. Further increase in lime rate to 2 t ha^{-1} caused an increase in the number of grains per panicle of rice. Rahman *et al.* (2002) also reported that the highest rice yield (4.9 t ha^{-1}) was recorded with the application of lime in an acidic soil compared to other treatments. Soil pH was increased and crop growth significantly improved in direct seeded rice system due to lime application (Arshad and Gill, 1996).

2.3.3 Effect of Secondary Nutrients on the Content and Uptake of Nutrients by Plants

Liming of rice grown in acidic red and laterite soils not only ameliorate soil acidity related problems but also supply Ca and increases the uptake of Ca by the plant (Fox *et al.*, 1991; Samui and Mandal, 2003). Application of Mg improved the contents of N, Ca, Mg and Fe in rice (Sahrawat *et al.,* 1999). Preman (2015) also reported that supply of Mg either through soil or as foliar application registered higher Mg content in rice.

There are also reports that uptake, translocation and metabolism of essential micronutrients such as Zn may be inhibited by lime application, through an increase in soil pH and the surface adsorption of zinc by crystalline $CaCO_3$.

2.3.4 Effect of Secondary Nutrients on Nutrient Availability in Soil

Liming with dolomite considerably increased soil pH and enhanced plant available phosphorus status by about 45% in soils very poor in available phosphorus, while differences in humus content and plant available potassium were non-significant (Rastija *et al.,* 2014).

Soil pH, available P, B, exchangeable Ca and Mg contents in the soil were significantly increased by the application of lime in rice soils. Application of dolomite (56% CaO and 40% MgO) also resulted in an increase in the pH values and soil available P (Rahman *et al.,* 2002).

Significant increase in available Ca, Mg, pH and base saturation of an Oxisol of Brazil was reported with increasing levels of lime (0 to 20 t ha^{-1}) application (Fageria and Stone, 2002).

Increasing lime application also tends to hinder the uptake of P, Zn, Cu, Mn, and Fe and increase the uptake of Ca and Mg in different crops. A decrease was observed in potassium uptake following high lime application which might be due to the antagonistic effects with Ca and Mg. The reduction in micronutrient uptake can be attributed to increased soil pH resulting in decreased availability of these elements to plants (Fageria *et al.*, 1995).

2.4 ROLE OF MICRONUTRIENTS IN PLANTS

2.4.1 Functions of Micronutrients

Iron is required for electron transport during photosynthesis and is a constituent of iron porphyrins and ferredoxins, both of which are essential components of the photosynthetic process. Fe is also involved in many processes like energy transfer within the plant and nitrogen fixation. It is a component of many enzymes and and is necessary for the synthesis of chlorophyll and also helps to maintain the structure of chloroplasts. Thus iron application leads to an increase in plant height, increased leaf area and higher crop production (Abbas *et al.*, 2009; Zayed *et al.,* 2011; Ali, 2012; Bameri *et al.,* 2012).

Manganese plays a major role in the physiological processes in plants by acting as an activator of several enzymes and as a catalyst for splitting water molecules during the process of photolysis (Gardner *et al.*, 1985; Humphrise, 2006; and Aref, 2012). According to Sutedjo (2008) and Agustina (2011), Mn could maintain the green condition of the leaves, especially of older leaves. With the application of Mn fertilisers the older leaves were able to photosynthesize which helped to increase the yield potential. Since Mn plays a key role in increasing the concentration of chlorophyll, the leaves remained green even when they were at the senescence stage (Benyamin and Dewi, 2014).

Copper is needed for photosynthesis and respiration. It also plays a critical role in the formation of pollen grains and for the fertilization process in rice (Dobermann and Fairhurst, 2000).

Zinc is an essential nutrient required for several biochemical processes in the rice plant, including chlorophyll production and membrane integrity. It is involved in a number of physiological processes during plant growth and metabolism, including enzyme activation, protein synthesis, metabolism of carbohydrates, lipids, auxins and nucleic acids, gene expression and regulation, and reproductive development, especially pollen formation (Marschner 1995; Cakmak, 2000; Mengel and Kirkby, 2001; Chang *et al.*, 2005). Fox and Guerinot (1998) asserted that Zn is required for the functioning of more than 300 plant enzymes. Studies carried out at IRRI (2000) revealed that application of zinc activates and increases tillering capacity in rice as a result of improved enzymatic activity. Brown *et al.* (1993) reported that application of Zn fertilisers to rice grown on calcareous soils significantly increased tryptophan concentration (a precursor for the biosynthesis of IAA) in rice grains. Moreover, the plants deficient in Zn had decreased pollen production, leading to an increased proportion of empty grains (Marschner, 1995).

Boron plays an important role in plant reproduction as it can induce pollen tube germination (Bolanos *et al.,* 2004) and improve pollination and grain setting in different cultivars (Aslam *et al.,* 2002). Boron is also involved in carbohydrate metabolism, sugar transport and pollen viability in rice (Dobermann and Fairhurst, 2000). Cell division, cell wall synthesis, cell wall rigidity and plasma membrane integrity are also positively influenced by boron (Marschner, 1995). Dell and Huang (1997) reported that boron application increases leaf expansion thereby the photosynthetic ability of plants.

2.4.2 Effect of Micronutrients on Plant Biometrics in Cereals

Maximum plant height (105 cm) was recorded with soil application of of Zn, B and Fe @ 54, 10 and 1197 mg kg^{-1} respectively, in direct seeded rice grown in a Brazilian Oxisol (Fageria, 2015).

Both root length and root dry weight were reported to be increased in a quadratic fashion with increasing levels of Zn (0 to 80 mg kg^{-1}) and Cu (0 to 40 mg kg^{-1}) in direct seeded rice (Fageria, 2015). A decrease in root growth was reported beyond 5 mg B kg^{-1} soil. He also reported that root growth (maximum length and dry weight) was significantly improved by the addition of Fe to the soil.

Foliar application of 0.3% of microfertilizers (iron chelate 13.2 %, copper chelate 14% and 14% zinc,) at tillering, stem elongation and heading stages of rice recorded about 8% increase in plant height compared to control (Naeini *et al.,*2014). The maximum plant height and tillers per m^2 was obtained by the foliar application of $FeSO_4$ + $MnSO_4$+ $ZnSO_4$ @ 1.6 kg, 1 and 3 kg respectively per 100 L of water/acre in wheat plants (Zain *et al.,* 2015).

Naik and Das (2007) reported that adequate supply of zinc produced more number of productive tillers per m^2 and Slaton *et al.* (2002) reported that application of zinc significantly affected total number of tillers. Maximum number of branches per panicle was recorded in the treatment where foliar application zinc was done 15 days after transplanting at the rate of 0.5 % $ZnSO_4$ solution (Musthafa *et al.,* 2011). Zinc application increases tillering capacity in rice (IRRI, 2000).

Four sprays of 0.5% solution of $MnSO_4$ and 1.0% solution of $FeSO_4$ at 40, 50, 60 and 70 days after sowing recorded significantly higher plant height (101.6 cm) dry matter (15.1 t ha^{-1}), leaf-area index (3.6) and effective tillers per m^2 (312.7) in aromatic rice (Singh and Walia, 2013). The highest plant height (88 cm), number of plants per m^2 (418) and flag leaf area (30 cm^2) were obtained due to foliar application of Fe at 1000 mg per L in rice (Quadir *et al.,* 2013).

Boron application is reported to increase the ability of plants to produce more number of leaves and tillers (Khan *et al*., 2006). B application induce plant growth due to its involvement in the formation of cell wall and improving growth parameters like tillering capacity shoot and root lengths and shoot and root weights (Ehsan- ul- haq *et al.,* 2009). Correa *et al*. (2006) observed that adequate boron availability in soil improves root growth of rice. Bameri *et al.* (2012) reported that root growth in wheat was improved by spraying micronutrients.

2.4.3 Effect of Foliar Application of Micronutrients on Yield Attributes and Yield of Cereals

A foliar micronutrient spray containing $MnSO_4$ (0.5%) and $FeSO_4$ (1%) at 40, 50, 60 and 70 days after sowing recorded significantly higher panicle length (26.2 cm), spikelets per panicle (73.5), grains per panicle (142.5), 1000-seed weight (22.0 g), grain yield (3.8 t ha^{-1}) and straw yield (9.5 t ha^{-1}), and gave higher net returns and benefit: cost ratio over the control in transplanted rice (Singh and Walia, 2013).

Foliar application of microfertilizers containing iron chelate (13.2 %), copper chelate (14%) and zinc (14%) registered higher grain yield, maximum number of grains per spike, panicle length and 1000 grain weight in Sazandegi cultivar of rice at Iran (Naeini *et al*., 2014).

Quadir *et al.* (2013) obtained maximum number of tillers per square meter (380.8), spikelets per panicle (151.8) and paddy yield (6.675 t ha^{-1}) with combined application of zinc and boron, whereas the highest 1000 grain weight was recorded where all the three micronutrients *viz.* zinc, boron and iron were applied in combination along with recommended dose of NPK fertilizers.

Foliar application of Cu and B (20 ppm Cu + 20 ppm B) could enhance rice productivity by 27% under field conditions compared to control (Liew *et al*., 2012).

Zayed *et al.* (2011) reported that foliar application of Zn, Fe and Mn (16% Zn + 12% Fe + 14% Mn) improved rice growth, dry matter production and panicle length compared to the no micronutrient control. Combined spray of micronutrients viz. zinc, copper, iron, manganese and boron was also reported to result in higher grain yield compared to control (Nadim *et al*., 2011).

Application of FYM and foliar spray of micronutrients such as $ZnSO_4$ (0.5%), $FeSO_4$ (2%) and sodium selenate (0.1%) recorded the highest grain (3.60 t ha^{-1}) and straw (5.20 t ha^{-1}) yields in rice (Baishya *et al*., 2016).

A study conducted at KAU, Thrissur revealed that the highest grain yield in rice (6.28 t ha^{-1}) was observed due to combined foliar application of Mg, Zn and B along with NPK as per recommendation (Preman, 2015). Application of Si along with Mn was also reported to increase the yield of rice (Benyamin and Dewi, 2014).

Stalin *et al.* (2011) also reported that combined foliar application of 0.5% of $CuSO_4$, $ZnSO_4$, $FeSO_4$ and $MnSO_4$, 0.05% boric acid and 0.01% sodium molybdate at active tillering, panicle initiation and at flowering stages increased the yield and concentration of these nutrients in rice grain.

Foliar application of $FeSO_4$ @ 0.25% along with $ZnSO_4$ @ 0.5 %, registered 36 per cent increase in grain yield over no micronutrient application in rainfed upland rice (Ramana *et al.*, 2006).

Soil application of 38 to 54 mg kg^{-1} Zn, 17 to 24 mg Cu, 3 to 10 mg B, and 283 to 1500 mg Fe per kg of soil in direct seeded rice resulted in higher straw yield, grain yield, panicle number and harvest index (Fageria, 2002).

Gurmani *et al.* (1988) studied the effect of Fe, Mn, Zn and Cu on the yield and yield attributes of rice and reported that Zn and Mn alone and the combined application of Mn and Cu increased the yield significantly. Zinc, Mn and Cu application increased the grain yield by 15, 11 and 10% over NPK, respectively.

An experiment conducted by Zeidan *et al.* (2010) produced higher grain and straw yields, 1000 grain weight and number of grains per spike of wheat grown in sandy soil due to foliar application of Fe, Mn and Zn.

El-Ghamry *et al.* (2009) reported that foliar application of micronutrients (B, Zn and Mo) along with farm yard manure recorded a significant increase in grain and straw yield (6.1 and 7.5 t ha^{-1} respectively) as compared to control (5.69 and 6.93 t ha^{-1} in wheat grown in salt affected areas.

Combined foliar spray of micronutrients (1% $CuSO_4$+ 1% $ZnSO_4$ + 0.5% $MnSO_4$) along with NPK gave higher grain yield of 7.25 t ha^{-1} in winter wheat (Stepien and Wojtkowiak, 2016).

Significant improvement in number of grains per spike and 1000 grain weight was noticed in wheat plants when the nutrient mixture ‘Plant Care’ containing N 200 g, P_2O5- 200 g, K_2O- 200 g, Zn- 750 mg, Fe -1500 g, Cu- 750 mg, B- 300 mg, Mn-750 mg, Mg-375 mg and Mo- 8 mg was sprayed on wheat foliage at tillering, booting and milking stages. The foliar spray of micronutrients also gave maximum grain and straw yields while the effect on harvest index was found to be non-significant (Hussain *et al*., 2005)

Field experiments carried out to study the response of barley varieties (*Hordeum vulgare L.*) to increasing levels of zinc (control, 9, 18, and 27 kg Zn ha^{-1}) in Zn deficient calcareous soils registered significant increases in grain yield (29%) over the no micronutrient control (Kenbaev and Sade, 2002)

2.4.4 Effect of Applied Micronutrients on Content and Uptake of Nutrients

According to Pal and Joshy (2016), foliar application of Zn, Fe and B along with soil application of recommended dose of N, P, K, farmyard manure, green manure and straw mulch in rice, significantly increased the Zn and Fe concentration in grain (15.7 ppm) and straw (36 ppm).

Application of FYM and foliar spray of micronutrients such as $ZnSO_4$ (0.5%), $FeSO_4$ (2%) and sodium selenate (0.1%) significantly increased the content of N, P, K, Zn, Fe and Se (1.43%, 0.51%, 0.31%, 21.0 mg kg^{-1}, 20.95 mg kg^{-1}, 0.04 mg kg^{-1} respectively) in rice grain (Baishya *et al*., 2016).

Foliar application of Zn was observed to cause significant increase in the Fe concentration in grain and straw of rice plants (Wang *et al*., 2015). According to Kutman *et al.* (2011), enriching N fertilization with Zn in the form of foliar fertilizers cause an increase in Zn and Fe content of rice grain.

Significant increase in grain Zn concentration was observed with foliar application of $ZnSO_4$ (0.5%) in rice when applied after flowering, with larger increases when applications were repeated at four stages viz. panicle initiation, booting followed by 1 and 2 weeks after flowering (Boonchuay *et al*., 2013).

Application of Zn and B at the doze 10 kg of and 2 kg ha^{-1} along with recommended doses of N and P in rice resulted in significantly higher content and uptake of micronutrients (B, Zn, Cu, Fe and Mn) in grains (Bhutto, *et al.,* 2013). Combined foliar application of 0.5% of $CuSO_4$, $ZnSO_4$, $FeSO_4$ and $MnSO_4$, 0.05% boric acid and 0.01% sodium molybdate at active tillering, panicle initiation and at flowering stages increased the content of these nutrients in rice grain (Stalin *et al.*, 2011).

Foliar application of Zn at panicle initiation stage of rice was found to be effective in increasing grain Zn contents 2-fold (Phattarakul *et al.*, 2011). According to Pessarakli (2009), foliar spray of Zn increased the concentration of Zn and Fe in rice grain by 99% and 8%, respectively, while the application of Mn caused an increase of 7 per cent in Mn content.

Foliar application of 0.1% $FeSO_4 .7H_2O$ along with 0.2% $H_3B_3O_3$ significantly increased the concentration of Fe in rice grain by 18.95 % and that of Zn by 26.7 % compared to the no micronutrient control (Jin *et al.*, 2008).

Uptake of N, Ca, and Cu in rice was decreased by the foliar application of zinc (Fageria, 2002) while Zhang *et al.* (2008) reported a significant increase in iron concentration in paddy seed (18.9%) due to the application of iron and boron.

Narwal *et al.* (2012) observed that foliar application of Zn, Fe, and Mn effectively increased the concentration of this nutrient in the grains of 14 varieties of winter wheat. Foliar application of 1% $CuSO_4$, 1% $ZnSO_4$ and 0.5% $MnSO_4$ increased Cu and Zn content in wheat grain (22.6% and 17.7%, respectively) (Stepien and Wojtkowiak, 2016).

2.5. FACTORS AFFECTING MICRONUTRIENT AVAILABILITY

Several factors like soil texture, pH, organic matter content, nutrient interaction etc. affect the availability of nutrients especially micronutrients to the crop.

2.5.1 Texture

Fine textured soils are better in holding nutrients when compared to coarse textured soils. Bhanwaria *et al.* (2011) reported that coarse textured soils were found to be more prone to Fe, Mn, Cu, Zn and B deficiencies while Mandhal and Jha (1970) reported that the amount of available micronutrient content has been found to be increased with an increase in clay content of soil. Soils dominated by kaolinite type clay minerals were reported to show higher availability of boron compared to illite and montmorillonite dominates soils (Das, 2000).

2.5.2 Soil pH

The micronutrient cations are most soluble and available under acidic condition. In very acid soils there is a relative abundance of iron, manganese, zinc and copper ions. As the pH is raised, their availability decreases since ionic forms of cations are changed to the hydroxide or oxide form. The availability of B, Cu, Fe, Mn and Zn usually decreases and Mo increases as soil pH increases (Fageria *et al*., 1990).

2.5.3 Organic Matter

Soil organic matter content has been related to increased, decreased or no effect on the availability of different micronutrients to crop plants (Mortvedt, 2000). Addition of organic materials may increase the micronutrient solubility through the mechanism of chelation reactions (Tisdale *et al.,* 1993). Chaudhary and Narwal (2005) reported that the application of FYM significantly increased the chelation of micronutrients by DTPA in soil.

2.5.4 Nutrient Interactions

Interactions between nutrients can affect the availability and thereby uptake of micronutrients. Synergistic effects on Ca, Mg, Na, P and Cu were triggered by increasing the Mn concentrations in nutrient solution whereas antagonistic action was observed on K and Zn in rice (Lidon, 1999). Excess P adversely affects the utilization of Zn, Fe and Cu due to the formation of metal phosphates (Tisdale *et al.,* 1993). Iron in excess adversely affects the utilization of Zn and Mn in rice (Verma and Thripathi, 1983) and excess of Zn, Mn, and Cu induces Fe-deficiency in wheat plants (Fasaei *et al.,* 2008).

2.6. WETLAND vs UPLAND RICE

Upland rice refers to rice grown on both flat and sloping fields that are prepared and seeded under dry conditions, and depend on rainfall for moisture. The rice plant is physiologically, morphologically, and anatomically adapted to water-logged, anaerobic soils. Rice grown under upland conditions is subjected to different degrees of moisture stress, is generally shorter, has fewer tillers and less leaf area. The sterility is higher; the effective tiller percentage is lower and flowering is delayed than lowland rice and also produces less dry matter, and has a lower harvest index or grain-to-straw ratio. These factors or their combinations contribute to relatively lower grain and straw yields (Ponnamperuma, 1955; Senewiratne and Mikkelsen, 1961; Chaudhry and McLean, 1963). Upland fields also have more weeds, which compete for nutrients and light compared to lowland fields.

In wetland rice standing water is beneficial due to rice by elimination of water stress control of weeds, regulation of the microclimate and by providing a favourable chemical and microbiological environment to the rice roots (Ponnamperuma, 1955).

2.7. UPTAKE OF NUTRIENTS BY WETLAND AND UPLAND RICE

The pH of acidic soils increases and alkaline soils decreases as a result of flooding, thereby pH of most soils tends to become neutral following saturation (Patrick and Reddy, 1978). This change in soil pH causes a general increase in the plant availability of plant nutrients. But, a wide range of soil pH is encountered in upland rice soils where pH never converges to the neutral range. Hence application of lime in acid soils and gypsum in alkaline soils is necessary to neutralise the pH and to increase the nutrient availability (Sahrawat, 2012).

Organic matter status of soils under continuous submergence is either maintained or even increased compared to soils under upland system of rice cultivation (Witt *et al*., 2000). The organic matter content of soils under aerobic rice decreases due to enhanced rate of decomposition (Cheng *et al*., 2009).

The available P status of acidic soils increases due to submergence. The insoluble Fe and Al phosphates will be reduced to form soluble phosphates and this result in increase in higher P availability (Ponnamperuma, 1972). The available P is low in aerobic rice soils due to precipitation of P as Fe - P and Al-P in acidic soils and Ca-P in alkaline soils. Maximum availability of P occurs under neutral soil reaction (Linquist *et al*., 1997).

Fageria *et al*. (2011) reported that competition of K, Ca and Mg with dominant cations Fe^{2+} and Mn^{2+} results in low plant uptake of these nutrient elements under submerged condition, while under aerobic condition, K, Ca and Mg present in the soil solution is available for plants due to less competition for uptake under acidic situation.

The solubility and availability of Fe increases due to submergence in soils because of reduction of insoluble Fe^{3+} to soluble Fe^{2+} (Becker and Asch, 2005). Most of the Fe is present in the soil in the insoluble form in aerobic rice soils. The bio available form of Fe is very low under this system of rice cultivation (Sahrawat, 2012).

Under submerged conditions, the oxidized form of Mn (Mn^{4+}) which is commonly found in soils is reduced to Mn^{2+}. This leads to increase in solubility of Mn thus improving its availability (Ponnamperuma, 1972). But Mn deficiency does not prevail in acidic soils under aerobic conditions (Sahrawat, 2012).

A decrease in available Zn is associated with high P availability, precipitation of $Zn(OH)_2$ with an increase in pH, formation of insoluble franklinite ($ZnFe_2O_4$) in acidic soils and low redox potential which favors the precipitation of Zn as ZnS under acidic condition (Srinivasarao *et al*., 2008)

Under aerobic system of rice cultivation availability of zinc is increased since the content of soluble phosphates and sulphides are low under this situation (Gao *et al*., 2012).

2.8 EFFECT OF MODE OF APPLICATION OF NUTRIENTS ON SOIL AND PLANTS

Soil application of different nutrients may not be equally effective because of the negative effects of pH, nutrient interactions and nutrient losses. Continuous soil application of micronutrients many lead to their accumulation leading to toxic levels in soils. Foliar application has been found to be favourable where the soil applied fertilizers may not become fully available before maturity of the crop (Ganapathy *et al*., 2008).

Micronutrients are required only in small amounts by plants and foliar application of these nutrients is more effective compared to soil application (Fageria *et al*., 2009). Jin *et al*. (2008) also reported that foliar spray of different micronutrients has been reported to be equally or more effective than soil application because of efficient uptake of nutrients.

Foliar application also helps in rapid utilization of nutrients and permits the correction of deficiencies in less time than would be required by soil application. Furthermore, foliar fertilization is more advantageous in nutrient absorption compared to soil application at early stages of crop growth when plant roots are not well developed (Fageria *et al*., 2009).

Micronutrients such as boron, which is immobile in plant tissues when sprayed directly on developing parts such as flower buds and flowers in low concentration, ensures their adequate supply at critical stages of development (Brown and Shelp, 1997). Foliar application of Fe is also preferred over soil application because after application in the soil, Fe gets oxidized and is made unavailable whereas residual effects are absent under foliar application (Sadana and Nayyar, 2000). Other advantages of foliar sprays include lower application rates compared to that of soil application, uniform coverage on the applied area, immediate response to the applied nutrient and correction of deficiencies during the growing season itself (Zayed *et al.*, 2011).

Foliar fertilization cannot be a substitute for soil application but can only complement it. 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 which are not easily translocated from to leaves (Ca, Mg and Mn) within the plant (Shayganya *et al.*, 2012).

2.9 EFFECT OF ORGANICS ON RICE

2.9.1 Effect on Yield Attributes and Yield

Organic matter is indispensable for improving yield parameters and producing better yield in crops.

Significant increase in yield components of rice was observed in plots receiving FYM in comparison with the unfertilized ones (Dutta and Bandyopadhyaya, 2003) and combination of organic manure with inorganic fertilizer in rice out yielded the treatment receiving fertilizers alone (Ganapathi *et al.*, 2006). Integration of FYM with inorganic fertilizers produced increased dry matter of shoot, LAI and higher total and productive tillers compared to the application of FYM alone or no the fertilizer treatment in upland rice (Naing Oo *et al.*, 2010).

Yield determining factors such as number of panicles per m^2, number of filled grains per panicle and weight of 1000 grains were improved due to the application of half the dose of nitrogen through fertilizers and half through organic sources like green leaves, neem cake and FYM (Vasantharao *et al.*, 2004).

Investigations on the combined effect of different nutrient management practices by Imtilemla *et al.* (2009) on the nutrient availability and grain yield of upland rice showed that the application of full dose of fertilizers in combination with FYM @ 10 t ha^{-1} resulted in maximum grain yield coupled with higher levels of available macro and micronutrients in the soil. Neemsar (150kg ha^{-1}) and 100% NPK as fertilizers significantly improved the yield determining characters of the rice plant.

FYM application @ 20 t ha^{-1} was found to be superior in rice compared to FYM @ 10 t ha^{-1} and no FYM by producing 14.9 and 14.7 % more grain yield and 34.1 and 34.8 % more straw yield respectively (Priyanka *et al.,* 2013).

2.9.2 Effect on Soil Physical Properties

Organic manure application has positive effect on soil physical properties. Application of FYM @ 10 t ha^{-1} resulted in reduction in bulk density of soil from 1.45 to 1.32 control treatment and an increase in filled pores and water holding capacity in rice soils by 5 per cent (Singh and Sharma, 2005).

Addition of FYM increased the soil organic carbon by 44 per cent and WHC by 16 per cent in a 32 year long term manurial trial of rice-wheat cropping system (Rasool *et al.,* 2007).

2.9.3 Effect on Soil Chemical Properties

EC of soil was enhanced due to organic manures in combination with fertilizers. Hati *et al.* (2006) noticed enhanced EC of soils due to the application 100 per cent NPK (fertilizer) + FYM in comparison with absolute control and the pure fertilizer treatments after a 28 year period experimentation in a soybean-wheat-maize rotation.

Organic manures, FYM, wheat crop residue and green manure application combined with inorganic fertilizers resulted in significant reduction in soil pH compared to no nutrient treatment or the treatment receiving the inorganic fertilizers alone in rice (Yaduvanshi, 2001). In contrast to the above report, Brar *et al.* (2015) reported that EC values were not significantly affected due to continued application of inorganic fertilizers either alone or in conjunction with FYM after 36 cycles of rice-wheat system.

2.9.4 Effect on Carbon Pool and Nutrient Availability

In rice- wheat cropping system increased values for Carbon Management Index (CMI) was obtained for the treatment receiving entire amount of nitrogen in the form of FYM. Application of fertilizers as per recommended dose also improved the CMI over control (Verma *et al.,* 2012)

Blair *et al.* (2006) reported that continuous application of organic manures with inorganics significantly enhanced the CMI compared to the pure chemical fertilizer treatments.

Application of rice straw compost increased the CMI value as compared to control in a in rice- wheat cropping system (Sodhi *et al.,* 2009). Prakash *et al.* (2016) observed that addition of FYM and fertilizer P in an integrated manner resulted in higher soil organic carbon, labile carbon pool and a higher CMI after seven years of experimentation on a rice- wheat cropping system.

NPK fertilizers alone or integrated with organic manures had a positive effect on labile carbon (Chaudhary *et al.,* 2017). Residue addition had also resulted in significantly higher lability index (LI) values in surface and subsurface soils compared to the treatment where residues were removed (Gosh *et al.,* 2016).

FYM in combination with inorganic fertilizers gave higher soil extractable P, total available N and exchangeable K in upland rice (Naing Oo *et al*., 2010). Combined application of 100 % fertilizer NPK (90: 45:45) and 10 t ha^{-1} FYM resulted in higher value for exchangeable Ca, Mg, available P and K in soil (Selvi *et al.*, 2003).

The application of cow dung, daincha and green manures in combination with chemical fertilizers not only increased the organic C, total N, available P, and available S but also increased the exchangeable K, available Zn, available Fe, and available Mn in soils (Saha *et al.,* 2006).

2.9.5 Effect on Uptake of Nutrients

Chettri and Mondal (2005) reported higher N P K uptake when rice crop was fertilized with 75 % recommended dose of N P K through chemical fertilizers along with 10 t ha^{-1} FYM during kharif and boro seasons.

Significant increase in total uptake of Zn, Cu, Mn and Fe with the combined application of organics and recommended dose of fertilizers was reported by Kumar *et al.* (2012).

2.10 EFFECT OF MICRONUTRIENT APPLICATION IN ORGANICALLY RAISED CROPS

Rainfed upland rice crop has performed its best with the application of Fe and Zn either through foliage or soil coupled with mulching with bagasse or rice husk (Ramana *et al.*, 2006).

El-Ghamry *et al.* (2009) reported that foliar application of micronutrients (B, Zn and Mo) along with farm yard manure recorded a significant increase in grain and straw yield (6.1 and 7.5 t ha^{-1}, respectively) as compared to control (5.69 and 6.93 t ha^{-1}) in wheat grown on salt affected areas.

Organic farming and integrated nutrient management practices produced comparable yield in rice as that of full nutrients as chemicals inputs (increased the N and P contents of soil and appreciable improvement in organic carbon levels) (Kuruvila *et al.*, 2009) in a rice-vegetable diversified cropping system in Kerala.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The study entitled "Secondary and micronutrient management for enhancing soil health and productivity in upland rice" was carried out at College of Agriculture, Vellayani with a field experiment in farmer's field, Venganoor, Thiruvananthapuram during 2016-'18. The details of the experiment, materials used and the methodology adopted are presented in this chapter.

3.1 EXPERIMENTAL SITE

The experimental field lies at 8° 41' 56''N latitude and 77° 01' 92''E longitude at an altitude of 28 m above mean sea level.

3.1.1 Climate and Season

The field experiment was carried out during the first crop season (*Virippu*) of the year 2017-'18. The maximum and minimum temperature during the experimental period ranged from 29.8 °C to 33.6 °C and 23.6 °C to 25.8 °C, respectively. A total rainfall of 679 mm was recorded during the crop period. The relative humidity ranged from 85 to 98 per cent. The weather data during cropping period is illustrated in Fig. 1.

3.2 MATERIALS

3.2.1 Crop and Variety

The rice variety used for the investigation was the red kernelled, medium duration (115-120 days) variety Uma (Mo-16), which is non-lodging and resistant to brown plant hopper. The seeds were procured from Integrated Farming System Research Station (KAU), Karamana, Thiruvananthapuram.

3.2.2 Manures and Fertilizers

Calcium carbonate and dolomite were used as liming materials. Well decomposed farmyard manure and neem cake were used as the organic source.

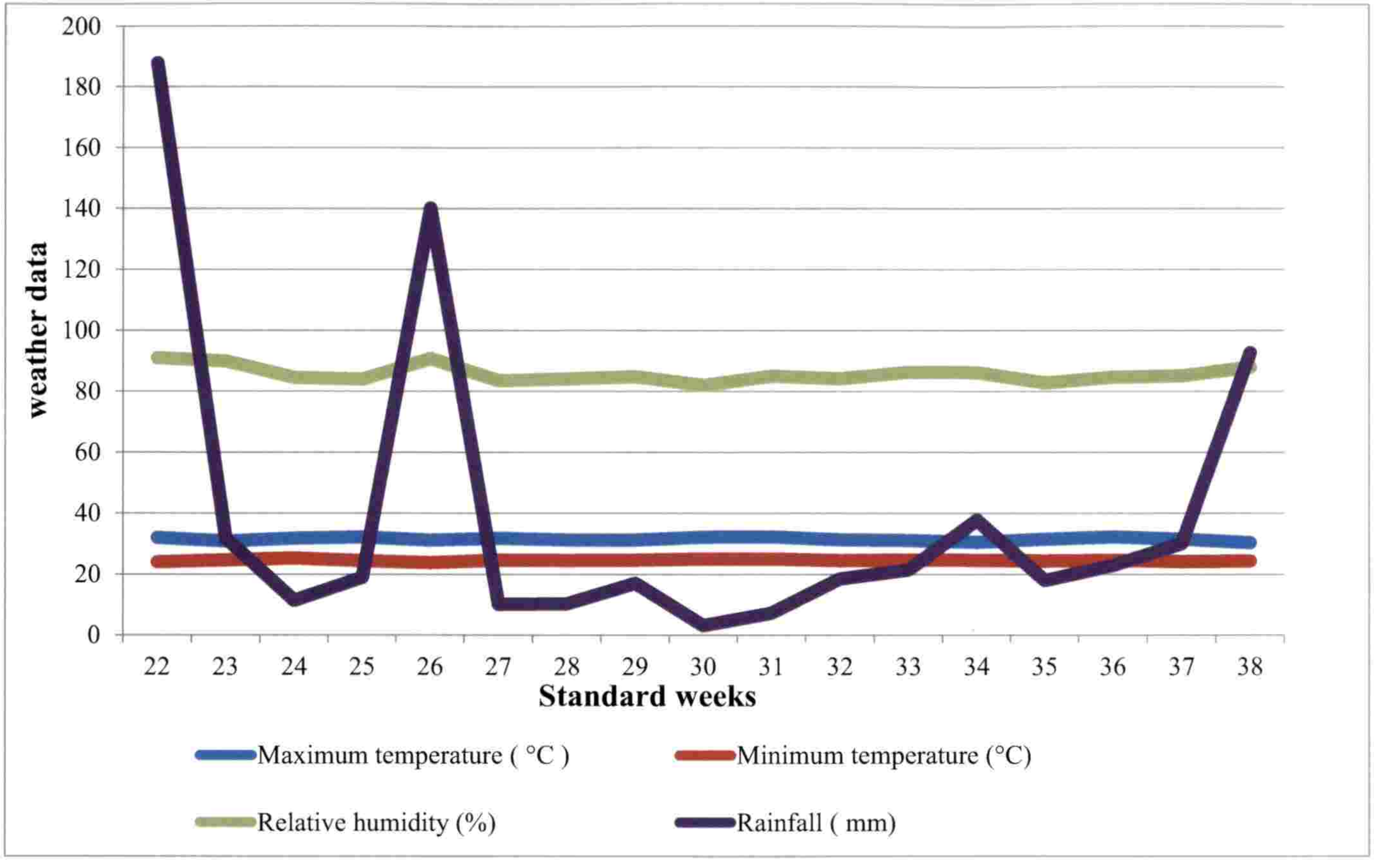

Fig. 1. Weather data during the cropping period: May - September, 2017

Fertilizers used as inorganic nutrient sources were urea (46 % N), rajphos (20 % P_2O_5) and muriate of potash (60 % K_2O).

3.2.3 Nutrient Sources for Foliar Nutrition

Sampoorna KAU multimix (containing Zn (7%), B (4.5%), Cu (0.5%), Fe (0.2%), Mn (0.2%) and Mo (0.02%)) and the prepared micronutrient solution were used for foliar spray. The micronutrient solution was prepared by dissolving $FeSO_4.\ 7H_2O$ (1 g), $ZnSO_4.\ 7H_2O$ (2.5 g), Borax (1 g), $MnSO_4.\ H_2O$ (0.25 g) and $CuSO_4.\ 5H_2O$ (0.25g) in one litre of water to get the following composition (Table 1).

Table 1. Composition of micronutrient solution used for foliar spray

Sl. No.	Nutrient source	Concentration (%)
1	$FeSO_4.7H_2O$	0.1
2	$ZnSO_4.7H_2O$	0.25
3	Borax ($Na_2B_4O_7.10\ H_2O$)	0.1
4	$MnSO_4.\ H_2O$	0.025
5	$CuSO_4.\ 5H_2O$	0.025

3.3 METHODS

3.3.1 Design and Layout

Design : Randomised Block Design

Treatments : 10

Replications : 3

Crop : Rice

Variety : Uma

Location : Farmer's field, Venganoor, Thiruvananthapuram

Plot size : 5m x 4m

Season : Ist crop season (virippu), 2017-'18

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

3.3.2 Treatments

T_1	Absolute control
T_2	KAU PoP* with lime
T_3	KAU PoP with dolomite
T_4	KAU PoP for organic farming**
T_5	T_2 + foliar application of micronutrient solution
T_6	T_2 + foliar application of KAU sampoorna multimix
T_7	T_3 + foliar application of micronutrient solution
T_8	T_3 + foliar application of KAU sampoorna multimix
T_9	T_4 + foliar application of micronutrient solution
T_{10}	T_4 + foliar application of KAU sampoorna multimix

* FYM- 5 t ha^{-1}, N: P_2O_5: K_2O - 60:30:30 kg ha^{-1}

** FYM- 5 t ha^{-1} + 600-800 kg of neem cake per ha

Foliar sprays of 0.5 % of prepared micronutrient solution and 1 % KAU sampoorna multimix was given during the critical growth stages of the crop *viz.* active tillering, panicle initiation and one week after flowering. Spray volume used was 300 L ha^{-1} during the active tillering stage and 500 L ha^{-1} during the panicle initiation and flowering stages.

3.3.3 Land Preparation

The field was ploughed well and weeds and stubbles of the area were removed. The experimental area was divided into 3 blocks with 10 plots each, of size 5 m x 4 m and was separated with bunds 30 cm width. Drainage channels

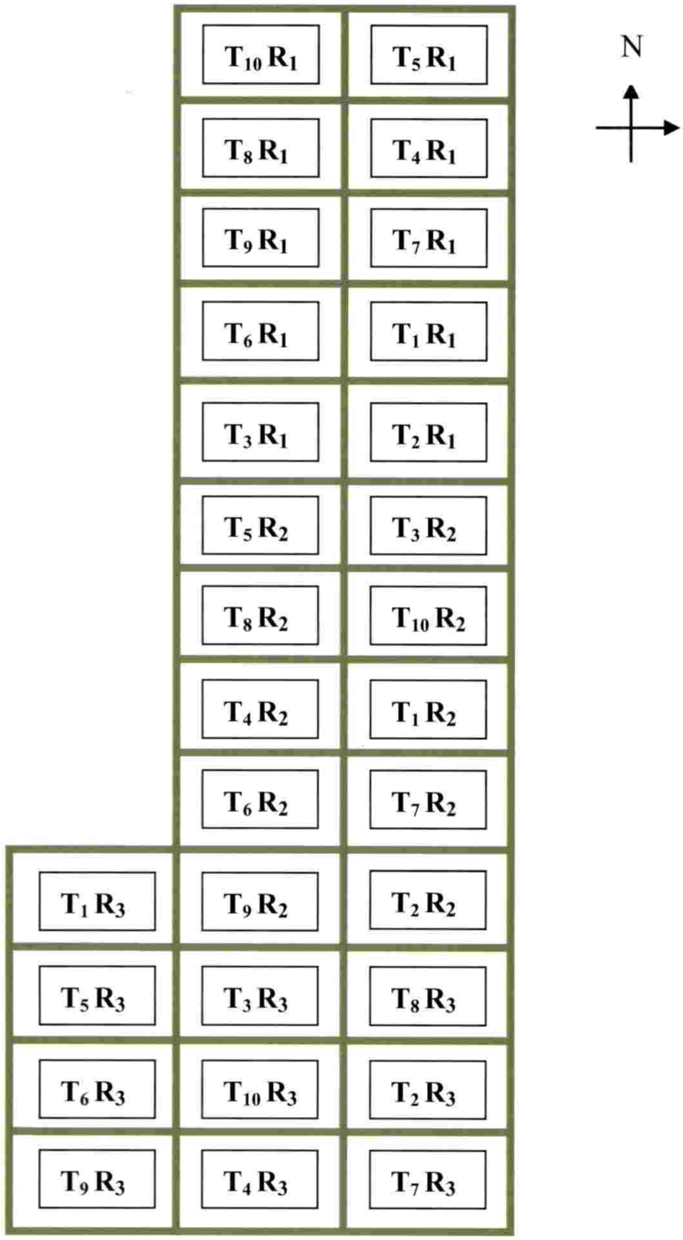

Fig. 2. Layout of the experimental field

Seedling stage

Tillering stage

General view of the plot at harvest stage

Plate 1. Different growth stages of rice in the field

were also provided. Organic manures were incorporated into each plot as per the treatments.

3.3.4 Dibbling

Healthy seeds of Uma @ 80 kg ha^{-1} were dibbled in the main field area at a spacing of 20 cm x 15 cm, one week after the addition of organic manures.

3.3.5 Manure and Fertilizer Application

Organic manures and fertilizers were applied as per the Package of Practices recommendations of Kerala Agricultural University (KAU, 2016; KAU PoP for organic farming). Foliar application of micronutrients (sampoorna multimix or micronutrient solution) were given during the critical growth stages of the crop *viz.* active tillering, panicle initiation and one week after flowering.

3.3.6 Thinning and Gap Filling

Thinning and gap filling were done to maintain uniform population of two seedlings per hill.

3.3.7 Water Management

Irrigation was scheduled as per the requirement of crop. A total of 12-15 irrigations were given during the crop seasons.

3.3.8 Weed Management

Two hand weedings were done at 20 and 40 DAS before fertiliser application.

3.3.9 Harvest

The crop was harvested from the net plot area of each plot, leaving two border rows from all sides. After threshing and winnowing, the grain and straw yields were recorded separately.

3.4 OBSERVATIONS

The details of different observations taken during the experiment are described below:

3.4.1 Plant Biometric Observations

3.4.1.1 Height of Plant

Plant height was measured from the base of the plant to the tip of the longest leaf or to the tip of the longest ear head whichever was taller and expressed in cm.

3.4.1.2 Total Number of Tillers

In each net plot, four quadrates each of 0.25 m^2 size were placed at random and the total tillers were counted and expressed as total number of tillers per m^2.

3.4.1.3 Root Length after Harvest

Root length was taken after harvest from the five sample hills of each plot using a meter scale, the mean was worked out and expressed in cm.

3.4.1.4 Root Dry Weight after Harvest

The five sample hills from each plot were uprooted, cleaned and were oven dried at 70 °C until constant weights were obtained, and the average worked out and expressed in grams.

3.4.1.5 Root Volume after Harvest

After harvest, the five sample hills were uprooted and the root volume was measured by water displacement method. The average worked out and the volume was expressed in cm^3 per hill.

3.4.2 Yield Attributes and Yield

3.4.2.1 Number of Productive Tillers per m^2

The ear bearing tillers from an area of $1m^2$ were counted and expressed as number of productive tillers per m^2.

3.4.2.2 Length of Panicle

Panicle length was measured from the neck to the tip of the five randomly selected panicles of each selected hill and the average was expressed in cm.

3.4.2.3 Weight of Panicle

The grains from the five randomly selected panicles were removed, dried, weighed and the weight was recorded as grain weight per panicle in grams.

3.4.2.4 Number of Spikelets per Panicle

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

3.4.2.5 Percent Filled Grains

The number of filled grains and chaff were counted separately from the five randomly selected panicles of the selected hills, and the mean was worked out and per cent filled grains was computed using the equation given below:

$$\text{Per cent filled grains} = \frac{\text{Number of filled grains per panicle}}{\text{Total number of grains per panicle}} \times 100$$

3.4.2.6 Thousand Grain Weight

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

3.4.2.7 Grain and Straw Yield

The crop was harvested, threshed and winnowed separately from the net plot area of each plot and the weight of grain and straw obtained were expressed in kg ha^{-1}

3.5 CHEMICAL ANALYSIS

3.5.1 Soil Analysis

Composite soil samples were drawn from all the experimental plots and the processed samples were analyzed for pH, EC, CEC, organic carbon and soil available nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn and B) using standard procedures (Table 2).

Table 2. Standard procedures followed for chemical analysis of soil samples

Sl. No.	Parameter	Method	Reference
1	Bulk density	Undisturbed core sample	Black *et al.* (1965)
2	Water holding capacity	Core method	Gupta and Dakshinamurthy (1980)
3	Textural analysis	International pipette method	Robinson (1922)
4	pH	pH meter	Jackson (1973)
5	EC	Conductivity meter	Jackson (1973)
6	CEC	Neutral normal ammonium acetate method	Jackson (1973)
7	Organic carbon	Walkley and Black rapid titration method	Walkley and Black (1934)
8	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
9	Available P	Bray No. 1 extraction and estimation using spectrophotometer	Bray and Kurtz (1945)

10	Available K	Neutral normal ammonium acetate extraction and estimation using flame photometer	Jackson (1973)
11	Exchangeable Ca and Mg	Versenate titration method	Hesse (1971)
12	Available Fe, Mn, Cu and Zn	0.1 N HCl extraction and estimation using atomic absorption spectrophotometer	Sims and Johnson (1991)
13	Available B	Hot water extraction and estimation by Azomethine-H colorimetry using spectrophotometer	Gupta (1967)
14	Lability Index	C_L (sample) / C_L (reference)	Blair *et al.* (1995)
15	Carbon Pool Index	SOC (sample) / SOC (reference)	Blair *et al.* (1995)
16	Carbon Management Index	Carbon Pool Index x Labile Pool Index	Blair *et al.* (1995)

3.5.2 Plant Analysis

Sample plants collected from each plot at harvest were oven dried at 70 ° C to a constant weight, powdered well and used for analysis. Single acid digestion method using H_2SO_4 was adopted for nitrogen estimation and diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio) was employed for all other nutrients. Chemical analysis of grain, straw and root was carried out as outlined in Table 3.

Table 3. Standard procedures followed for chemical analysis of plant samples

Sl. No.	Element	Method	Reference
1	Total N	Kjeldahl method	Jackson (1973)
2	Total P	Vanado molybdate yellow colour method	Piper (1966)
3	Total K	Flame photometry	Jackson (1973)

4	Total Ca, Mg	Versanate titration method	Hesse (1971)
5	Total Fe, Mn, Cu and Zn	Atomic absorption spectrometer	Lindsay and Norvel (1978)
6	Total B	Azomethine – H colorimetric method	Wolf (1971)

3.5.2.1 Nutrient Uptake

Straw, grain and root samples were dried in a hot air oven at 70° C and dry weights were taken for calculating the nutrient uptake using the following formula:

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{Concentration of nutrient (\%) x Dry matter production (kg ha}^{-1})}{100}$$

3.5.2.2 Protein Content of Grain

Protein content of grain was calculated by multiplying the N content of the grain with the factor 6.25 and expressed in percentage (Simpson *et al.,* 1965).

3.6 PEST AND DISEASE INCIDENCE

Observation on the incidence of major pest and disease was made.

3.7 ECONOMICS OF CULTIVATION

The cost of cultivation, gross returns and benefit: cost ratio (gross returns/cost of cultivation) of each treatment was calculated on the basis of prevailing market price of different inputs and outputs and wages for labourers engaged.

3.8 STATISTICAL ANALYSIS

The data generated from the experiment were statistically analysed using the technique of Analysis of Variance for Randomised Block Design (Cochran and Cox, 1965) and the significance was tested using F test. Wherever the F values were found significant, critical difference was calculated at five per cent and one per cent probability levels.

RESULTS

4. RESULTS

The results obtained from the field experiment conducted at College of Agriculture Vellayani and at farmer's field Venganoor, Thiruvananthapuram, to investigate the effect of secondary and micronutrient application under organic and integrated nutrient management practices, on nutrient uptake, soil health and thereby the productivity of upland rice are presented in this chapter.

4.1 INITIAL SOIL PROPERTIES OF THE EXPERIMENTAL SITE

The basic physical, chemical and physico-chemical properties of the soil of the experimental site before start of the experiment are presented in Table 4. The bulk density of the soil was 1.45 Mg m^{-3} with water holding capacity of 23.9 per cent and porosity of 42 per cent. The texture of the soil was observed to be sandy clay loam with a textural composition of 60.9 per cent sand, 6.3 per cent silt and 31.7 per cent clay.

The soil of the experimental site was very strongly acidic (pH- 4.95), and the electrical conductivity was normal (0.612 dS m^{-1}). Chemical analysis of the soil revealed that organic carbon (0.79 per cent) and available N (358 kg ha^{-1}) contents were medium in status. The available P (37 kg ha^{-1}) and K (450.8 kg ha^{-1}) contents were found to be in the higher range. The soil was sufficient in the secondary nutrients Ca (385.9 mg kg^{-1}) and Mg (264.0 mg kg^{-1}). Among the micronutrients, available Fe (20.48 mg kg^{-1}), Mn (15.47 mg kg^{-1}), Cu (3.31 mg kg^{-1}) and Zn (3.45 mg kg^{-1}) were found to be sufficient while B content (0.30 mg kg^{-1}) of soil was found to be deficient.

4.2 EFFECT OF TREATMENTS ON PLANT BIOMETRIC CHARACTERISTICS

The effect of treatments on growth attributes *viz.* height of plants, total and productive tiller per m^2, root length, dry weight and volume at harvest stage are presented in Tables 5 and 6.

Table 4. Initial properties of the soil of the experimental site

Sl. No.		Status
I. Physical properties		
1	Bulk density ($Mg\ m^{-3}$)	1.45
2	Water holding capacity (%)	23.90
3	Porosity (%)	42.00
II. Mechanical composition		
1	Sand (%)	60.9
2	Silt (%)	6.3
3	Clay (%)	31.7
4	Texture	Sandy clay loam
III. Chemical properties		
1	pH	4.95
2	EC ($dS\ m^{-1}$)	0.612
3	Organic Carbon (%)	0.79
4	Available N ($kg\ ha^{-1}$)	358.0
5	Available P_2O_5 ($kg\ ha^{-1}$)	37.0
6	Available K_2O ($kg\ ha^{-1}$)	450.8
7	Available Ca ($mg\ kg^{-1}$)	385.9
8	Available Mg ($mg\ kg^{-1}$)	264.0
9	Available Fe ($mg\ kg^{-1}$)	20.48
10	Available Mn ($mg\ kg^{-1}$)	15.47
11	Available Cu ($mg\ kg^{-1}$)	3.31
12	Available Zn ($mg\ kg^{-1}$)	3.45
13	Available B ($mg\ kg^{-1}$)	0.30

The results revealed that the effect of treatments was significant with respect to height of plants. Highest value of 103.86 cm was observed for T_6 (T_2+ KAU sampoorna multimix) which was on par with all the treatments except T_1. Absolute control recorded the lowest value of 86.73 cm.

Significant difference in total number of tillers per m^2 at harvest was observed due to the application of treatments. Treatments which received foliar application of micronutrient solution or sampoorna multimix along with KAU PoP with dolomite or lime i.e. (T_5 to T_8) significantly increased the total tillers per m^2 compared to the other treatments, with T_7 (T_3 + micronutrient solution) giving the highest value (396.40). The organic farming treatment alone (T_4) or along with micronutrient spray through either of the micronutrient sources (T_9 and T_{10}) recorded significantly lower total tillers than the KAU PoP treatments (T_2 and T_3) with or without micronutrient supplementation.

The treatment effects were found to be significant with respect to the number of productive tillers per m^2. Highest number (305.0) of productive tillers per m^2 was recorded for the treatments T_5 and T_7 receiving micronutrient solution and was found to be on par with the other treatments receiving foliar application of sampoorna multimix along with lime or dolomite. KAU PoP with lime or dolomite (T_2 and T_3) gave significantly higher number of productive tillers compared to the organic farming treatments (T_4, T_9 and T_{10}).

The effect of different treatments on root length was found to be significant (Table 6). Among the different treatments, the highest root length of 18.9 cm was recorded for the organic farming treatment supplemented with KAU sampoorna multimix (T_{10}), which was on par with the pure organic treatment T_4 and with T_9 where T_4 was supplemented with foliar spray of micronutrient solution. Root length of treatments receiving micronutrients along with lime or dolomite was on par with KAU PoP alone (T_2 and T_3).

Table 5. Effect of treatments on plant biometric characteristics at harvest

Treatment	Height of plants (cm)	Total number of tillers m^{-2}	Productive tillers m^{-2}
T_1- Absolute control	86.73	181.33	139.33
T_2- KAU PoP with lime	101.86	340.00	275.50
T_3- KAU PoP with dolomite	101.20	325.83	257.00
T_4- KAU PoP for organic farming	101.33	269.16	217.50
T_5- T_2 + micronutrient solution	102.40	382.50	305.00
T_6- T_2+ KAU sampoorna multimix	103.86	369.66	301.83
T_7- T_3 + micronutrient solution	102.66	396.40	305.00
T_8- T_3 + KAU sampoorna multimix	103.53	386.36	302.90
T_9 - T_4 + micronutrient solution	101.73	283.33	232.50
T_{10}- T_4 + KAU sampoorna multimix	101.73	283.33	240.00
CD (0.05)	3.059	26.770	22.870

Table 6. Effect of treatments on root parameters at harvest

Treatment	Root length (cm)	Root dry weight (g hill $^{-1}$)	Root volume (cm^3)
T_1- Absolute control	12.20	5.40	11.60
T_2- KAU PoP with lime	15.90	9.20	20.92
T_3- KAU PoP with dolomite	16.00	9.22	20.17
T_4- KAU PoP for organic farming	17.43	9.53	21.50
T_5- T_2 + micronutrient solution	16.30	9.29	20.28
T_6- T_2+ KAU sampoorna multimix	16.47	9.20	20.25
T_7- T_3 + micronutrient solution	16.34	8.83	20.77
T_8- T_3 + KAU sampoorna multimix	16.20	9.05	20.17
T_9 - T_4 + micronutrient solution	17.53	9.42	21.73
T_{10}- T_4 + KAU sampoorna multimix	18.90	9.33	21.80
CD (0.05)	2.240	1.753	2.147

Higher root dry weight was observed for the organic farming treatments with or without micronutrient application, with the highest value obtained for T_4 (9.53 g $hill^{-1}$) which was on par with all the treatments except absolute control.

A perusal of the data revealed that root volume varied from the lowest value of 11.60 cm^3 in T_1 (absolute control) to the highest of 21.80 cm^3 in T_{10} (T_4 + KAU sampoorna multimix) which was on par with all the treatments except absolute control.

4.3 EFFECT OF TREATMENTS ON YIELD ATTRIBUTES OF RICE

Table 7 presents the influence of different treatments on yield attributes of upland rice *viz.* length of panicle, weight of panicle, number of spikelets per panicle, per cent filled grains and thousand grain weight.

The effect of various treatments was significant on the length of panicle of upland rice. Foliar application of micronutrients either as micronutrient solution or as sampoorna multimix along with KAU PoP (lime or dolomite) registered significantly higher values compared to the other treatments. Treatment T_8 receiving foliar application of sampoorna multimix along with KAU PoP + dolomite gave the highest value (23.43 cm).

Effect of different treatments on weight of panicle was found to be significant. Weight of panicle was the highest (2.41 g) for T_8 (T_3 + sampoorna multimix) which was on par with all other treatments where foliar application of micronutrient solution or sampoorna multimix were applied. Treatments which did not receive micronutrient application, including absolute control gave significantly lower values than T_8. Among the organic farming treatments, those receiving foliar application of micronutrients (sampoorna multimix or micronutrient solution) gave higher values for panicle weight compared to the pure organic treatment, T_4.

Data show that the number of spikelets per panicle was the highest for T_8 (154.73) and it was found to be on par with all the micronutrient supplemented

Table 7. Effect of treatments on yield attributes of rice

Treatment	Length of panicle (cm)	Weight of panicle (g)	Number of spikelets $panicle^{-1}$	Per cent filled grains (%)	Thousand grain weight (g)
T_1- Absolute control	15.33	1.30	91.60	77.03	22.03
T_2- KAU PoP with lime	20.67	2.04	143.47	82.33	23.07
T_3- KAU PoP with dolomite	20.77	2.03	145.88	82.42	22.90
T_4- KAU PoP for organic farming	20.53	1.88	137.40	79.13	22.77
T_5- T_2 + micronutrient solution	22.50	2.31	149.50	85.63	23.47
T_6- T_2+ KAU sampoorna multimix	22.50	2.39	150.13	85.87	23.40
T_7- T_3 + micronutrient solution	21.67	2.35	151.33	85.60	23.03
T_8- T_3 + KAU sampoorna multimix	23.43	2.41	154.73	87.17	23.53
T_9 - T_4 + micronutrient solution	21.27	2.17	139.33	83.30	22.87
T_{10}- T_4 + KAU sampoorna multimix	21.13	2.15	140.73	83.17	22.90
CD (0.05)	2.527	0.362	13.602	4.477	NS

treatments either as foliar micronutrient solution or as sampoorna multimix along with KAU PoP (lime or dolomite) (T_5 to T_7) and KAU PoP (lime or dolomite) alone (T_2 and T_3).

The highest value for per cent filled grains was recorded for T_8 (87.17 per cent) receiving dolomite and foliar application of sampoorna multimix which was on par with all the treatments receiving micronutrients. The treatments receiving foliar micronutrient solution with lime or sampoorna multimix along with lime (T_5 to T_7) were on par with KAU PoP (lime or dolomite). Micronutrient application to the organic farming treatments increased the per cent filled grains, while absolute control recorded the lowest value (77.03 per cent).

No significant variation was observed in 1000 grain weight due to the application of different treatments.

4.4 EFFECT OF TREATMENTS ON GRAIN AND STRAW YIELDS

Grain and straw yield of rice as influenced by different treatments presented in Table 8, show that the different treatments showed significant effect on grain yield, with the treatment receiving micronutrients either as micronutrient solution or as sampoorna multimix along with KAU PoP (lime or dolomite) giving significantly higher value compared to all other treatments, the highest value (4158 kg ha^{-1}) being recorded for T_8 (T_3 + KAU sampoorna multimix). Yields obtained for the treatments receiving KAU PoP with lime or dolomite and without micronutrient application (T_2 and T_3) were on par with the organic farming treatments supplemented with micronutrients (T_9 and T_{10}).

Straw yield was the highest (4897 kg ha^{-1}) for KAU PoP + lime treatment receiving foliar application of micronutrient solution (T_5) and was on par with the KAU PoP treatments receiving lime or dolomite with or without micronutrient application either as micronutrient solution or as sampoorna multimix. Straw yield for the organic farming treatments were comparatively lower than the INM treatments with or without micronutrients, with significant reduction compared to

Table 8. Effect of treatments on grain and straw yield of upland rice

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1- Absolute control	1055	2269
T_2- KAU PoP with lime	3390	4337
T_3- KAU PoP with dolomite	3372	4328
T_4- KAU PoP for organic farming	2808	4130
T_5- T_2 + micronutrient solution	3888	4897
T_6- T_2+ KAU sampoorna multimix	4024	4321
T_7- T_3 + micronutrient solution	3894	4372
T_8- T_3 + KAU sampoorna multimix	4158	4362
T_9 - T_4 + micronutrient solution	2936	4084
T_{10}- T_4 + KAU sampoorna multimix	3276	3933
CD (0.05)	472.56	645.9

T_5. Application of micronutrients did not increase the straw yield of organic farming treatments.

4.5 EFFECT OF TREATMENTS ON THE NUTRIENT CONTENT OF INDEX LEAF AT PANICLE INITIATION STAGE

The influence of secondary and micronutrient management on the nutrient content of index leaf at panicle initiation stage is presented in Table 9.

Analysis of data shows that the applied treatments significantly influenced the concentration of nitrogen in index leaf at panicle initiation stage. N content was the highest (1.27 per cent) for T_6 (T_2 + KAU sampoorna multimix) which was on par with all the treatments receiving foliar micronutrient application or KAU PoP (lime or dolomite) alone. Organic farming treatment without micronutrient application (T_4) gave lower value (1.04 per cent).

Application of liming materials alone or along with foliar micronutrient application gave significantly higher content of P in index leaf compared to the organic farming treatments or absolute control, with T_6 (T_2+ KAU sampoorna multimix) giving the highest value (0.29 per cent), which was on par with the treatments receiving KAU PoP (lime or dolomite) alone.

Potassium content of index leaf varied from 1.25 per cent in absolute control to 2.09 per cent in T_7 (T_3+ micronutrient solution). All the treatments receiving foliar application of micronutrients along with KAU PoP (dolomite or lime) had higher K content and were on par with each other. Foliar application of micronutrient solution increased the K content of index leaf in organic farming.

The treatment effect was found to be significant with respect to Ca content in index leaf. Application of liming materials with or without micronutrients increased the Ca content, with the treatment T_2 receiving lime as per ΔpH lime giving the highest value (0.26 per cent) which was on par with the treatment receiving foliar application of micronutrient solution along with lime or dolomite and with KAU PoP (dolomite) without micronutrient application. The organic farming treatment (T_4) gave Ca content significantly lower than the other treatments except absolute control. Application of micronutrients increased the Ca content of index leaf in organic treatments (T_9 and T_{10}).

The different treatments exhibited significant effect on Mg content of index leaf at panicle initiation stage. KAU PoP along with dolomite (T_3) or with foliar application of sampoorna multimix (T_8) gave the highest Mg content (0.36 per cent) in index leaf which was on par with all the treatments receiving liming materials (T_2, T_5, T6 and T_7) with or without micronutrients. Lower Mg content was recorded for the organic farming treatments compared to the KAU PoP (lime or dolomite) treatments.

The data presented show that the content of iron in index leaf at panicle initiation stage was improved by the application of micronutrients. Treatment T_5 (T_2 + micronutrient solution) registered the highest content of iron (422.17 mg kg^{-1}) at panicle initiation stage and was found to be on par with all the treatments receiving foliar application of micronutrients either as micronutrient solution or as sampoorna multimix along with KAU PoP (lime or dolomite). Iron content of KAU PoP treatments without micronutrients and organic farming treatments were on par.

Observations revealed that micronutrient application had significant effect on Mn content of index leaf. Foliar application of micronutrient solution along with KAU PoP (lime or dolomite) gave significantly higher Mn content, with T_7 (T_3 + micronutrient solution) recording the highest value (358.67 mg kg^{-1}). The absolute control recorded the lowest value (295.05 mg kg^{-1})

The index leaf tissue analysis revealed significant difference in the copper content at panicle initiation stage. Highest copper content (12.77 mg kg^{-1}) was recorded with foliar application of KAU sampoorna multimix along with KAU PoP (lime) i.e. T_6 and was on par with T_5, T_7 and T_8. Though micronutrient application gave higher values for Cu content in organic farming treatments, the increase was not significant.

Table 9. Nutrient content of index leaf at panicle initiation stage of rice*

Treatment	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn	B
T_1- Absolute control	0.90	0.19	1.25	0.11	0.14	301.55	295.05	5.48	48.26	7.94
T_2- KAU PoP with lime	1.22	0.26	1.67	0.26	0.32	344.00	317.40	8.64	55.73	8.86
T_3- KAU PoP with dolomite	1.19	0.26	1.77	0.24	0.36	339.21	318.67	8.93	56.74	8.92
T_4- KAU PoP for organic farming	1.04	0.24	1.75	0.17	0.27	322.21	302.64	6.61	50.08	8.62
T_5- T_2 + micronutrient solution	1.23	0.28	1.96	0.24	0.32	422.17	345.09	11.52	62.60	9.97
T_6- T_2+ KAU sampoorna multimix	1.27	0.29	1.99	0.25	0.34	410.32	341.69	12.77	59.79	10.19
T_7- T_3 + micronutrient solution	1.14	0.27	2.09	0.24	0.34	415.09	358.67	12.49	66.04	10.15
T_8- T_3 + KAU sampoorna multimix	1.19	0.28	2.01	0.23	0.36	412.22	342.20	11.64	64.23	10.39
T_9 - T_4 + micronutrient solution	1.13	0.25	1.87	0.20	0.29	348.37	325.07	7.91	54.20	8.35
T_{10}- T_4 + KAU sampoorna multimix	1.12	0.23	1.76	0.21	0.30	346.48	320.19	7.48	55.19	8.53
CD (0.05)	0.193	0.032	0.180	0.083	0.056	63.506	27.000	3.754	9.280	1.451

*N, P and K in % and others in mg kg^{-1}

The analytical results of foliar Zn content at panicle initiation stage as influenced by different treatments revealed that zinc concentration was the highest (66.04 mg kg^{-1}) for treatment T_7 (T_3 + micronutrient solution) and was on par with all the treatments which received either form of micronutrients along with KAU PoP (lime or dolomite).

Significant increase in boron content of index leaf at panicle initiation stage was obtained due to micronutrient application along with KAU PoP (lime or dolomite). Treatments receiving foliar application of micronutrients along with KAU PoP (lime or dolomite) was found to be on par with each other, with T_8 (T_3 + sampoorna multimix) recording the highest value (10.39 mg kg^{-1}).

4.6 EFFECT OF TREATMENTS ON NUTRIENT CONTENT AND UPTAKE BY STRAW, GRAIN AND ROOT

4.6.1 Nitrogen

The effect of secondary and micronutrient application on the content and uptake of nitrogen in straw, grain and root is given in Table 10.

The nitrogen content in straw was found to be significantly influenced by the treatments. Supplementation of micronutrients along with lime or dolomite gave the higher values for N content in straw which were on par with T_8 (T_3 + sampoorna multimix) registering the highest value (1.27 per cent). T_8 was also on par with treatments receiving KAU PoP alone (lime or dolomite) without micronutrient supplementation. Nitrogen content of straw for the organic farming treatment alone or with foliar micronutrient application was low but on par with KAU PoP (lime or dolomite) treatment.

Data on the effect of different treatments on grain nitrogen content revealed that the values were higher and on par for all the treatments receiving foliar micronutrient application, with T_7 (T_3 + micronutrient solution) registering the highest value (1.23 per cent). The organic farming treatment (T_4) and absolute control registered lower values for N content of grain.

Table 10. Effect of treatments on the content and uptake of N in straw, grain and root

Treatments	N Content (%)			Uptake (kg ha^{-1})		
	Straw	Grain	Root	Straw	Grain	Root
T_1- Absolute control	0.60	0.78	0.15	13.982	8.30	2.79
T_2- KAU PoP with lime	1.12	1.08	0.18	48.62	36.78	5.57
T_3- KAU PoP with dolomite	1.06	1.16	0.15	45.16	39.08	4.50
T_4- KAU PoP for organic farming	0.91	1.00	0.22	37.61	28.18	6.88
T_5- T_2 + micronutrient solution	1.23	1.12	0.11	60.45	43.08	3.43
T_6- T_2+ KAU sampoorna multimix	1.26	1.16	0.19	55.01	46.56	5.85
T_7- T_3 + micronutrient solution	1.26	1.23	0.19	55.00	48.03	5.56
T_8- T_3 + KAU sampoorna multimix	1.27	1.19	0.18	55.52	49.80	5.43
T_9 - T_4 + micronutrient solution	0.95	1.08	0.187	38.87	31.80	5.53
T_{10}- T_4 + KAU sampoorna multimix	0.96	1.04	0.15	37.60	34.35	4.43
CD (0.05)	0.234	0.231	NS	13.547	9.867	NS

The data presented shows that treatments could not exert any significant influence root nitrogen content.

Nitrogen uptake by straw was significantly influenced by the different treatments, with those receiving liming materials with or without micronutrient supplementation giving higher uptake values. Foliar application of micronutrient solution along with KAU PoP (lime) (T_5) recorded the highest value (60.45 kg ha^{-1}) and was found to be on par with all the treatments receiving micronutrient application along with lime or dolomite and KAU PoP (lime) alone. Straw uptake of nitrogen for the treatments receiving micronutrients along with dolomite (T_7 and T_8) was found to be on par with T_3 with dolomite alone. Organic farming treatment receiving micronutrients (T_9 and T_{10}) recorded nitrogen uptake values on par with KAU PoP (lime or dolomite).

The highest nitrogen uptake (49.8 kg ha^{-1}) by grain was recorded by T_8 where micronutrients were supplemented with dolomite and was found to be on par with the treatments receiving micronutrients along with lime or dolomite or KAU PoP (lime or dolomite) alone.

The uptake of nitrogen by root did not show significant variation due to the application of treatments.

4.6.2 Phosphorus

The effect of treatments on the content and uptake of phosphorus in straw, grain and root is given in Table 11.

The treatment effect was found to be significant with respect to straw P content. Foliar application of micronutrients as sampoorna multimix or micronutrient solution along with KAU PoP (lime) resulted in the highest straw P content (0.25 per cent) which was on par with all the treatments receiving micronutrient application (T_7 to T_{10}) and the KAU PoP (lime or dolomite) treatments. Organic farming treatments with micronutrient supplementation registered higher straw P content (0.24 and 0.23 per cent) compared to pure organic treatment (T_4) (0.18 per cent).

Grain and root P contents were found to be non- significant with respect to different treatments.

The treatments exhibited significant effect on straw P uptake, with T_5 (T_2 + micronutrient solution) registering the highest value (12.11 kg ha^{-1}). Micronutrient application along with lime or dolomite generally gave higher values for P uptake which were on par with T_5.

Phosphorus uptake by grain was the highest (7.53 kg ha^{-1}) for treatment T_7 (T_3 + micronutrient solution) and was on par with the treatments receiving micronutrients along with KAU PoP (lime or dolomite). The organic farming treatment (T_4) and absolute control (T_1) gave significantly lower P uptake values.

No significant variation was observed in P uptake by root due to the application of treatments.

4.6.3 Potassium

Influence of different treatments on the content and uptake of K by straw, grain and root is presented in the Table 12.

Observations revealed that application of liming materials (KAU PoP) alone or along with foliar application of micronutrients improved the potassium content of straw. Foliar application of sampoorna multimix along with lime (T_6) gave the highest value (1.14 per cent) which was on par with all the treatments receiving foliar application of micronutrients along with KAU PoP (lime or dolomite) or KAU PoP (lime or dolomite) alone. The organic farming treatment (T_4) gave significantly lower straw potassium content.

Treatment effects were found to be significant with respect to grain potassium content also. Foliar application of sampoorna multimix along with dolomite (T_8) resulted in the highest grain potassium content (0.49 per cent)

Table 11. Effect of treatments on the content and uptake of P in straw, grain and root

Treatment	P Content (%)			Uptake (kg ha^{-1})		
	Straw	Grain	Root	Straw	Grain	Root
T_1- Absolute control	0.15	0.13	0.018	3.38	0.89	0.322
T_2- KAU PoP with lime	0.23	0.18	0.023	9.75	5.60	0.702
T_3- KAU PoP with dolomite	0.23	0.16	0.023	9.99	5.55	0.706
T_4- KAU PoP for organic farming	0.18	0.14	0.027	7.54	3.87	0.782
T_5- T_2 + micronutrient solution	0.25	.17	0.027	12.11	5.68	0.807
T_6- T_2+ KAU sampoorna multimix	0.25	0.17	0.026	10.81	6.92	0.801
T_7- T_3 + micronutrient solution	0.22	0.19	0.029	9.60	7.53	0.843
T_8- T_3 + KAU sampoorna multimix	0.24	0.18	0.026	10.61	7.50	0.774
T_9 - T_4 + micronutrient solution	0.23	0.16	0.022	9.65	4.70	0.657
T_{10}- T_4 + KAU sampoorna multimix	0.24	.14	0.027	9.39	5.43	0.789
CD (0.05)	0.028	NS	NS	1.907	1.942	NS

Table 12. Effect of treatments on the content and uptake of K in straw, grain and root

Treatment	K Content (%)			Uptake (kg ha^{-1})		
	Straw	Grain	Root	Straw	Grain	Root
T_1- Absolute control	0.81	0.31	0.2	18.42	3.25	3.49
T_2- KAU PoP with lime	1.07	0.45	0.213	47.08	15.48	6.446
T_3- KAU PoP with dolomite	1.01	0.45	0.213	43.6	15.3	6.345
T_4- KAU PoP for organic farming	0.92	0.4	0.24	38.14	11.15	7.487
T_5- T_2 + micronutrient solution	1.08	0.44	0.187	53.07	17.42	5.696
T_6- T_2+ KAU sampoorna multimix	1.14	0.47	0.24	49.06	19.21	7.225
T_7- T_3 + micronutrient solution	1.07	0.44	0.213	46.65	17.41	6.195
T_8- T_3 + KAU sampoorna multimix	1.09	0.49	0.24	47.73	20.38	7.062
T_9 - T_4 + micronutrient solution	0.95	0.43	0.173	38.97	12.53	5.341
T_{10}- T_4 + KAU sampoorna multimix	0.98	0.44	0.227	38.64	14.3	7.04
CD (0.05)	0.148	0.067	NS	10.615	3.527	NS

which was on par with the rest of the treatments except organic farming treatment (T_4) and absolute control (T_1).

No significant variation was observed in K content of root due to the application of treatments.

Straw potassium uptake was significantly influenced by different treatments. The treatments receiving foliar application of micronutrients along with lime or dolomite resulted in higher values for straw potassium uptake and was on par with KAU PoP (lime or dolomite). Foliar application of micronutrient solution along with lime (T_5) recorded the highest straw uptake (53.07 kg ha^{-1}) value. The uptake values for organic farming treatments (T_4, T_9 and T_{10}) were significantly lower.

Grain potassium uptake was significantly increased by foliar application of micronutrients along with lime or dolomite. The treatment receiving foliar application of sampoorna multimix along with dolomite (T_8) gave the highest grain uptake (20.38 kg ha^{-1}) which was on par with the rest of the treatments receiving micronutrients along with KAU PoP (lime or dolomite). Micronutrient supplementation of organic farming treatments increased the grain potassium uptake but the increase was not significant.

Treatment effects were not significant with respect to the uptake of K by root.

4.6.4 Calcium

The content and uptake of Ca by straw, grain and root is presented in Table 13.

Observations on Ca content in straw showed that variation in nutrient management produced significant influence on the content values. Straw Ca content was the highest (0.35 per cent) for treatment T_2 receiving lime as per ΔpH which was on par with all the treatments except T_4 and T_1. Application of micronutrients to organic farming treatments gave higher Ca uptake values though the increase was not significant.

The treatment effect was found to be significant with respect to grain Ca content also. Highest grain Ca content (0.19 per cent) was observed for the treatment T_5 (foliar application of micronutrient solution along with lime), which was on par with all the treatments receiving liming materials with or without micronutrients. The organic farming treatments gave significantly lower values for grain Ca content. Absolute control recorded the lowest values for grain Ca content (0.1 per cent).

The treatments could not exert any significant influence on root calcium content.

Calcium uptake by straw showed significant influence due to the different treatments. The treatment T_5 (T_2+ foliar application of micronutrient solution) gave higher values for Ca uptake (16.76 kg ha^{-1}) and was found to be on par with all the treatments except the organic farming treatments and absolute control.

Grain Ca uptake was also significantly influenced by liming and foliar micronutrient application. Foliar application of sampoorna multimix along with KAU PoP (lime) (T_6) registered the highest value (7.6 kg ha^{-1}) and was on par with all the treatments except T_1, T_3, T_4 and T_9.

The treatment effects were not significant with respect to the uptake of Ca by root.

4.6.5 Magnesium

The effect of different treatments on the content and uptake of Mg by straw, grain and root are presented in Table 14.

Magnesium content of straw was significantly influenced by the treatments, with treatments T_3 (KAU PoP + dolomite) and T_8 (T_3+ foliar application of sampoorna multimix) giving the highest values (0.33 per cent)

Table 13. Effect of treatments on the content and uptake of Ca in straw, grain and root

Treatment	Ca Content (%)			Uptake (kg ha^{-1})		
	Straw	Grain	Root	Straw	Grain	Root
T_1- Absolute control	0.21	0.10	0.160	4.78	1.17	2.813
T_2- KAU PoP with lime	0.35	0.19	0.133	15.27	6.33	3.978
T_3- KAU PoP with dolomite	0.30	0.16	0.160	12.97	5.43	5.126
T_4- KAU PoP for organic farming	0.24	0.12	0.187	9.86	3.39	5.907
T_5- T_2 + micronutrient solution	0.34	0.19	0.133	16.76	7.50	3.996
T_6- T_2+ KAU sampoorna multimix	0.35	0.19	0.160	15.14	7.60	4.858
T_7- T_3 + micronutrient solution	0.34	0.17	0.107	14.87	6.59	3.133
T_8- T_3 + KAU sampoorna multimix	0.31	0.17	0.173	13.39	6.94	5.227
T_9 - T_4 + micronutrient solution	0.28	0.13	0.127	12.14	3.82	3.839
T_{10}- T_4 + KAU sampoorna multimix	0.29	0.13	0.133	11.40	4.39	3.960
CD (0.05)	0.086	0.048	NS	4.387	2.029	NS

Table 14. Effect of treatments on the content and uptake of Mg in straw, grain and root

Treatment	Mg Content (%)			Uptake (kg ha^{-1})		
	Straw	Grain	Root	Straw	Grain	Root
T_1- Absolute control	0.22	0.102	0.048	4.95	1.08	0.855
T_2- KAU PoP with lime	0.27	0.128	0.096	11.75	4.30	2.856
T_3- KAU PoP with dolomite	0.33	0.132	0.096	14.56	4.45	2.817
T_4- KAU PoP for organic farming	0.22	0.107	0.064	9.35	2.98	2.105
T_5- T_2 + micronutrient solution	0.27	0.124	0.064	13.29	4.83	1.935
T_6- T_2+ KAU sampoorna multimix	0.27	0.128	0.080	11.81	5.09	2.387
T_7- T_3 + micronutrient solution	0.32	0.130	0.080	13.75	5.04	2.360
T_8- T_3 + KAU sampoorna multimix	0.33	0.127	0.096	14.64	5.50	2.946
T_9 - T_4 + micronutrient solution	0.24	0.114	0.080	9.85	3.34	2.547
T_{10}- T_4 + KAU sampoorna multimix	0.25	0.109	0.080	10.06	3.58	2.534
CD (0.05)	0.0640	0.0160	NS	3.315	0.837	NS

which were on par with all the treatments receiving dolomite or lime with or without micronutrients and the KAU PoP (lime) treatment alone. Mg content of organic farming treatments receiving micronutrients were on par with KAU PoP with lime (T_2).

From the table it is clear that the treatments could exert significant effect on grain Mg content. Grain Mg content was the highest (0.132 per cent) for the treatment T_3 receiving KAU PoP with dolomite as liming material, which was on par with the treatments receiving micronutrients along with lime or dolomite i.e. T_5 to T_8. T_1 recorded the lowest value (0.102 per cent) for grain Mg content.

Root content of Mg at harvest did not vary significantly due to the application of treatments.

Observations revealed that straw magnesium uptake was significantly improved by different treatments compared to control. Highest value (14.64 kg ha^{-1}) was recorded for treatment T_8 (T_3 + sampoorna multimix) which was found to be on par with treatments T_2, T_3, T_5, T_6 and T_7.

Nutrient management practices significantly influenced the uptake of magnesium by grain, with the highest value (5.50 kg ha^{-1}) recorded by T_8 (T_3 + sampoorna multimix) which was on par with the treatments receiving micronutrients along with lime or dolomite (T_5 to T_7). The treatments receiving liming materials (lime or dolomite) had uptake values significantly higher than the organic farming treatments T_4, T_9 and T_{10}.

Uptake of Mg by root was not affected significantly by the different treatments.

4.6.6 Iron

The effect of secondary and micronutrient management on the content and uptake of iron by straw, grain and root is presented in Table 15.

The concentration of iron in straw was significantly influenced by the treatments. Application of micronutrients significantly increased the iron content in straw. Foliar application of micronutrient solution along with KAU PoP (dolomite) i.e. T_7 registered the highest value of 451.80 mg kg^{-1} and was found to be on par with all the other treatments receiving micronutrients either as micronutrient solution or as sampoorna multimix along with KAU PoP (lime or dolomite). The organic farming treatments receiving micronutrients (T_9 and T_{10}) gave significantly higher content of iron in straw compared to KAU PoP alone (T_2 to T_3) or the pure organic treatment (T_4).

Effect of treatments on grain iron content was also found to be significant. Foliar application of sampoorna multimix along with dolomite (T_8) recorded significantly higher grain iron content value of 230.64 mg kg^{-1} followed by sampoorna multimix application along with lime (T_6). Foliar application of micronutrient solution also gave higher iron content values compared to KAU PoP (T_2 and T_3) or the organic farming treatments (T_4, T_9 and T_{10}) but the increase was not significant.

Root content of iron at harvest stage was not influenced by the different treatments.

Data revealed that the treatments had exerted significant effect on the uptake of iron by straw. The highest uptake of iron by straw (1.97 kg ha^{-1}) was recorded by treatment T_7 (T_3 + micronutrient solution) which was on par with T_5, T_6 and T_8. Straw uptake of iron by the organic farming treatments receiving micronutrients (T_9 and T_{10}) was significantly higher than the pure organic treatment (T_4).

The values for grain iron uptake showed that the treatment effect was significant, with micronutrient application giving higher uptake values compared to the treatments without micronutrient supplementation. Among the different treatments, T_8 (T_3 + KAU sampoorna multimix) recorded the highest value (0.985

kg ha^{-1}) and was on par with T_6 (T_2 + KAU sampoorna multimix) with an uptake of 0.868 kg ha^{-1}

Uptake of iron by root was not affected significantly by the different treatments.

4.6.7. Manganese

The results pertaining to the effect of different treatments on the content and uptake of Mn by straw, grain and root are presented in Table 16.

Treatments receiving foliar application of micronutrient solution along with lime (T_5) gave the highest straw Mn content (353.33 mg kg^{-1}) compared to the other treatments. All the treatments receiving lime or dolomite supplemented with micronutrients were on par with each other with respect to manganese content of straw.

Significant differences in grain manganese contents were observed among different treatments with the values ranging from 25.17 mg kg $^{-1}$ for T_1 (absolute control), to 59.87 mg kg $^{-1}$ for T_7 (T_3 + micronutrient solution). Grain manganese contents of the treatments receiving micronutrients along with lime or dolomite were on par with T_7. Foliar spray of micronutrients to the organic farming treatment through either of the sources increased the content of manganese in grains though the differences were not significant.

No significant variation was observed in Mn content of root due to different treatments

A perusal of the data revealed that the different treatments had significant effect on the uptake of Mn by straw. The highest straw manganese uptake (1.73 kg ha^{-1}) was observed in T_5 (T_2 + micronutrient solution) which was on par with T_7 (T_3 + micronutrient solution). Straw manganese uptake was also significantly higher for the treatments receiving sampoorna multimix along with KAU PoP (T_6 and T_8) compared to the organic farming treatments and the treatments receiving KAU PoP alone (T_2 and T_3).

Table 15. Effect of treatments on the content and uptake of Fe in straw, grain and root

Treatment	Fe Content (mg kg^{-1})			Uptake (kg ha^{-1})		
	Straw	Grain	Root	Straw	Grain	Root
T_1- Absolute control	238.06	113.44	124.93	0.53	0.118	0.229
T_2- KAU PoP with lime	268.26	164.62	146.73	1.17	0.557	0.446
T_3- KAU PoP with dolomite	280.00	165.81	146.31	1.211	0.560	0.440
T_4- KAU PoP for organic farming	255.98	133.97	101.32	1.054	0.381	0.370
T_5- T_2 + micronutrient solution	440.40	174.62	136.20	1.85	0.663	0.417
T_6- T_2+ KAU sampoorna multimix	409.32	215.53	121.46	1.78	0.868	0.366
T_7- T_3 + micronutrient solution	451.80	169.74	137.13	1.97	0.660	0.396
T_8- T_3 + KAU sampoorna multimix	409.32	230.64	121.47	1.78	0.985	0.370
T_9 - T_4 + micronutrient solution	377.26	157.81	138.30	1.53	0.462	0.437
T_{10}- T_4 + KAU sampoorna multimix	375.01	160.80	129.58	1.47	0.525	0.398
CD (0.05)	62.729	48.328	NS	0.412	0.177	NS

Table 16.Effect of treatments on the content and uptake of Mn in straw, grain and root

Treatment	Mn Content (mg kg^{-1})			Uptake (kg ha^{-1})		
	Straw	Grain	Root	Straw	Grain	Root
T_1- Absolute control	253.58	25.17	49.86	0.572	0.02	0.089
T_2- KAU PoP with lime	258.97	35.63	52.13	1.10	0.12	0.158
T_3- KAU PoP with dolomite	256.63	35.83	52.53	1.11	0.12	0.158
T_4- KAU PoP for organic farming	249.42	34.88	50.00	1.02	0.09	0.157
T_5- T_2 + micronutrient solution	353.33	54.14	53.74	1.73	0.21	0.165
T_6- T_2+ KAU sampoorna multimix	330.66	44.30	55.34	1.43	0.18	0.168
T_7- T_3 + micronutrient solution	342.93	59.87	55.46	1.49	0.23	0.162
T_8- T_3 + KAU sampoorna multimix	327.20	48.07	55.74	1.42	0.20	0.166
T_9 - T_4 + micronutrient solution	270.62	38.52	50.40	1.09	0.11	0.157
T_{10}- T_4 + KAU sampoorna multimix	263.01	40.66	50.80	1.03	0.13	0.156
CD (0.05)	65.046	10.297	NS	0.237	0.046	0.0330

The effect of treatments on grain Mn uptake was significantly influenced by micronutrient application. Foliar application of micronutrient solution along with KAU PoP (dolomite) (T_7) registered the highest value (0.23 kg ha^{-1}) which was found to be on par with T_5, T_6 and T_8 and significantly higher than KAU PoP alone (T_2 and T_3). Micronutrient application to the organic farming treatments increased the grain manganese uptake, though not significant.

Manganese uptake by root was also significantly increased by foliar micronutrient application to the KAU PoP treatments (T_2 and T_3) compared to the organic farming treatments and KAU PoP (lime or dolomite) alone.

4.6.8 Copper

The results on the content and uptake of copper by straw, grain and root as affected by secondary and micronutrient management are presented in Table 17.

Copper content was significantly higher for the treatments receiving micronutrient foliar spray either as micronutrient solution or as sampoorna multimix along with KAU PoP (lime or dolomite). The highest straw copper content (14.76 mg kg^{-1}) was recorded by T_6 (T_2+ KAU sampoorna multimix) which was on par with the treatments receiving micronutrients along with lime or dolomite (T_5 to T_8). In general the KAU PoP (lime or dolomite) and the organic treatments gave lower straw copper contents though non-significant increase was observed in copper content of straw for organic farming treatments due to micronutrient application.

Copper content of grain was found to be significantly higher for treatment T_6 (T_2+ KAU sampoorna multimix) with a value of (12.8 mg kg^{-1}) which was found to be on par with all the treatments except the pure organic treatment (T_4) and absolute control (T_1).

Copper content of root was not significantly influenced by the application of various treatments.

Data on copper uptake by straw indicated that foliar application of micronutrient solution along with KAU PoP (lime) i.e. (T_5) resulted in higher uptake value (0.06 kg ha^{-1}) which was on par with treatments T_6 to T_8.

Foliar application of sampoorna multimix along with KAU PoP (lime) registered the highest value for copper uptake (0.05 kg ha^{-1}) by grain which was on par with T_5, T_7 and T_8, receiving micronutrient spray along with lime or dolomite. Absolute control registered the lowest value.

No significant difference was observed in root copper uptake due to the different treatments.

4.6.9 Zinc

The treatment effects of the content and uptake of zinc by straw, grain and root are presented in Table 18.

Effect of treatments on straw zinc content was found to be significant. Foliar application of micronutrients significantly increased the straw zinc content, with application of micronutrient solution along with KAU PoP (lime) (T_5) giving the highest straw zinc value (92.46 mg kg^{-1}) which was on par with the treatments receiving micronutrients along with lime or dolomite (T_6, T_7 and T_8) and significantly higher than the organic farming treatments and KAU PoP (lime or dolomite) with or without micronutrient application and the absolute control.

Foliar application of micronutrients along with KAU PoP (lime or dolomite) (T_5 to T_8) recorded the highest grain zinc content and was on par with each other. Grain zinc content varied from 21.97 mg kg^{-1} for T1 (absolute control) to 72.34 mg kg^{-1} for T_8 (T_3 + sampoorna multimix).

Zinc content of root was not influenced by the treatments.

The different treatments had exerted significant effect on the uptake of zinc by straw. Treatment T_5 (T_2 + micronutrient solution) recorded significantly higher uptake value (0.46 kg ha^{-1}) and was found to be on par with T_7 (T_3+

Table 17. Effect of treatments on the content and uptake of Cu in straw, grain and root

Treatment	Cu Content (mg kg^{-1})			Uptake (kg ha^{-1})		
	Straw	Grain	Root	Straw	Grain	Root
T_1- Absolute control	6.17	5.29	4.58	0.01	0.01	0.008
T_2- KAU PoP with lime	10.64	9.61	7.12	0.04	0.03	0.022
T_3- KAU PoP with dolomite	10.53	8.92	5.53	0.04	0.03	0.017
T_4- KAU PoP for organic farming	8.61	7.28	5.10	0.03	0.02	0.016
T_5- T_2 + micronutrient solution	13.51	11.61	5.86	0.06	0.04	0.018
T_6- T_2+ KAU sampoorna multimix	14.76	12.80	5.52	0.06	0.05	0.017
T_7- T_3 + micronutrient solution	14.49	11.32	5.21	0.06	0.04	0.015
T_8- T_3 + KAU sampoorna multimix	13.63	11.46	6.09	0.06	0.04	0.018
T_9 - T_4 + micronutrient solution	9.90	10.25	5.947	0.04	0.03	0.019
T_{10}- T_4 + KAU sampoorna multimix	9.48	10.53	5.253	0.03	0.03	0.016
CD (0.05)	3.423	5.293	NS	0.016	0.011	NS

Table 18. Effect of treatments on the content and uptake of Zn by straw, grain and root

Treatment	Zn Content (mg kg^{-1})			Uptake (kg ha^{-1})		
	Straw	Grain	Root	Straw	Grain	Root
T_1- Absolute control	38.98	21.97	46.93	0.08	0.02	0.085
T_2- KAU PoP with lime	73.84	43.94	55.84	0.33	0.15	0.170
T_3- KAU PoP with dolomite	63.11	49.31	55.09	0.27	0.16	0.168
T_4- KAU PoP for organic farming	64.48	35.59	54.93	0.27	0.10	0.173
T_5- T_2 + micronutrient solution	92.46	63.61	54.02	0.46	0.25	0.166
T_6- T_2+ KAU sampoorna multimix	86.48	72.02	55.14	0.36	0.29	0.167
T_7- T_3 + micronutrient solution	87.76	70.21	55.84	0.38	0.27	0.163
T_8- T_3 + KAU sampoorna multimix	81.10	72.34	56.53	0.35	0.30	0.168
T_9 - T_4 + micronutrient solution	75.18	49.97	53.20	0.31	0.15	0.166
T_{10}- T_4 + KAU sampoorna multimix	71.47	47.84	54.93	0.28	0.16	0.170
CD (0.05)	17.399	18.234	NS	0.088	0.076	0.047

micronutrient solution). No significant difference was observed in straw zinc content among the KAU PoP (lime or dolomite) treatments, the organic farming treatments (T_4, T_9 and T_{10}) and the KAU PoP treatments supplemented by foliar application of micronutrient solution.

The uptake of zinc by grain was significantly influenced by the various treatments. Foliar application of micronutrients along with lime or dolomite gave significantly higher zinc uptake by grain, with the treatment T_8 (T_3 + foliar application of sampoorna multimix) registering the highest uptake value (0.30 kg ha^{-1}). Foliar micronutrient supplementation to the KAU PoP (lime or dolomite) treatments significantly increased the grain zinc uptake compared to the organic farming treatments (T_4, T_9 and T_{10}) and KAU PoP (lime or dolomite) alone (T_2, T_3).

Zinc uptake by root was significantly higher for all the treatments compared to absolute control.

4.6.10 Boron

The results on the effect of different treatments on the content and uptake of boron by straw, grain and root are summarised in Table 19.

The values for straw boron content showed that the treatment effects were significant compared to control. Foliar application of sampoorna multimix along with KAU PoP (dolomite) (T_8) registered significantly higher content (11.47 mg kg^{-1}) of boron which was on par with all the treatments receiving micronutrient spray (micronutrient solution or sampoorna multimix) along with KAU PoP (dolomite or lime). The pure organic farming treatment (T_4) gave significantly lower straw boron content compared to the organic farming treatments supplemented with micronutrients (T_9 and T_{10}).

Grain boron content was also higher for the KAU PoP treatments supplemented with micronutrients. Treatment T_8 receiving foliar application of sampoorna multimix along with dolomite gave the highest grain boron content

(8.83 mg kg^{-1}) which was on par with treatments T_5 to T_7 where micronutrients were given along with lime or dolomite.

Boron content in root was also significantly higher for the micronutrient supplemented treatments in general.

Data on uptake of boron by straw indicated that foliar application of micronutrients along with KAU PoP gave significantly higher values for boron uptake compared to the treatments without micronutrients. The treatment receiving foliar application of micronutrient solution along with KAU PoP (lime) (T_5) registered higher value (0.055 kg ha^{-1}) for boron uptake and was found to be on par with T_6, T_7 and T_8. Straw uptake of boron by the organic farming treatments were found to be on par with KAU PoP (lime or dolomite) alone.

The data presented shows that foliar application of micronutrients significantly improved the uptake of boron by grain. Among the different treatments, sampoorna multimix along with KAU PoP (dolomite) registered the highest value (0.037 kg ha^{-1}) and was found to be on par with T_5, T_6 and T_7. All the other treatments including absolute control gave significantly lower uptake values.

Boron uptake by root was remarkably lower for the absolute control treatment than all the integrated nutrient management treatments.

4.7 EFFECT OF TREATMENTS ON PROTEIN CONTENT IN GRAIN

The data on protein content of grain is presented in Table 20. The treatment receiving foliar application of micronutrient solution along with lime (T_7) gave the highest value for protein content (7.7 per cent) which was on par with all the treatments except absolute control.

4.8 EFFECT OF TREATMENTS ON SOIL PHYSICAL PROPERTIES

Table 21 shows the effect of different treatments on soil physical properties. Data indicate that the application of secondary and micronutrients had

Table 19. Effect of treatments on the content and uptake of B in straw, grain and root

Treatment	B Content (mg kg^{-1})			Uptake (kg ha^{-1})		
	Straw	Grain	Root	Straw	Grain	Root
T_1- Absolute control	7.99	5.44	0.32	0.018	0.006	0.001
T_2- KAU PoP with lime	8.89	6.37	1.06	0.039	0.022	0.003
T_3- KAU PoP with dolomite	8.50	6.64	1.10	0.037	0.022	0.003
T_4- KAU PoP for organic farming	8.17	5.80	0.94	0.034	0.016	0.003
T_5- T_2 + micronutrient solution	11.11	8.47	1.19	0.055	0.033	0.004
T_6- T_2+ KAU sampoorna multimix	11.32	8.41	1.12	0.05	0.035	0.003
T_7- T_3 + micronutrient solution	10.81	8.20	1.09	0.047	0.032	0.003
T_8- T_3 + KAU sampoorna multimix	11.47	8.83	1.22	0.050	0.037	0.004
T_9 - T_4 + micronutrient solution	9.70	6.25	0.94	0.040	0.018	0.003
T_{10}- T_4 + KAU sampoorna multimix	9.67	6.58	0.97	0.038	0.022	0.003
CD (0.05)	1.458	2.167	0.193	0.0120	0.0090	0.0010

Table 20. Effect of treatments on crude protein content in grain

Treatment	Protein content (%)
T_1- Absolute control	4.90
T_2- KAU PoP with lime	6.76
T_3- KAU PoP with dolomite	7.23
T_4- KAU PoP for organic farming	6.30
T_5- T_2 + micronutrient solution	7.00
T_6- T_2+ KAU sampoorna multimix	7.23
T_7- T_3 + micronutrient solution	7.70
T_8- T_3 + KAU sampoorna multimix	7.46
T_9 - T_4 + micronutrient solution	6.76
T_{10}- T_4 + KAU sampoorna multimix	6.53
CD (0.05)	1.437

no significant effect on soil physical properties like bulk density, water holding capacity and porosity. Organic management practices resulted in lower values for bulk density and higher values for WHC and porosity.

4.9 EFFECT OF TREATMENTS ON SOIL REACTION

The effect of various treatments on the soil pH, EC and CEC is presented in Table 22.

4.9.1 pH

Effect of different treatments on soil pH was significant and the values ranged from 4.85 to 5.19. Application of different treatments increased the pH of the soil compared to absolute control. Rise in soil pH due to different nutrient management practices was less for organic farming treatments though the differences were not significant compared to the inorganic treatments. The highest soil pH was recorded for T_2 and the lowest for absolute control.

4.9.2 Electrical Conductivity

Though the treatments had no significant effect on EC, supply of nutrients through different nutrient management practices gave higher values for EC compared to absolute control.

4.9.3 Cation Exchange Capacity

The cation exchange capacity of soil was positively influenced by the applied treatments, with all treatments receiving different nutrient management practices showing higher values compared to absolute control, though the increase was not significant.

4.10 EFFECT OF TREATMENTS ON SOIL NUTRIENT CONTENT AFTER HARVEST

The results pertaining to the effect of different treatments on the soil nutrient status after harvest of the crop are given in Table 23.

Table 21. Effect of treatments on soil physical properties

Treatment	Bulk density ($Mg\ m^{-3}$)	WHC (%)	Porosity (%)
T_1- Absolute control	1.45	22.6	41.2
T_2- KAU PoP with lime	1.42	23.6	41.0
T_3- KAU PoP with dolomite	1.43	22.4	41.7
T_4- KAU PoP for organic farming	1.40	23.8	42.8
T_5- T_2 + micronutrient solution	1.44	23.1	41.2
T_6- T_2+ KAU sampoorna multimix	1.43	22.6	41.7
T_7- T_3 + micronutrient solution	1.42	22.7	42.3
T_8- T_3 + KAU sampoorna multimix	1.42	23.0	42.3
T_9 - T_4 + micronutrient solution	1.40	23.1	42.8
T_{10}- T_4 + KAU sampoorna multimix	1.41	23.3	42.7
CD (0.05)	NS	NS	NS

Table 22. Effect of treattments on soil pH, EC and CEC

Treatment	pH	EC ($dS\ m^{-1}$)	CEC (c mol (p+) kg^{-1})
T_1- Absolute control	4.85	0.49	6.06
T_2- KAU PoP with lime	5.19	0.56	6.26
T_3- KAU PoP with dolomite	5.16	0.52	6.20
T_4- KAU PoP for organic farming	5.01	0.52	6.20
T_5- T_2 + micronutrient solution	5.18	0.52	6.20
T_6- T_2+ KAU sampoorna multimix	5.18	0.50	6.13
T_7- T_3 + micronutrient solution	5.16	0.54	6.10
T_8- T_3 + KAU sampoorna multimix	5.17	0.52	6.16
T_9 - T_4 + micronutrient solution	5.02	0.50	6.19
T_{10}- T_4 + KAU sampoorna multimix	5.03	0.52	6.18
CD (0.05)	0.120	NS	NS

4.10.1 Organic Carbon

The increase in organic carbon values obtained due to integrated nutrient management was not significant. Though organic carbon content of soil after harvest was not significantly affected by the treatments, generally higher values were obtained for the organic farming treatments. The least organic carbon values was obtained for T_1.

4.10.2 Available Nitrogen

Available nitrogen status was influenced by different treatments. Soil available N was on par for all the treatments except organic farming and absolute control, with treatment T_6 receiving foliar application of sampoorna multimix along with lime giving the highest value (343.6 kg ha^{-1}).

4.10.3 Available Phosphorus

The available P content of the soil after harvest showed the maximum value for T_7 (39.8 kg ha^{-1}) and minimum value for T_1 (25.40 kg ha^{-1}). Available P was on par for all the treatments except absolute control.

4.10.4 Available Potassium

Available K content increased from 209.2 kg ha^{-1} in T_1 (absolute control) to 376.2 kg ha^{-1} in T_6 (T2+ KAU sampoorna multimix), which was on par with all treatments except the organic treatments and absolute control.

4.10.5 Exchangeable Calcium

Liming materials significantly increased the soil Ca level with treatment T_5 receiving foliar application of micronutrient solution along with lime registering the highest value (366.6 mg kg^{-1}). This was on par with all the treatment supplied with lime or dolomite. The organic farming treatments registered significantly lower levels of Ca.

4.10.6 Exchangeable Magnesium

Data pertaining to exchangeable Mg content of soil after harvest revealed that treatment T3 (KAU PoP with dolomite) recorded the highest (224.0 mg kg^{-1}) value which was on par with the treatment receiving dolomite (T7 and T8). The organic farming treatments registered significantly lower values and absolute control recorded the lowest value.

4.10.7 Available Iron

The different treatments had significant effects on the availability of iron content in soil compared to control. The highest available iron content was recorded by the treatment T_6 (T2+foliar application of KAU Sampoorna multimix) which was on par with all the treatment except T_1.

4.10.8 Available Manganese

The data revealed that available manganese content of soil varied from 11.3 mg kg^{-1} in T_1 to 12.9 mg kg^{-1} in T_9 which was on par with all the treatments except absolute control.

4.10.9 Available Copper

The effect of different treatments on the availability of Cu content of soil samples after harvest was significant with the highest value (2.45 mg kg^{-1}) recorded for treatment T_8 (T_3 + KAU Sampoorna multimix) which was on par with all the treatments receiving micronutrients along with lime or dolomite. The pure organic treatment registered relatively lower copper content in soil.

4.10.10 Available Zinc

Perusal of the data revealed that available zinc content of soil varied from 2.75 mg kg^{-1} in T1 (absolute control) to 4.39 mg kg^{-1} in T_7 (T_3 + micronutrient solution). Available zinc content of treatments receiving foliar application of micronutrients was on par with each other.

Table 23. Effect of treatments on soil chemical properties*

Treatments	OC	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn	B
T_1- Absolute control	0.75	293.3	25.4	209.2	286.6	124.0	18.4	11.3	0.54	2.75	0.093
T_2- KAU PoP with lime	0.83	339.1	39.7	374.9	364.0	168.3	26.2	12.5	1.14	3.69	0.200
T_3- KAU PoP with dolomite	0.83	329.9	38.3	373.6	360.0	224.0	26.7	13.4	1.10	3.87	0.223
T_4- KAU PoP for organic farming	0.85	309.5	36.5	328.5	313.3	144.0	20.6	12.2	0.92	3.21	0.170
T_5- T_2 + micronutrient solution	0.82	337.6	37.2	361.9	366.6	160.0	28.4	11.5	2.27	4.15	0.220
T_6- T_2+ KAU sampoorna multimix	0.84	343.6	39.5	376.2	365.0	160.0	29.7	12.0	2.20	4.32	0.223
T_7- T_3 + micronutrient solution	0.84	324.1	39.8	367.6	361.6	196.6	26.6	11.6	2.12	4.39	0.217
T_8- T_3 + KAU sampoorna multimix	0.83	325.5	37.5	372.3	363.3	194.6	27.6	12.6	2.45	4.11	0.200
T_9 - T_4 + micronutrient solution	0.86	310.6	36.8	343.0	323.3	154.3	24.5	12.9	1.08	3.45	0.190
T_{10}- T_4 + KAU sampoorna multimix	0.85	315.2	37.0	338.6	326.6	146.0	24.9	12.3	1.07	3.66	0.187
CD (0.05)	NS	26.44	4.56	32.84	32.52	44.87	6.37	1.56	0.800	0.955	0.0360

*OC in %, N, P and K in kg ha^{-1}, others in mg kg^{-1}

4.10.11 Available Boron

Availability of B in soil showed significant variation among the treatments. Treatment T_6 (T_2+ KAU Sampoorna multimix) recorded the highest value (0.223 mg kg^{-1}) which was on par with all the treatments except T_4 and absolute control.

4.10.12. Lability Index of Soil Carbon

The lability index of carbon in soil influenced by different treatments are presented in Table 24. Though the treatment effect was found to be non-significant, organic farming treatments registered higher values compared to control.

4.10.13 Carbon Management Index

The impact of nutrient management practices on Carbon Management Index of soil after harvest of the crop presented in Table 24, revealed that the treatment effects were not significant.

4.11 EFFECT OF TREATMENTS ON ECONOMICS OF CULTIVATION

Effect of treatments with regard to B: C ratio is given in Table 25. Foliar application of micronutrients (sampoorna multimix or micronutrient solution) along with KAU PoP (dolomite or lime) was more economical, resulting in significantly higher B: C ratio with the highest value (1.43) given by T_8 (T_3 + sampoorna multimix).

Table 24. Effect of treatments on carbon pools

Treatment	Lability Index	Carbon Management Index
T_1- Absolute control	0.843	0.787
T_2- KAU PoP with lime	0.903	0.907
T_3- KAU PoP with dolomite	0.893	0.913
T_4- KAU PoP for organic farming	0.913	0.960
T_5- T_2 + micronutrient solution	0.920	0.923
T_6- T_2+ KAU sampoorna multimix	0.880	0.910
T_7- T_3 + micronutrient solution	0.880	0.913
T_8- T_3 + KAU sampoorna multimix	0.880	0.903
T_9 - T_4 + micronutrient solution	0.920	0.970
T_{10}- T_4 + KAU sampoorna multimix	0.907	0.960
CD (0.05)	NS	NS

Table 25. Effect of treatments on economics of cultivation

Treatment	Total cost (₹ ha^{-1})	Gross income (₹ ha^{-1})	B: C ratio (₹ ha^{-1})
T_1- Absolute control	64000	33515	0.52
T_2- KAU PoP with lime	74400	92878	1.25
T_3- KAU PoP with dolomite	73200	92452	1.26
T_4- KAU PoP for organic farming	75700	79619	1.05
T_5- T_2 + micronutrient solution	79500	106136	1.34
T_6- T_2+ KAU sampoorna multimix	77400	106127	1.37
T_7- T_3 + micronutrient solution	78300	103635	1.32
T_8- T_3 + KAU sampoorna multimix	76200	109128	1.43
T_9 - T_4 + micronutrient solution	80800	82081	1.02
T_{10}- T_4 + KAU sampoorna multimix	78700	88471	1.12
CD (0.05)			0.14

DISCUSSION

5. DISCUSSION

The experimental findings from the present investigation entitled 'Secondary and micronutrient management for enhancing soil health and productivity in upland rice' with an objective to investigate the effect of secondary and micronutrient application under organic and integrated nutrient management practices, on enhancing the nutrient uptake and soil health, thereby the productivity of upland rice have been discussed in this chapter.

5.1 EFFECT OF TREATMENTS ON PLANT BIOMETRIC CHARACTERISTICS

5.1.1 Height of Plants

Plant height was significantly influenced by the treatments. The KAU PoP treatments and the organic treatments either alone or supplemented with micronutrients (T_2 to T_{10}) gave plant height statistically on par with each other. The treatment receiving KAU PoP with lime and micronutrient supplemented through sampoorna multimix (T_6) gave the highest value of 103.86 cm (Table 1). The absolute control receiving no manures or fertilizers gave plant height significantly lower than all other treatments. Thus supply of major essential nutrients either as organics or as inorganics leading to an increase in the content and uptake of these nutrients by the plant has resulted in increased growth of rice plants in terms of shoot length.

The increased shoot length for the treatments receiving micronutrients in addition to liming materials (T_5 to T_8) might be due to the role of microelements especially zinc and boron in cell division and meristamatic activity. Zinc plays an important role in auxin production whereas boron is essential for growth and development of new cells in plants. Similar reports were made by Naeini *et al.* (2014) and Zain *et al.* (2015). Boron and copper also play an important role in carbohydrate metabolism and protein synthesis. Iron plays an important role in promoting growth characteristics, being a component of ferrodoxin, an electron transport protein associated with chloroplast, thereby enhancing photosynthesis and improving vegetative growth (Hazra *et al.*, 1987). N, Ca and Mg also help in cell division, cell elongation and photosynthesis thereby improving plant physiological processes. Similar results were reported by Rahman *et al*. (2002).

5.1.2 Number of Total and Productive Tillers per m^2

Treatments which received micronutrients either as micronutrient solution or as sampporna multimix along with the KAU PoP treatments receiving integrated nutrient management practices (T_5 to T_8) produced significantly higher number of total and productive tillers per m^2 compared to the treatments without micronutrients. Treatment T_5 (T_2 + micronutrient solution) gave the highest number of total tillers while T_5 and T_7 (T_2 + micronutrient solution) recorded the highest number of productive tillers per m^2 (Fig. 3).

Micronutrient application during the active tillering stage increases the tillering capacity of rice. Studies carried out at IRRI (2000) indicated that zinc application improves the enzymatic activity and increases the tiller production in rice. Abbas *et al*. (2009) and Nadim *et al.* (2011) also reported that application of Fe alone or in combination with other micronutrients significantly increased the number of tillers compared to the no micronutrient control.

The number of panicle bearing tillers contributes towards the production potential of rice crop. Adequate supply of microelements have increased the uptake of other essential nutrients, which results in improvement of plant metabolic process ultimately translating to crop growth and tillering. Similar results were reported by Slaton *et al.* (2002) and Naik and Das (2007).

Soil amendments like lime and dolomite act as a source of Ca and Mg which contributes towards improved plant growth. Lime application was reported to improve the yield attributes of rice *viz.* number of panicle bearing tillers and grains per panicle (Chang and Sung, 2004).

Among the organic farming treatments, those receiving micronutrients produced enhanced number of productive tillers (T_9 and T_{10}) compared to organics alone (T_4). Since nutrients are released slowly in a phased manner under pure organic farming practices, growth is relatively slower, but foliar application helps in the quick absorption of nutrients. Similar results were published by

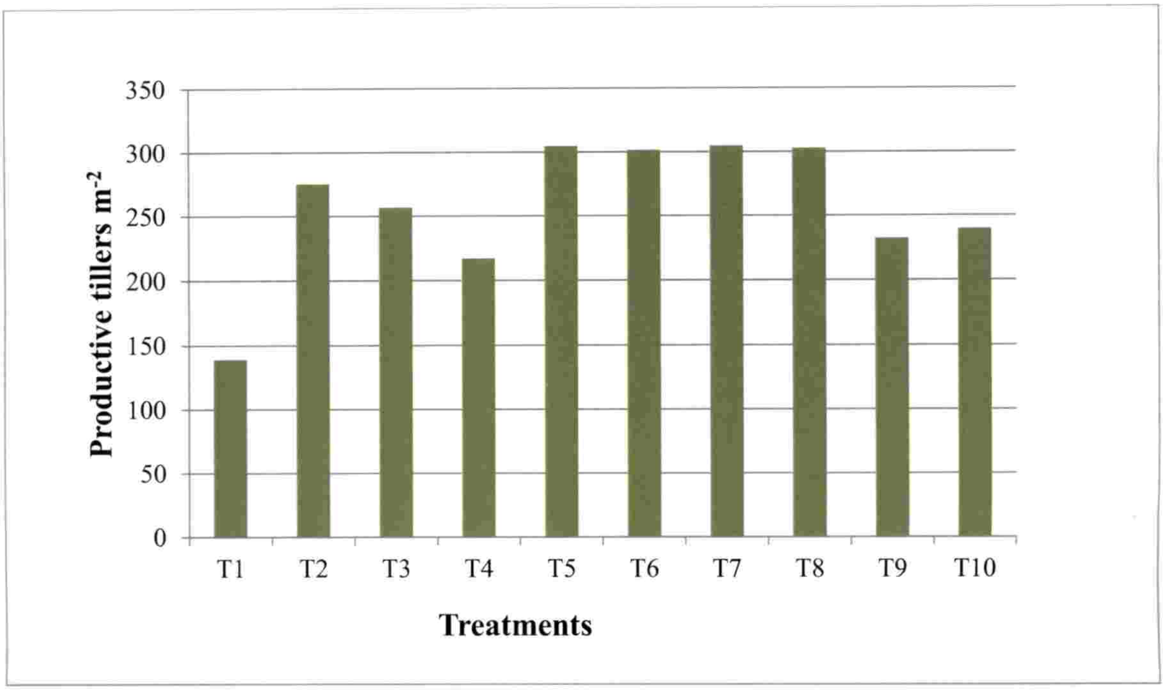

Fig. 3. Effect of treatments on Productive tillers per m^2

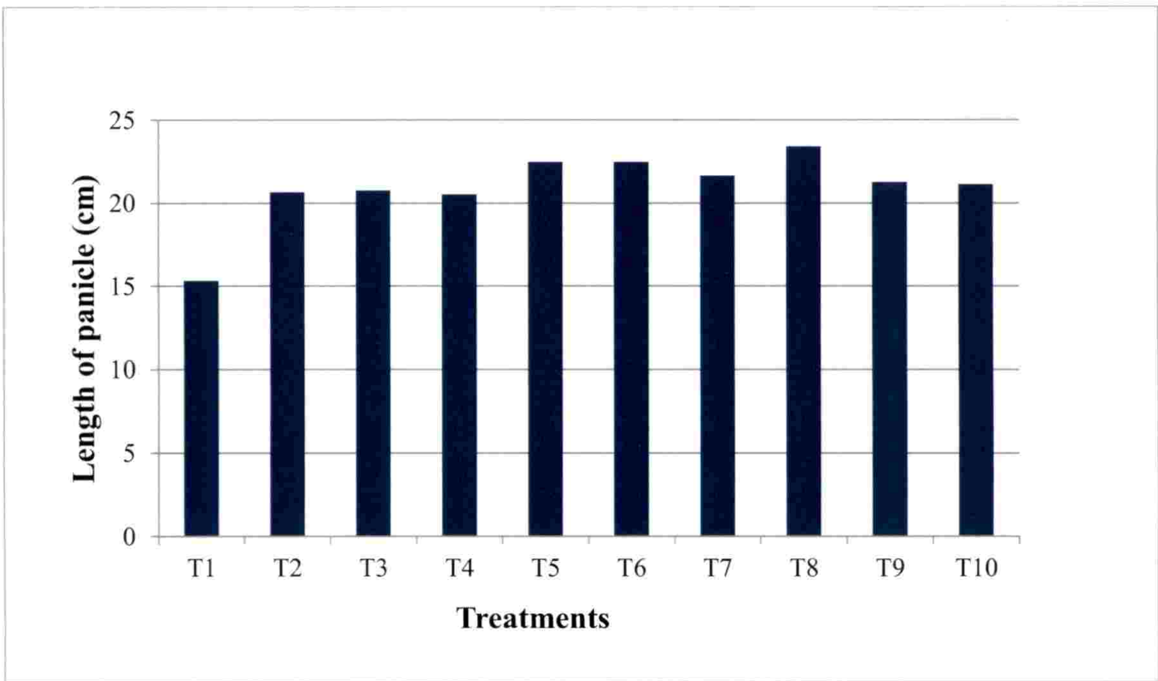

Fig. 4. Effect of treatments on length of panicle

Asewar *et al*. (2000) and Miller (2007). Significant increase in growth characters by the application of micronutrients in the organic and integrated nutrient management treatments might also be due to the enhanced metabolic and photosynthetic activity leading to an increased production of various metabolites responsible for cell division and cell elongation (Hatwar *et al*., 2003).

5.1.3 Root Parameters

Root parameters like root length, root dry weight and volume were higher for the organic farming treatments with or without micronutrients with significant increase obtained for root length. Root dry weight and volume were also highest for the organic farming treatments T_4 and T_{10} respectively with all treatments except T_1 on par. This is because incorporation of organic manures into the soil can bring beneficial effect on root growth by improving physical and chemical environments of rhizosphere soil (Sidiras *et al.,* 2001).

Increase in root length and volume might be due to the increased root proliferation under better soil conditions especially due to improvement in porosity and reduction in bulk density in the organically raised plots. Passioura (2002) also demonstrated that organic matter has a positive effect on soil physical properties by increasing soil porosity which favours root growth and function. This might be associated with the improvement of biological activity in the crop rhizosphere induced by amino acids and physiologically active substances present in the applied organic manures (Zhou and Luo, 1997; Prasert, 1997).

5.2 EFFECT OF TREATMENTS ON YIELD ATTRIBUTES AND YIELD

5.2.1 Length of Panicle and Weight of Panicle

Longer panicles and heavier grains were found in the treatments where micronutrients were supplemented, with treatment T_8 (T_3 + sampoorna multimix) giving the highest value (Fig. 4 and Fig. 5). Similar results were reported by Malakouti and Kavousi (2004) and Zayed *et al.* (2011) who stated that foliar application of Zn^{+2}, Fe^{2+} and Mn^{+2} twice, at 20 and 45 days after transplanting produced the highest values for chlorophyll content and panicle length. Foliar application of zinc and iron significantly increased the length of panicle in rice (Hemantaranjan and Gray, 1988).

The efficiency of micronutrients in improving the various metabolic processes in plants has been well established. This might have enhanced the accumulation of assimilates in the grains which resulted in heavier grains. Soleimani (2006) recorded significantly increased grain weight by the combined application of micronutrients *viz*. Zn, Fe, Mn and Cu along with NPK application.

5.2.2 Number of Spikelets per Panicle and Per cent Filled Grains

The highest number of spikelets per panicle and percentage of filled grains were observed when sampoorna multimix was sprayed along with KAU PoP (dolomite) (T_8) (Fig. 6 and 7). All the treatments receiving micronutrients gave per cent filled grains on par with T_8. The number of spikelets per panicle obtained for KAU PoP (lime or dolomite) was found to be on par when micronutrients were also supplemented.

The number of spikelets per panicle and per cent filled grains are important yield contributing characters of rice for improved productivity. Foliar application of micronutrients might have positively influenced dry matter partitioning from storage parts to sink. The improvement in number of grains per panicle by supplementing micronutrients might be due to reduced pollen sterility, improved pollen formation and fertilization and better grain setting. Micronutrients helps in better starch utilization resulting in higher seed set and translocation of assimilates to developing grains. This increases the grain weight and number of grains per panicle. Similar observations were reported by Rehman *et al.* (2012) and Quadir *et al.* (2013).

Adequate supply of micronutrients increased the uptake of other nutrients from soil leading to improved metabolic activities culminating in increased number of spikelets per panicle (Quadir *et al.* 2013).

Amelioration of soil acidity with lime and dolomite leading to increased supply of Ca and Mg might have also influenced grain formation since Ca and Mg

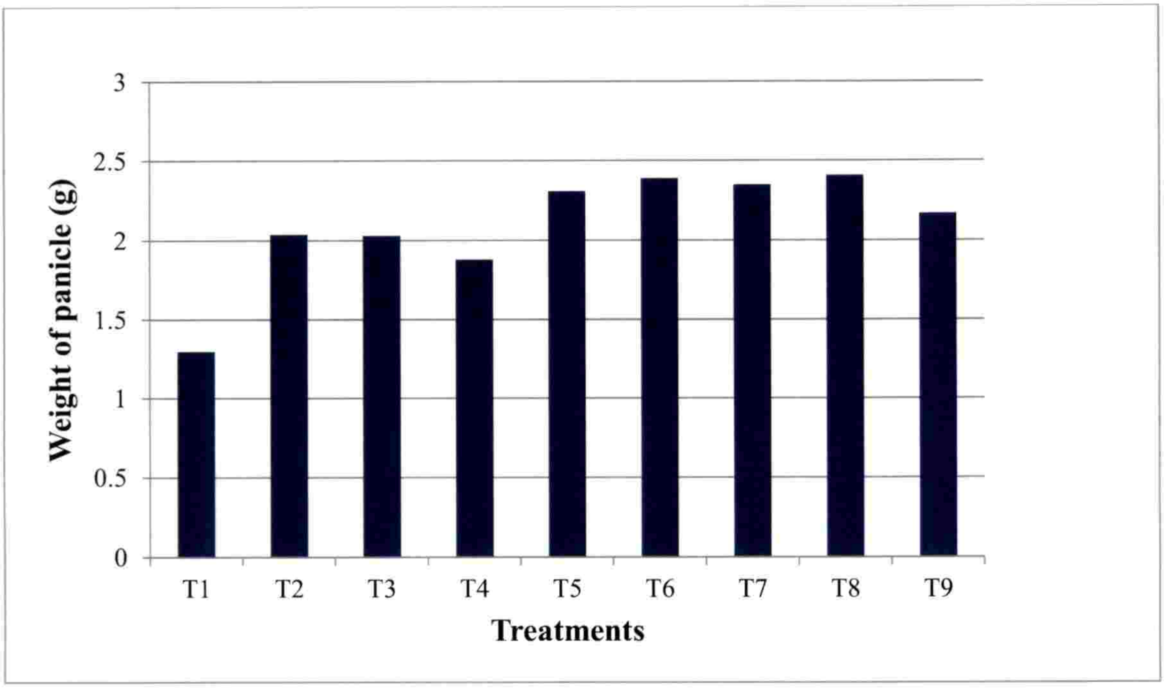

Fig. 5. Effect of treatments on weight of panicle

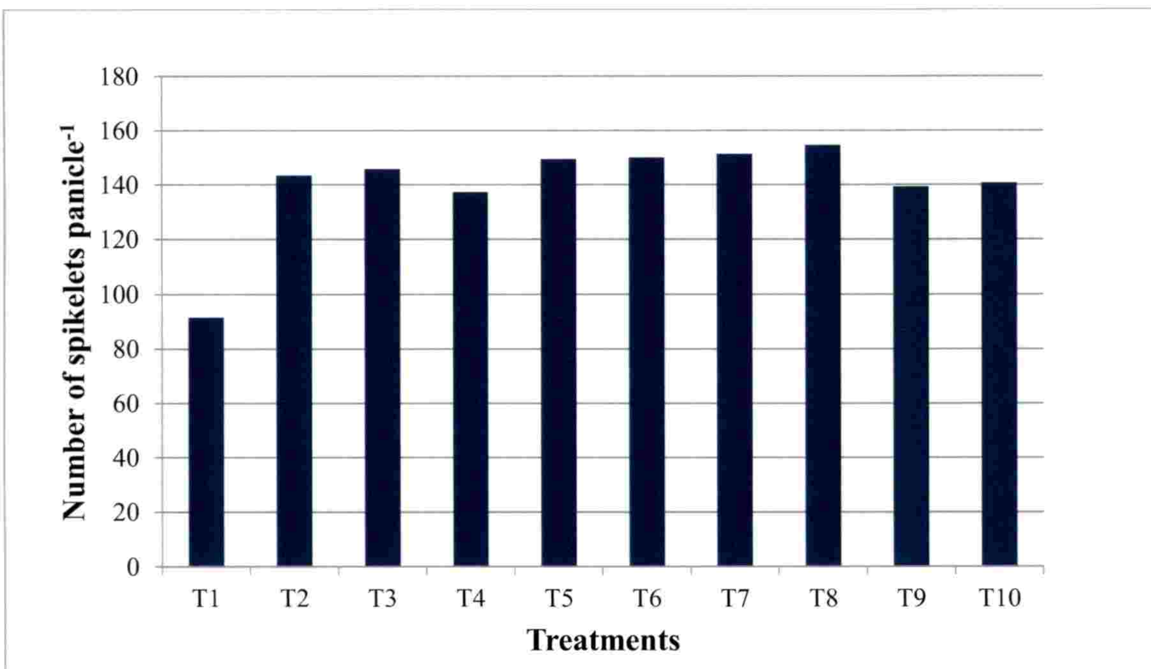

Fig. 6. Effect of treatments on number of spikelets per panicle

plays a pivotal role in maintaining nutritional balance and photosynthesis. Similar results were reported by Sahrawat *et al,* (1999).

Though organic matter is an important secondary source of micronutrients, most of these nutrients are held tightly in complex organic combinations and hence are available only over an extended period. This might be the reason for less number of filled grains per panicle under organic farming alone (T4) in rice, which is a short duration crop.

5.2.3 Grain Yield

Secondary and micronutrient management had profound effect on the grain yield of upland rice. Grain yield was enhanced in all KAU treatments receiving micronutrients along with lime or dolomite (T_5 to T_8) with the treatment T_8 (T_3 + sampoorna multimix) recording the highest yield value (Fig. 8). The increased grain yield in these treatments could be the direct effect of production of more number of productive tillers, longer panicle, heavier grains and higher number of grains per panicle.

Supplementing micronutrient as foliar spray resulting in adequate and timely supply at critical stages coupled with ease of absorption has culminated in enhanced grain yield. Savithri *et al.* (1999) and Tariq *et al.* (2007) also obtained maximum increase in rice yield by foliar application of micronutrients.

The higher yield obtained might be attributed to steady supply of nutrients at critical stages of the crop coupled with better nutrient assimilation which results in better plant growth and superior yield attributes responsible for high yield. Cedari and Malakouti (1998) reported that application of zinc sulfate, copper sulphate and iron sulphate, caused an yield increase of 20 per cent compared to control.

The positive effects of micronutrient application by foliar sprays on grain yield of rice can also be attributed to increase in chlorophyll content of leaves of rice which might have increased photosynthetic rate and resulted in more dry matter accumulation and leaf area index and hence led to more capture of solar radiation. This has resulted in enhanced values of growth parameters and yield attributing characters and ultimately higher grain yield (Gill and Walia, 2015).

Liming with CaO or dolomite was also found effective in giving higher yield due to amelioration of soil acidity thereby improving the availability of nutrients required by the plants. Similar results were reported by Rahman *et al.* (2002).

Organic farming treatments supplemented with micronutrients (T9 and T10) gave significantly higher grain yield compared to to pure organic treatment (T4). This might be due to the balanced nutrition including micronutrients provided to the plants at critical growth stages, favourably affecting the growth and yield attributes.

5.2.4 Straw Yield

Significant increase in straw yield over control was observed with KAU PoP (lime or dolomite or organic farming) alone (T_2 to T_4) or along with foliar application of micronutrient solution or sampoorna multimix (T_5 to T_{10}) (Fig. 9). Straw yield was found to be the highest (4897 kg ha^{-1}) for T_5 (T_2 + micronutrient solution) which was on par with KAU PoP treatments receiving micronutrients along with lime or dolomite (T_6 to T_8) or with lime or dolomite alone. Increased dry matter yield with foliar application of micronutrients was reported by Sadana and Nayyar (2002).

Micronutrients are involved in various physiological processes like enzyme activation, electron transport, chlorophyll formation and stomatal regulation which ultimately results in greater dry matter production. Inadequate levels of micronutrients may be responsible for lower plant growth and yield. Foliar application of nutrients at critical stages facilitated the easy absorption and utilization of these nutrients leading to accelerated plant growth (Khan *et al.*, 2010). Grewal *et al.*, (1997) also reported increased dry matter production in rice due to the application of micronutrients.

The omission of chemical fertilizers and organic manures in control plots leading to continuous mining of nutrients has resulted in low yield.

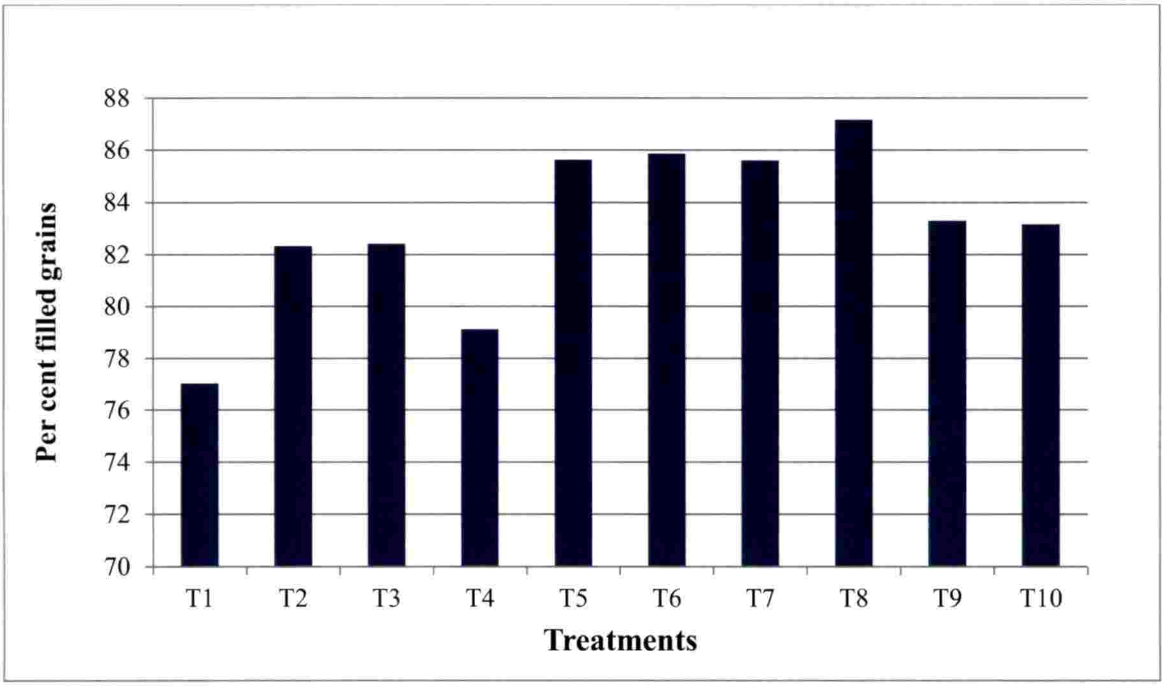

Fig.7. Effect of treatments on per cent filled grains

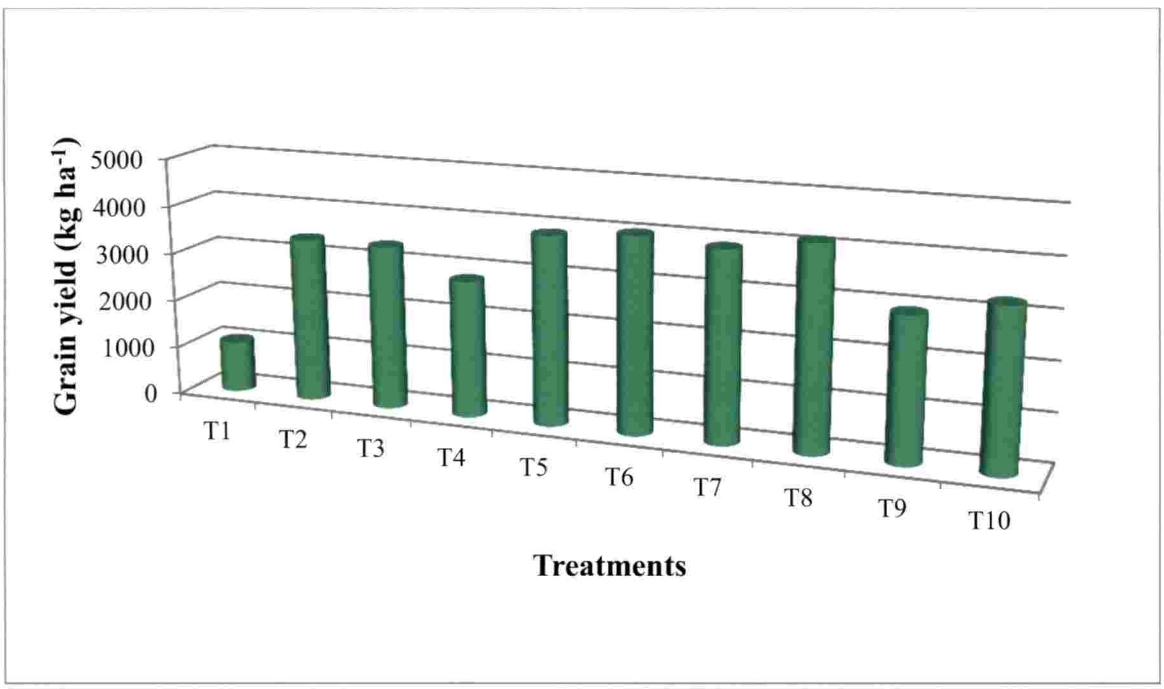

Fig. 8.Effect of treatments on grain yield

5.3 NUTRIENT CONTENT OF INDEX LEAF AT PANICLE INITIATION

Nutrient concentration of index plant part is an indication of the general nutrition of the crop. Increased N content of index leaf at panicle initiation stage was observed due to foliar micronutrient application with the highest value for T_6 receiving sampoorna multimix, closely followed by T_5 where micronutrients were supplied as micronutrient solution. Application of liming materials alone or along with foliar micronutrients gave significantly higher content of P in index leaf with T_6 giving the highest value. K content of index leaf increased due to foliar micronutrient application along with lime or dolomite, with T_7 giving the highest value. Similar results were reported by Bhanuvally *et al.* (2017).

Treatment T_2 (KAU PoP with lime) gave the highest Ca content which was also on par with all the micronutrient applied treatments. Mg content was highest in the dolomite applied treatments (T_3 and T_8) which were on par with other dolomite or lime applied treatments and the organic farming treatments supplemented with micronutrients (Fig. 10). Similar results were reported by Fox *et al*. (1991) and Sahrawat *et al*. (1999).

Concentration of Fe, Mn, Cu, Zn and B in index leaf was found to be higher for the treatments receiving foliar micronutrients along with KAU PoP (dolomite or lime) (Fig. 11 and 12). The highest values were recorded by T_5 for Fe, T_7 for Mn and Zn, T_6 for Cu and T_8 for B. These results are in corroboration with the findings of Farshid and Aref (2011). The difficulty in absorbing nutrients from soils is overcome due to foliar spray and hence nutrients are readily absorbed by leaves and translocated within the plant leading to quick and better results.

5.4 EFFECT OF TREATMENTS ON THE CONTENT AND UPTAKE OF NUTRIENTS

5.4.1 Nitrogen

Foliar application of micronutrients along with lime or dolomite gave the highest N content in straw and grain and was on par with KAU PoP (lime or dolomite). Grain content of N was also on par with the organic farming treatments receiving micronutrient spray. The straw and grain uptake of nitrogen were

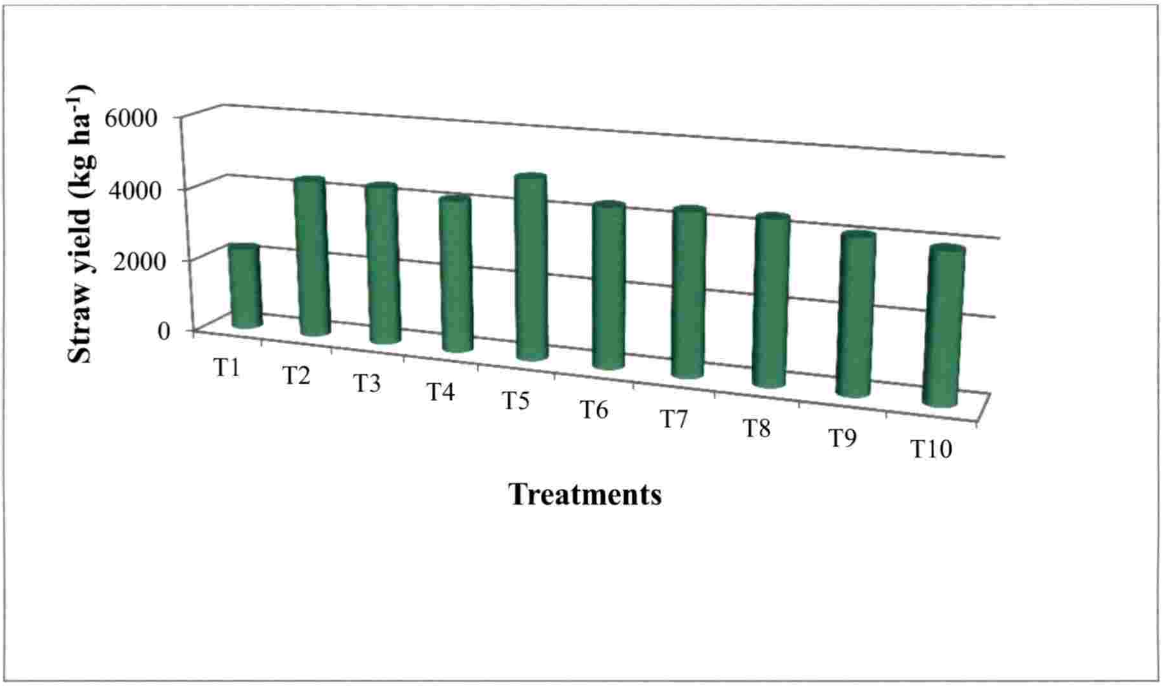

Fig. 9.Effect of treatments on straw yield

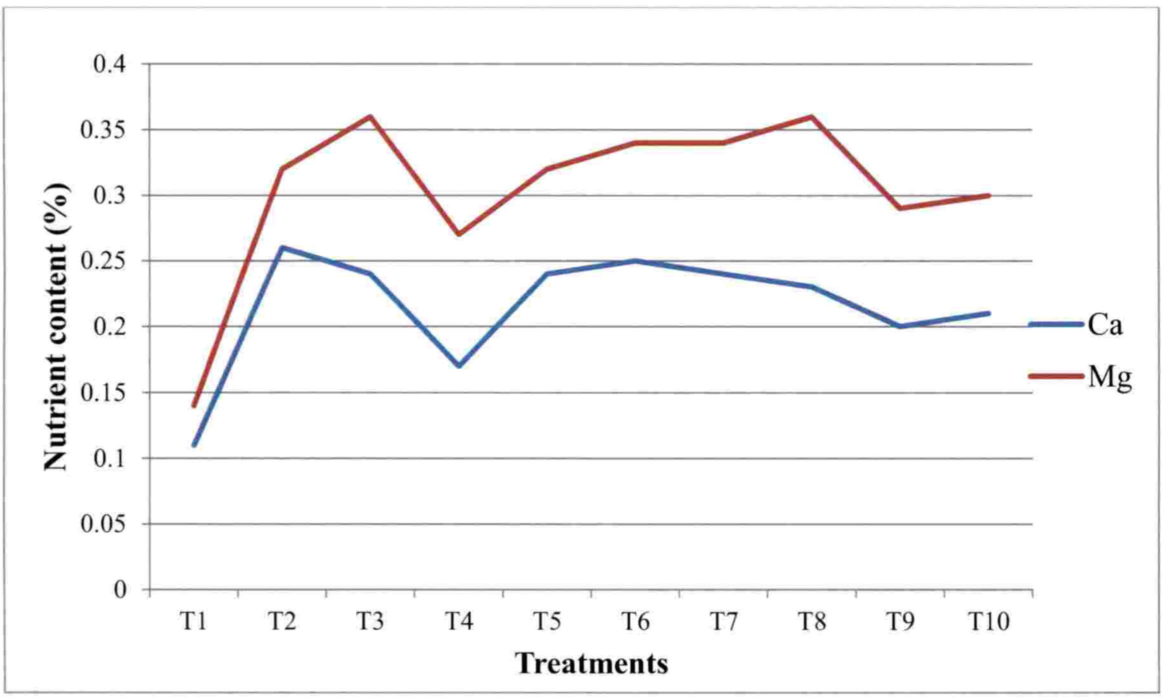

Fig. 10. Effect of treatments on the contents of Ca and Mg in index leaf

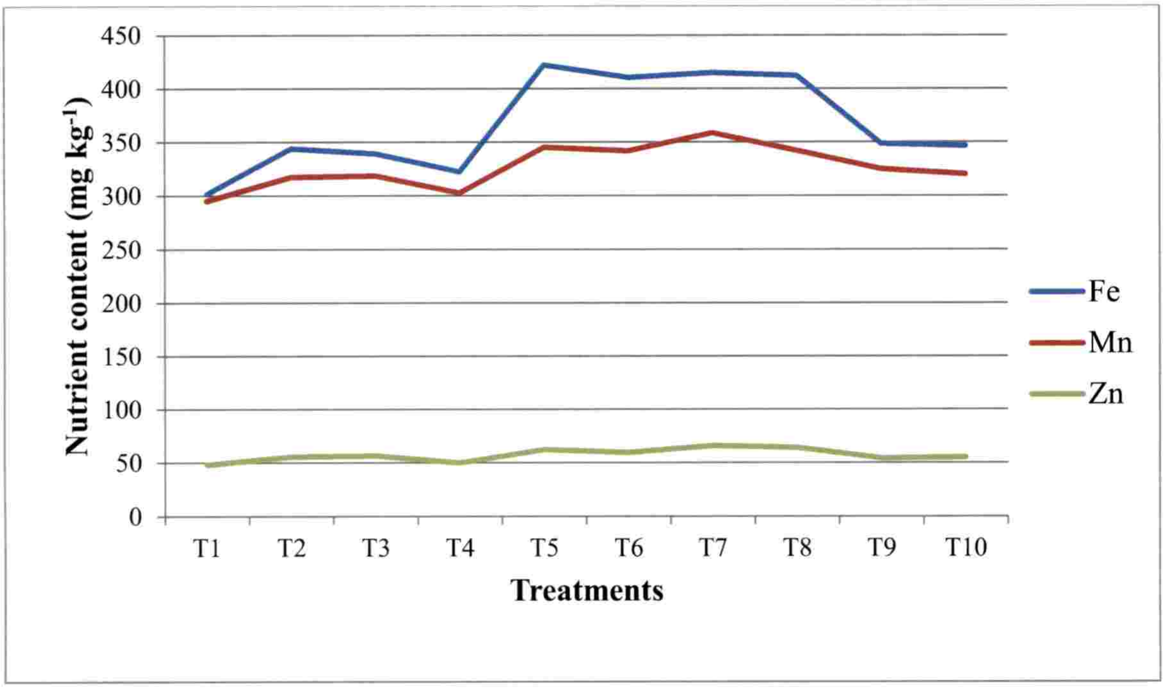

Fig. 11. Effect of treatments on the contents of Fe, Mn and Zn in index leaf

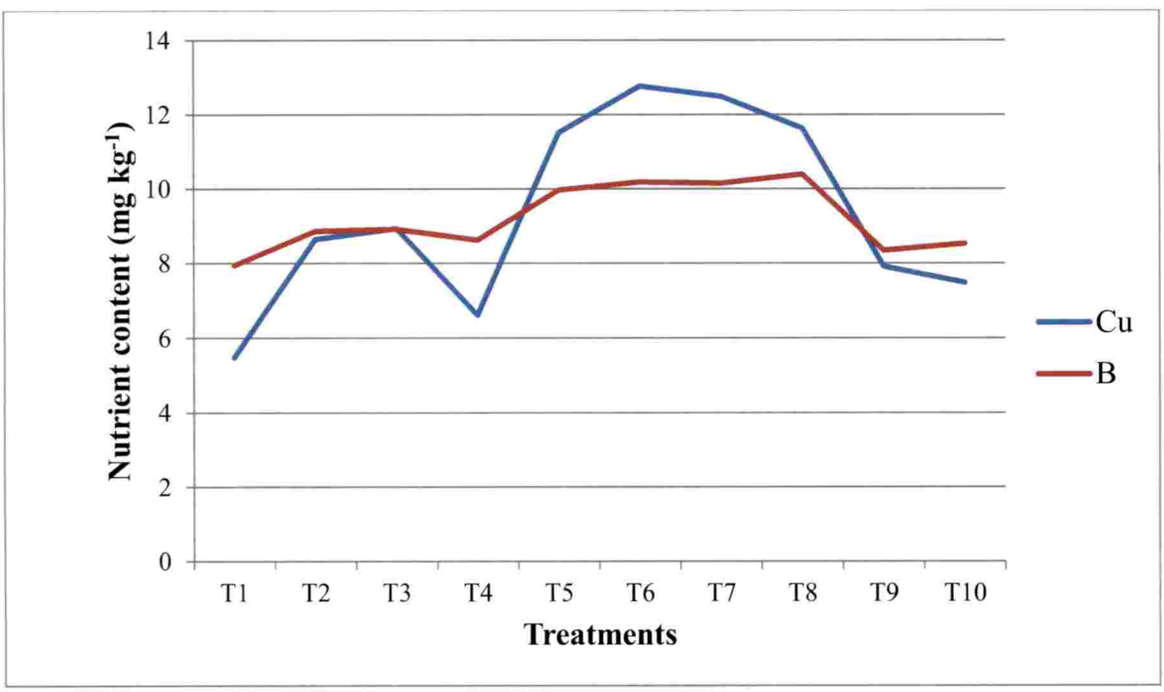

Fig. 12. Effect of treatments on B and Cu contents of index leaf

highest for the treatments T_5 (T_2 + micronutrient solution) and T_8 (T_3 + sampoorna multimix) respectively, which produced similar results for straw and grain yield (Fig. 13). Though the organic farming treatments resulted in significantly higher grain and straw yields compared to absolute control, yields were lower than the KAU PoP treatment, with significant reduction compared to KAU PoP + micronutrient treatments. The different treatments could not exert any significant influence on the content and uptake of nitrogen by root.

Micronutrients enhance nutrient metabolism in plants thereby the uptake of nutrients. The higher dry matter production as well as nitrogen concentration due to integrated nutrient management coupled with application of secondary and micronutrients might have contributed to better uptake of nitrogen.

5.4.2 Phosphorus

Phosphorus content and uptake by grain were significantly influenced by secondary and micronutrient management (Fig. 14). Foliar application of micronutrients (sampoorna multimix) along with KAU PoP (lime) (T_6) resulted in the highest straw P content which was on par with all the treatments which received foliar application of micronutrients (sampoorna mutimix or micronutrient solution) along with the KAU PoP (lime or dolomite) or KAU PoP (lime or dolomite) alone. Straw uptake was higher for the treatments receiving liming materials with or without micronutrient supplementation. The highest straw uptake was obtained for the treatment T_5 (T_2 + micronutrient solution). The organic farming treatments receiving micronutrient supplementation also gave significantly higher phosphorus uptake values for straw though lower than the integrated nutrient management treatments receiving micronutrients (T_5 to T_8) Treatment T_7 (T_3 + micronutrient solution) gave the highest grain phosphorus uptake. Similar result was reported by Baishya *et al.* (2016). Increase in availability of P and thereby its content and uptake in plants due to application of liming materials was also reported by Rahman *et al.* (2002).

No significant variation was observed in P content and uptake by root due to the application of treatments.

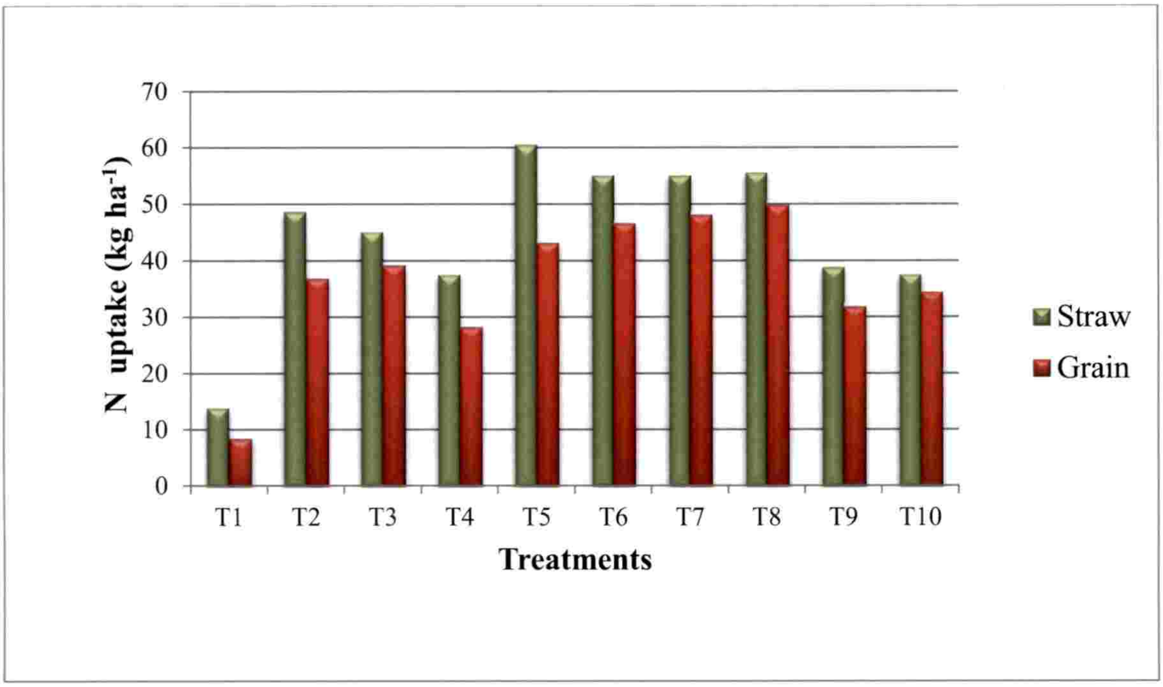

Fig. 13. Effect of treatments on N uptake by straw and grain

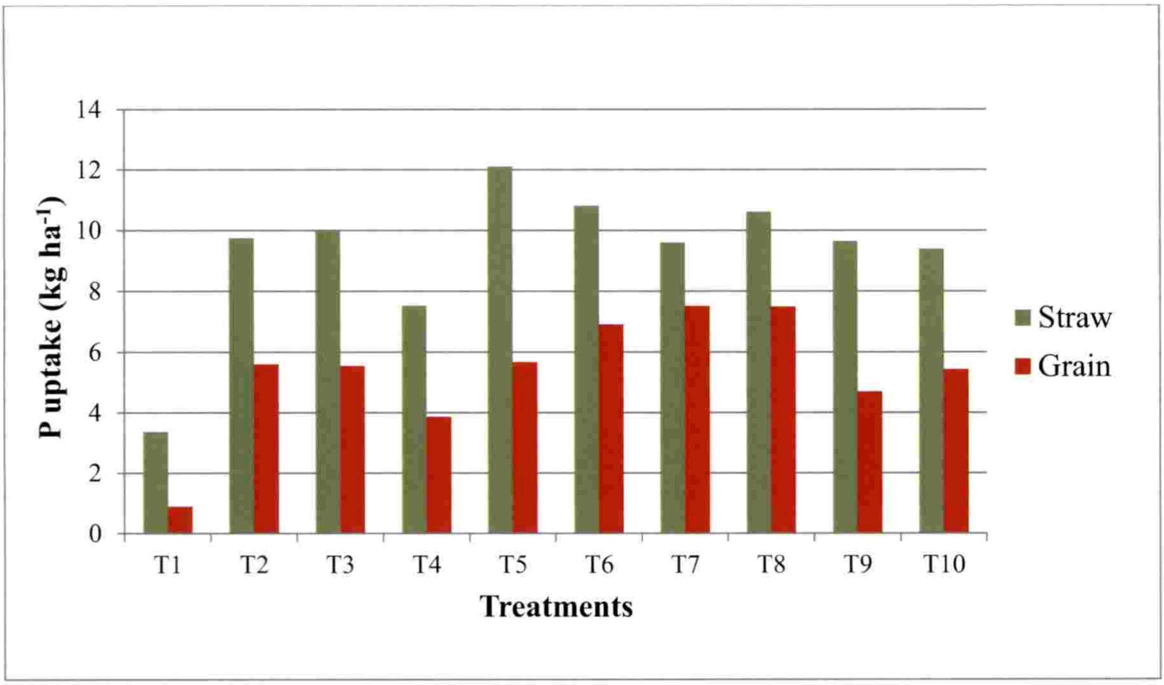

Fig. 14. Effect of treatments on P uptake by straw and grain

5.4.3 Potassium

K content and uptake by straw and grain were also higher for the treatments receiving secondary and micronutrient supplementation (Fig. 15). Foliar application of sampoorna multimix along with lime (T_6) or dolomite (T_8) gave the highest straw and grain potassium contents respectively and was on par with all the treatments receiving micronutrients along with liming materials or KAU PoP (lime or dolomite) alone. The straw and grain uptake of potassium were highest for the treatments T_5 (T_2 + micronutrient solution) and T_8 (T_3 + sampoorna multimix) respectively.

The higher content of K in the micronutrient supplemented treatments might be due to the presence of iron, zinc and sulphur in the mixture which have facilitated increased uptake of NPK over control (Ravi *et al*., 2008). Similar result was obtained by (Samui *et al.* 1981) who reported that K uptake was increased due to the application of Cu and Fe.

Treatment effects were not significant with respect to the content and uptake of K by root.

5.4.4 Calcium

Application of liming materials increased the concentration of Ca and Mg in soil thereby leading to an increased content and uptake of the same by the crop (Fig. 16).

There was a significant increase in the content and uptake of Ca by straw and grain by the applied treatments. Concentration of Ca in straw was the highest for T_2 receiving lime as per ΔpH and was on par with all the treatments except absolute control (T_1) and the pure organic treatment (T_4). Calcium uptake by straw was the highest for treatment T_5 where micronutrients were applied along with lime.

Application of liming materials (lime or dolomite) supplies Ca to the soil which can easily be absorbed by the plants. The Ca content in the absolute control and the organic treatments were lower even though the initial soil Ca level was higher.

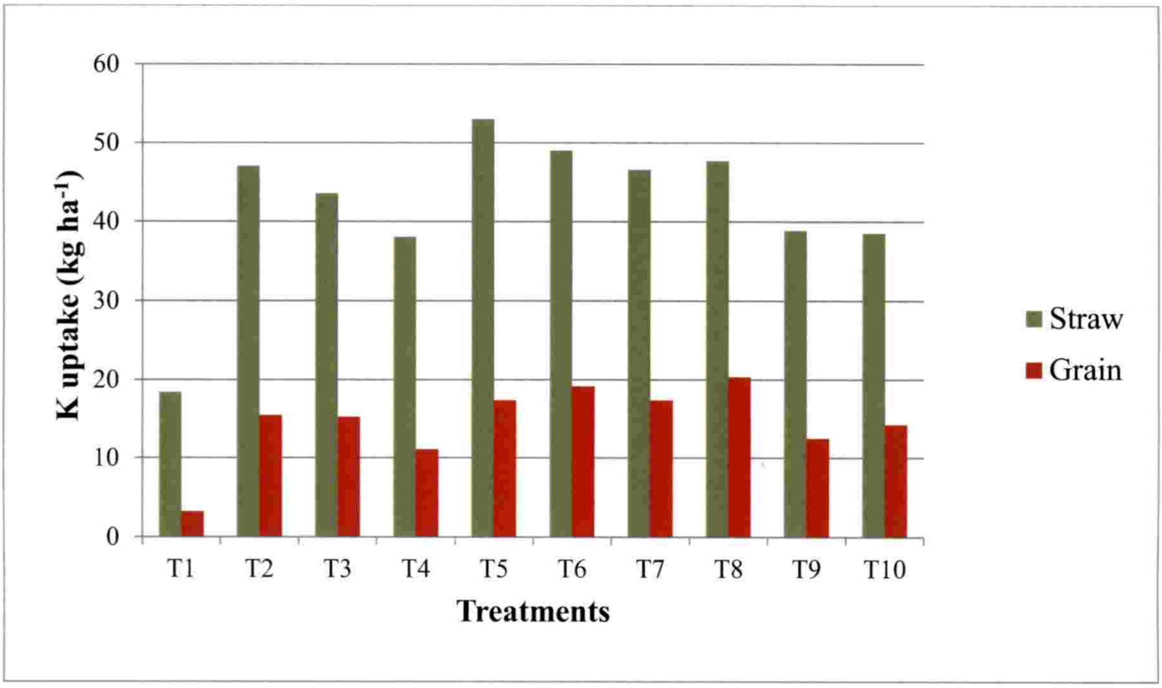

Fig. 15. Effect of treatments on K uptake by straw and grain

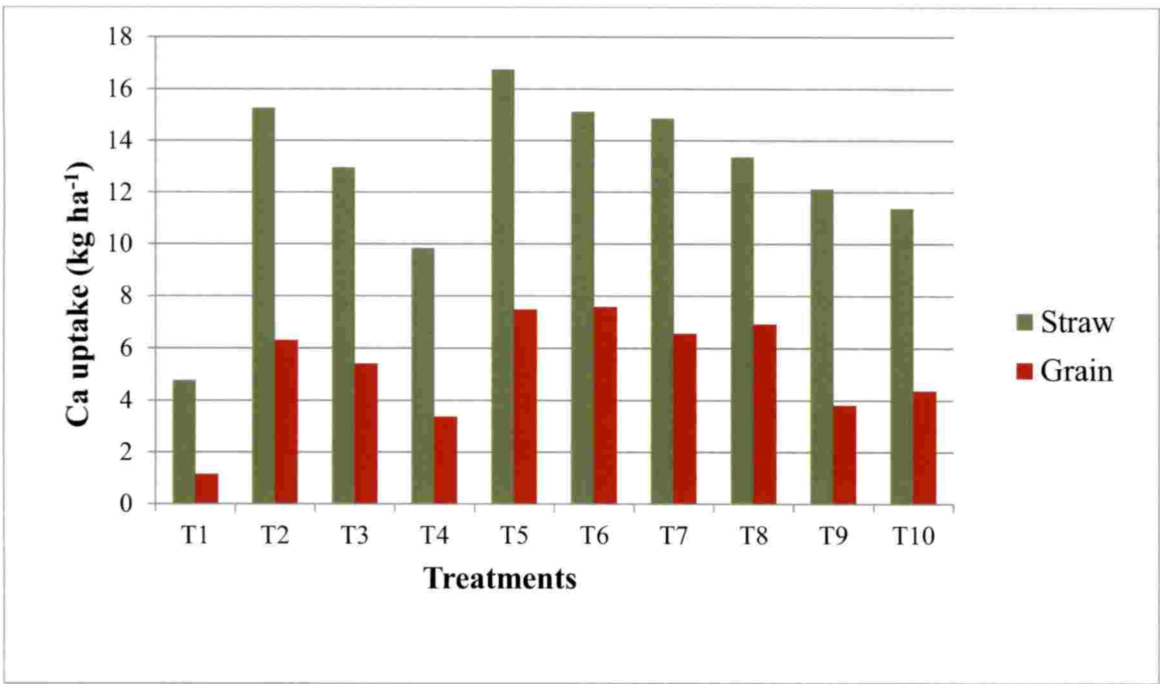

Fig. 16. Effect of treatments on Ca uptake by straw and grain

Improvement in Ca content of grain was noticed especially in treatments receiving liming materials either as lime or dolomite. Highest grain Ca was observed for T_5 (T_2 + micronutrient solution) and grain uptake was the highest for T_6 (T_2+ sampoorna multimix). Calcium is relatively immobile in the plant system and hence it is not translocated to grains leading to lower content and uptake compared to straw. The slightly higher grain Ca content in the respective micronutrient applied treatments might be due to the better translocation of nutrients from the vegetative parts to the reproductive parts of the plant which is induced by micronutrient application.

Treatment effects were not significant with respect to the content and uptake of Ca by root.

5.4.5 Magnesium

Mg content in straw was higher for treatment T_3 where dolomite was applied as liming material and for T_8 where dolomite was supplemented with micronutrients. Grain Mg content was also higher for T_3. Mg uptake was higher for T_8 in both straw and grain where sampoorna multimix was applied along with dolomite and this was on par with the treatments receiving micronutrients along with lime or dolomite or KAU PoP (lime or dolomite) alone (Fig. 17).

Dolomitic limestone application linearly increased Mg contents of rice since dolomite is an excellent source of the nutrients. Similar results were obtained by Duarte *et al.* (1999).

Content and uptake of Mg by root was not affected significantly by the different treatments.

5.4.6 Content and Uptake of Micronutrients by Straw and Grain

Only minor portion of the micronutrients present or applied to soil can be utilized by plants due to several antagonistic factors existing in the soil system. Hence foliar application of micronutrients must have exerted its direct effect on its composition due to direct absorption by the foliage. Application of micronutrients brought out significant increases in Fe, Mn, Cu, Zn and B content in straw and grain of the rice crop. Similar findings were also reported by, Rashid *et al.* (2004),

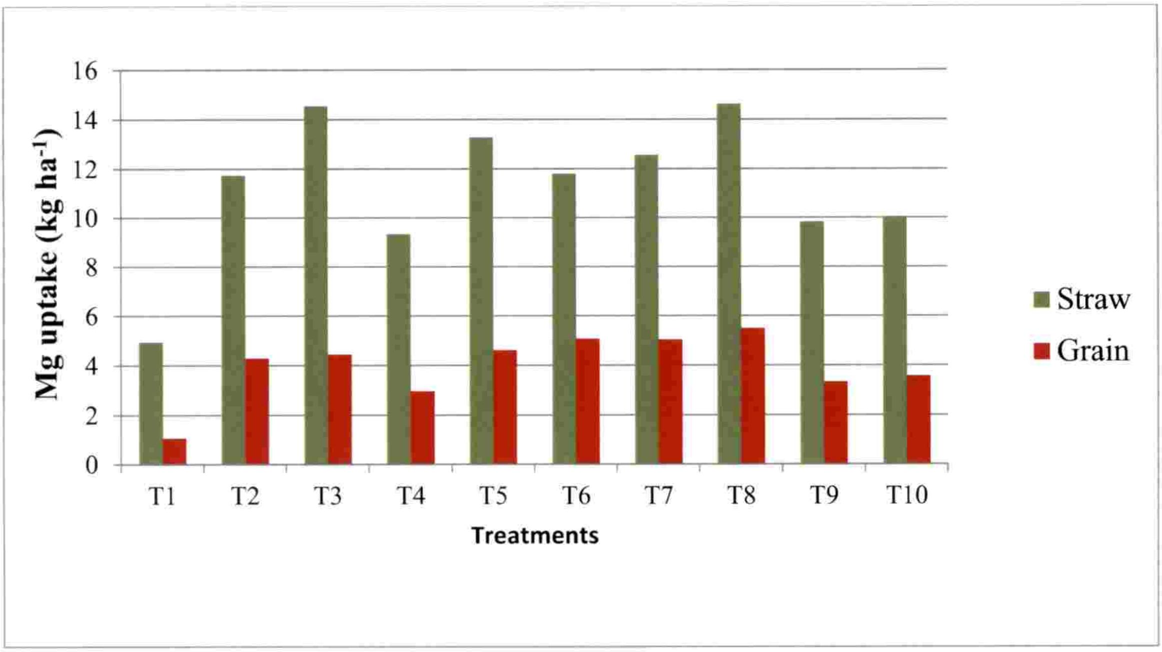

Fig. 17. Effect of treatments on Mg uptake by straw and grain

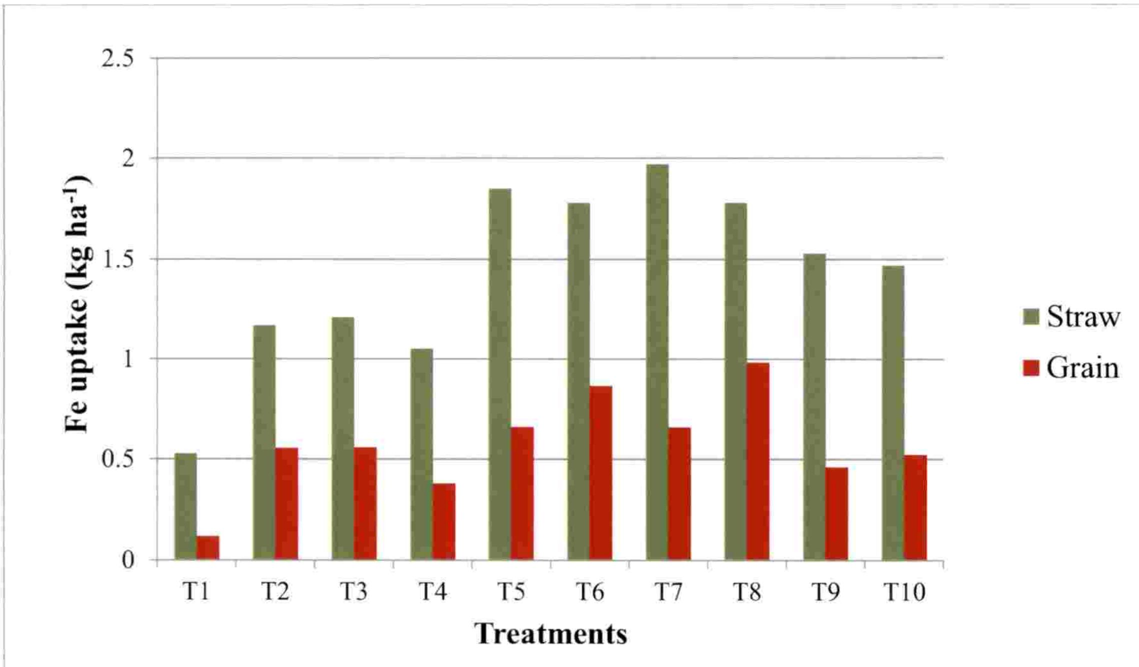

Fig. 18. Effect of treatments on Fe uptake by straw and grain

Jin *et al.* (2008), Narwal *et al.* (2012) and Stepien and Wojtkowiak, (2016) in rice. Mollah *et al.* (2009) demonstrated that fertilization of crops with NPK along with micronutrient addition increased the micronutrient (B, Zn, Cu, Fe and Mn) content of rice grains.

Fe concentration of straw in treated plants was found to be higher than that of control plants. Foliar application of micronutrients along with lime or dolomite gave significantly higher content of straw iron compared to other treatments and was on par with each other, with T_7 (T_3 + micronutrient solution) giving the highest value. Grain iron content was highest for the treatment T8 where sampoorna multimix was applied along with dolomite. Highest straw and grain uptake values were given by the corresponding treatments that recorded the highest straw and grain iron contents respectively (Fig. 18). Similar results were reported by Jin *et al.* (2008).

Root content and uptake of iron at harvest stage was not influenced by the different treatments.

Foliar application of micronutrients along with lime (T_5) produced the highest value for the content and uptake of manganese by straw, while treatment T_7 (T_3 + micronutrient solution) registered the highest grain manganese content and uptake (Fig. 19). Pessarakli (2009) reported an increase in Mn content due to foliar application of micronutrients. Manganese is not easily translocated within the plant system (Foth and Ellis, 1996) thereby resulting in reduced Mn content in grain.

No significant variation was observed in Mn content of root by different treatments. Manganese uptake by root was also significantly increased by foliar micronutrient application to the KAU PoP treatments (T2 and T3) compared to the organic farming treatments and KAU PoP (lime or dolomite) alone.

Foliar application of sampoorna multimix along with lime (T_6) gave the highest straw and grain copper content which was on par with the other treatments receiving micronutrients. Uptake of copper by straw and grain was highest for treatments receiving micronutrients either as micronutrient solution or as

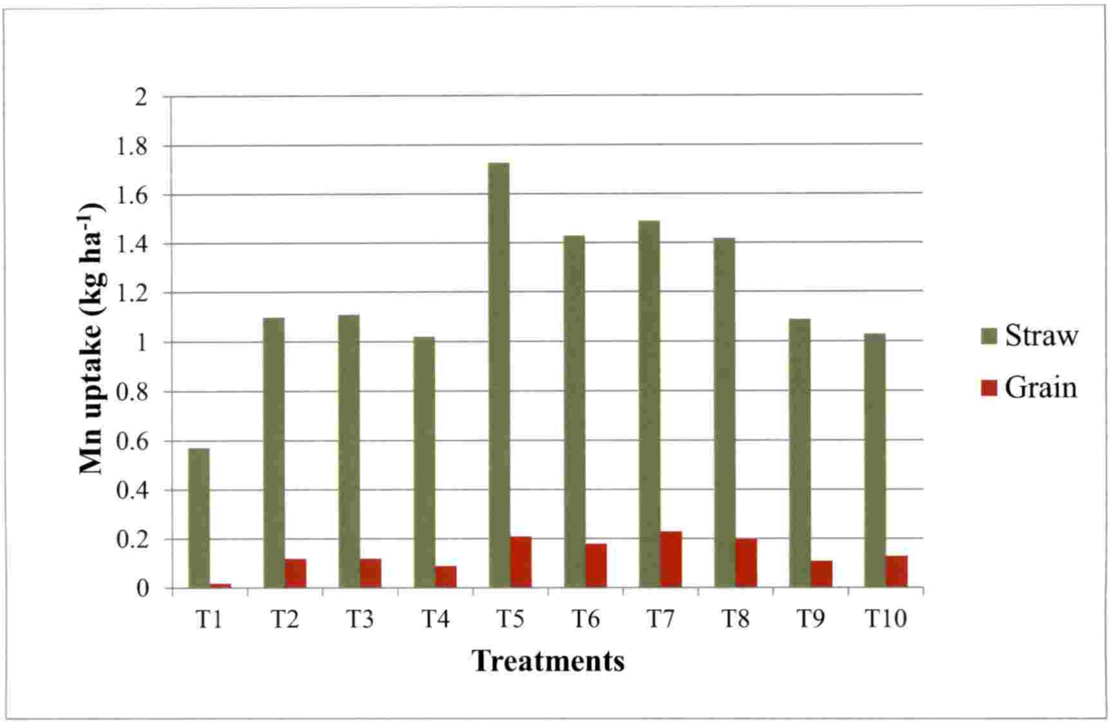

Fig. 19. Effect of treatments on Mn uptake by straw and grain

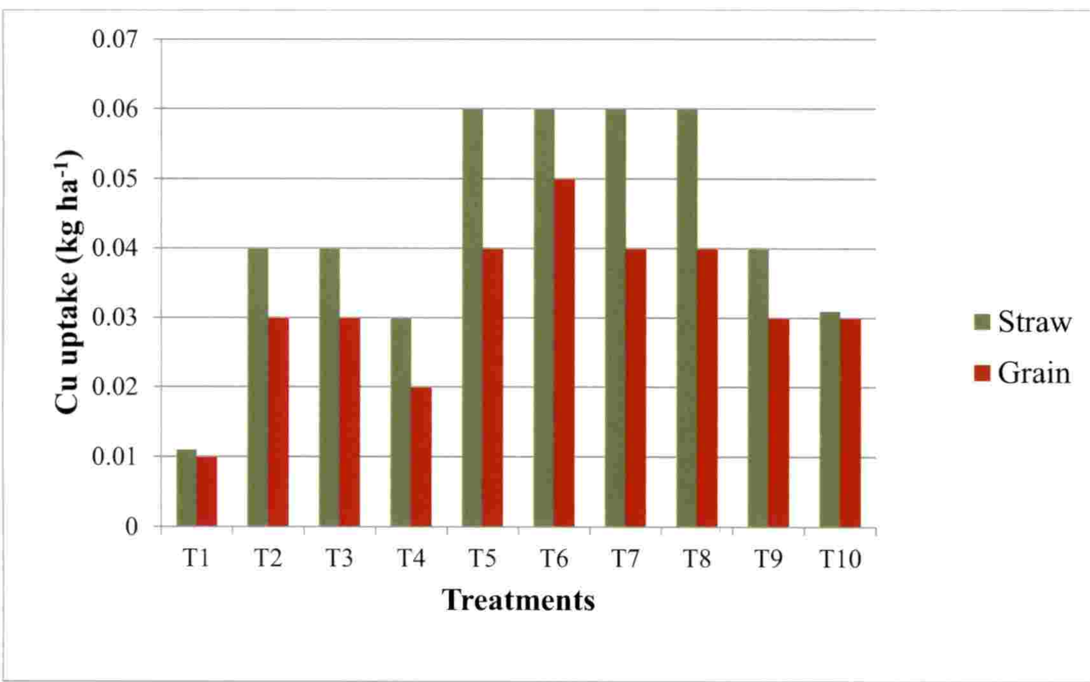

Fig. 20. Effect of treatments on Cu uptake by straw and grain

sampoorna multimix along with lime i.e. T_5 and T_6 respectively (Fig. 20). Similar result was obtained by Stalin *et al*. (2011).

Copper content and uptake by root was not significantly influenced by the application of various treatments

Treatment T_5 (T_2 + micronutrient solution) gave the highest straw zinc content which was on par with all the treatments receiving foliar application of micronutrients along with lime or dolomite. This increase in straw Zn content was due to its immediate absorption through the foliage. Zn applied through foliage in the dissolved form is easily absorbed and translocated through the phloem (Haslett *et al.*, 2001; Erenoglu *et al.,* 2002). Similar result was obtained by Cakmak (2008).

Grain zinc content was found to be the highest for treatment T_8 where sampoorna multimix was applied along with dolomite. This might be due to the translocation of zinc from vegetative parts to grain. Similar result was also obtained by Phattarakul *et al*. (2011) and Yuan *et al*. (2013). Monocotyledonous plants such as rice and wheat are good transporters of Zn from leaves and stem to their grains during the resproductive stage (Pearson *et al*., 1996). Higher Zn concentration in seed was reported when foliar Zn was applied after the flowering stage (Zadok *et al.* 1974).

Treatments T_5 and T_8 respectively recorded the highest values for straw and grain zinc uptake (Fig. 21). The higher dry matter production as well as zinc content in the foliage due to application of micronutrients on the leaf surface might have contributed to better uptake of zinc.

Zinc content of root was not influenced by the treatments whereas zinc uptake by root was significantly higher for all the treatments compared to absolute control.

Boron content in straw and grain was found to be significantly affected by the treatments, with T_8 (T_3 + sampoorna multimix) registering the highest straw and grain boron content which was on par with treatments receiving micronutrients along with KAU PoP (T_5 to T_7). The highest straw boron uptake was observed for T_5 where micronutrient solution was supplemented along with

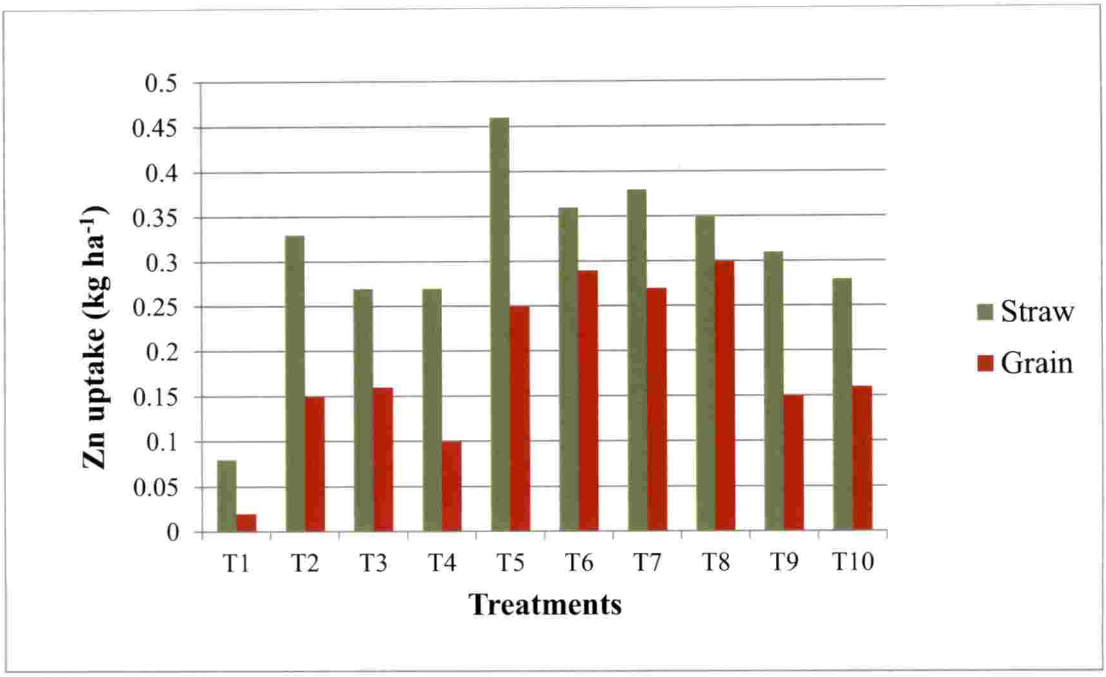

Fig. 21. Effect of treatments on Zn uptake by straw and grain

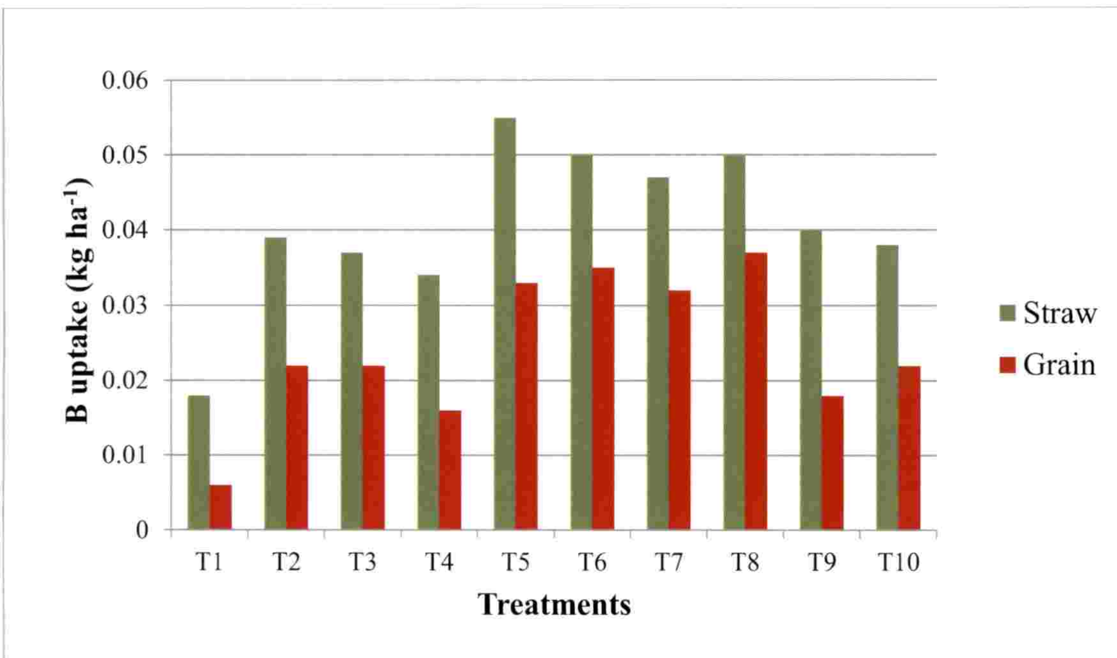

Fig. 22. Effect of treatments on B uptake by straw and grain

lime. Foliar application of sampoorna multimix along with dolomite (T_8) recorded the highest grain boron uptake values (Fig. 22). This might be due to the presence of boron binding compounds in the cell which might have increased the mechanism of boron uptake. Similar findings were reported by Jena *et al.* (2006) and Rashid *et al.* (2006). Uptake of boron within the rice plant is enhanced due to application of the boron fertilizer but only less content of boron is translocated to grains, whereas remaining portion is accumulated in the leaves and stem (Katyal and Singh, 1992). Pervaiz *et al.* (2012) reported that application of Zn and B showed increased chlorophyll content and led to an accumulation of Zn and B in grains.

Boron content of root was also significantly higher for the micronutrient supplemented treatments in general and boron uptake by root was significantly lower for the absolute control treatment than all the integrated nutrient management treatments.

Thus direct application of the micronutrients Fe, Mn, Cu, Zn and B at critical stages over the plant foliage enhanced the absorption of these nutrients in the plant parts thereby increasing the concentration.

5.5 EFFECT OF TREATMENTS ON PROTEIN CONTENT IN GRAIN

The treatment receiving foliar application of micronutrient solution along with lime (T_7) gave the highest value for protein content which was on par with all the treatments except absolute control. The higher nitrogen concentration with integrated nutrient management along with the application of secondary and micronutrients might have resulted in the higher protein content of grains. Similar result was reported by Zhao and Selim, (2010) and Zhang *et al.* (2012).

5.6 POST HARVEST SOIL CHEMICAL PROPERTIES AND NUTRIENT STATUS

The effect of treatments on soil nutrient status after harvest was studied and it was found that pH, N, P, K, Ca, Mg, Zn, B, Fe and Cu were found to be significantly affected by the treatments while the effect on OC, EC and CEC of soil were found to be non-significant.

Application of secondary and micronutrients had no significant effect on soil physical properties like bulk density, water holding capacity and porosity. Organic management practices resulted in lower values for bulk density and higher values for WHC and porosity. Similar results were reported by Singh and Sharma, (2005).

pH of soil was found to be significantly influenced by the different treatments. Treatment T_2 receiving KAU PoP + lime recorded the highest value for soil pH and was on par with all the treatments receiving lime or dolomite. It was observed that organic farming treatments caused a reduction in the pH of soil. Decomposition of organic manure results in the production of organic acids which slightly reduces the soil pH thereby increasing the acidity (Fageria and Nascente, 2014). Application of liming materials causes the hydrogen ions in the soil solution to react and get neutralised to form weakly dissociated water, and the Ca ions from limestone is left to undergo cation exchange reaction thereby reducing the acidity (Das, 2011).

Though the treatments had no significant effect on EC, different nutrient management practices gave higher values for EC compared to control.

Cation exchange capacity of soil was positively influenced by the applied treatments, with all treatments receiving different nutrient management practices showing higher values compared to absolute control though not significant. This might be due to the addition of organic matter to these treatments.

Though increase in organic carbon, lability index and carbon management index due to integrated nutrient management was not significant, generally higher values were obtained for the organic farming treatments. Similar results were reported by Verma *et al.* (2012).

Soil available N and K were on par for all the treatments except the organic ones and absolute control. The increase in available N due to the application of chemical fertilizers (T_2 to T_8) compared to absolute control may possibly be due to the direct addition of inorganic N to the available pool of soil (Yadav *et al.,* 2005).). Organic matter decomposition and further mineralization occur over several days in contrast to the immediate nutrient availability from chemical fertilizers.

Available P was on par for all the treatments except T_1. Rahman *et al.* (2002) reported that application of dolomite (56% CaO and 40% MgO) resulted in an increase in the pH values and available P in rice soils. Similar result was reported by Rastija *et al.*(2014). Application of liming materials inactivate the iron and aluminium thus increasing the level of available P in soil. Organic acids such as citrtate, malate and oxalate produced during decomposition of organic matter compete with inorganic P sorption sites and increases the availability of P in soil (Rana *et al.,* 2006). The progressive increase in available phosphorus due to each increment in agricultural limestone application could be explained due to the release of the organic phosphorus brought about by an increase in pH and a resulting change in the microflora of the soil.

Moreover, supplying plants with micronutrients, either through soil application, foliar spray, or seed treatment, increases yield and quality as well as macronutrient uses efficiency (Imtiaz *et al*., 2006).

Liming material addition significantly increased the soil Ca levels with T_5 registering the highest value. This is because liming of acid soils not only ameliorate soil acidity related problems but also supply Ca (Samui and Mandal, 2003).

Exchangeable Mg was maximum for the treatment T_3 where dolomite was applied as liming material and was on par with all the treatments receiving dolomite (T_7 and T_8). The higher content of Mg in soil may be due to the direct addition of the element from the liming material and greater availability due to balanced fertilization (Prasad, 1992).

Integrated or organic management practices increased the soil Fe, Mn and Zn levels in the soil. In general organic treatment gave significantly lower values for Cu and B. The contribution of foliar fertilization in increasing nutrient content of soils might be due to the washing and draining of fertilizer solution from leaves to the soil surface during rains (Nomura *et al.*, 2011).

SUMMARY

6. SUMMARY

The salient findings obtained from the study on "Secondary and micronutrient management for enhancing soil health and productivity in upland rice" are summarized in this chapter.

The experiment was carried out at College of Agriculture Vellayani and at farmer's field, Venganoor, Thiruvananthapuram during 2016-'18. The experiment was laid out in a randomized block design with three replications and ten treatments *viz.* absolute control (T_1), KAU PoP (T_2), KAU PoP + dolomite (T_3), KAU PoP for organic farming (T_4), foliar application of micronutrient solution or KAU sampoorna multimix respectively along with lime (T_5 and T_6), dolomite (T_7 and T_8) and organic farming treatment (T_9 and T_{10}). Foliar sprays of 0.5 % micronutrient solution (containing $FeSO_4.7H_2O$ 0.1%, $ZnSO_4.7H_2O$ 0.25%, borax 0.1%, $MnSO_4. H_2O$ 0.025%, and $CuSO_4. 5H_2O$ 0.025%) and 1 % KAU sampoorna multimix (containing Zn 7%, B 4.5%, Cu 0.5%, Fe 0.2%, Mn 0.2% and Mo 0.02%) was given during the critical growth stages of the crop *viz.* active tillering, panicle initiation and one week after flowering.

The soil of the experimental site before the crop was very strongly acidic, normal in EC, sandy clay loam in texture, medium in organic carbon and available N, high in available P and K, sufficient in available Fe, Mn, Cu, Zn, exchangeable Ca and Mg and deficient in available B.

Results revealed that foliar application of sampoorna multimix along with recommended lime application recorded the highest shoot length which was on par with all the treatments except absolute control. Foliar micronutrient application along with integrated nutrient management practices (T_5 to T_8) produced significantly higher total and productive tillers per m^2 compared to the other treatments, with T_7 giving the highest value.

Root length, dry weight and volume were higher for all the organic farming treatments, with significant increase obtained for root length compared to the INM treatments. Root dry weight and volume were highest for the organic farming treatments T_4 and T_{10} respectively with all treatments except T_1 on par.

Foliar application through either of the sources along with KAU PoP (lime or dolomite) registered significantly higher values for yield attributes, with T_8 giving the highest value for length of panicle, weight of panicle, number of spikelets per panicle and per cent filled grains. The thousand grain weight did not vary significantly among the treatments.

Micronutrient application along with KAU PoP (lime or dolomite) gave significantly higher grain yield compared to all other treatments with the highest value (4158 kg ha^{-1}) obtained for T_8. Highest straw yield (4897 kg ha^{-1}) was recorded by T_5 which was on par with the other micronutrient applied treatments (T_6 to T_8) and the KAU PoP treatments receiving lime or dolomite.

Increased nitrogen content of index leaf at panicle initiation stage was observed due to foliar micronutrient application, with the highest value for T_6. Application of liming materials alone or along with foliar micronutrients gave significantly higher content of P in index leaf, with T_6 giving the highest value. K content of index leaf increased due to foliar micronutrient application along with lime or dolomite, with T_7 giving the highest value. Treatment T_2 gave the highest Ca content which was also on par with all the micronutrient applied treatments. Mg content was highest in the dolomite applied treatments and was on par with the lime applied treatments.

Concentration of Fe, Mn, Cu, Zn and B in index leaf was found to be higher for the treatments receiving foliar micronutrients along with KAU PoP (dolomite or lime). The highest values were recorded by T_5 for Fe, T_7 for Mn and Zn, T_6 for Cu and T_8 for B.

Foliar application of micronutrients along with lime or dolomite gave the highest N contents in straw and grain, with T_8 and T_7 respectively registering the highest value and was on par with treatments receiving KAU PoP alone (lime or dolomite. The straw and grain uptake of nitrogen were the highest for treatments T_5 and T_8 respectively.

Foliar application of sampoorna multimix along with KAU PoP (lime) (T_6) gave the highest value for P and K contents in straw which was on par with all the treatments receiving foliar micronutrients along with KAU PoP (lime or dolomite). The treatment receiving micronutrient solution along with lime recorded the highest P and K uptake by straw. Foliar application of micronutrients along with dolomite gave the highest grain P and K uptake.

Concentration of Ca in straw and grain was found to be the highest for T_2 and T_5 receiving lime as per ΔpH and was on par with all the treatments except T_4 and T_1. Similarly Ca uptake by straw and grain was also found to be higher for treatments receiving lime i.e. T_5 and T_6, respectively.

Dolomite application gave significantly higher Mg content and uptake by straw and grain compared to absolute control and organic treatments.

Foliar application of micronutrients along with lime or dolomite (T_5 to T_8) gave significantly higher content of iron both in straw and grain compared to the other treatments. These treatments were on par with each other, with T_7 and T_8 respectively giving the highest content and uptake of iron in straw and grain.

Treatments receiving foliar application of micronutrient solution along with lime (T_5) recorded the highest value for manganese content and uptake by straw while treatment T_7 registered the highest grain manganese content and uptake.

The highest straw copper content was recorded by T_6 which was on par with the other treatments receiving micronutrients along with lime or dolomite (T_5, T_7 and T_8). Copper content of grain was found to be significantly higher for the treatment T_6 which was on par with all the treatments except T_4 and T_1. Uptake of copper by straw and grain was the highest for treatments receiving micronutrients (micronutrient solution or sampoorna multimix) with lime i.e. T_5 and T_6 respectively.

Treatment T_5 gave the highest straw zinc content and uptake and was on par with all the treatments receiving foliar application of micronutrients along with lime or dolomite. Grain zinc content and uptake was found to be the highest for treatment T_8 where sampoorna multimix was applied along with dolomite.

Foliar application of sampoorna multimix along with KAU PoP (dolomite) (T_8) registered the highest content of boron in straw and grain which was on par with all other treatments receiving micronutrient spray along with dolomite or lime. Highest straw boron uptake was observed for T_5 where micronutrients were supplemented along with lime. Treatment T_8 recorded the highest grain boron uptake.

Treatment receiving foliar application of micronutrient solution along with lime (T_7) gave the highest value for grain protein content which was on par with all the treatments except absolute control.

Application of secondary and micronutrients had no significant effect on soil physical properties like bulk density, water holding capacity and porosity but organic matter application improved the values. The treatments also had no significant effect on EC and CEC of the soil. Lower soil pH was obtained due to the application of organic manures compared to inorganic treatments though the differences were not significant compared to inorganic treatments. An increase was observed in organic carbon, lability index and carbon management index due to organic farming or integrated nutrient management though not significant.

Soil available N and K were on par for all treatments except the organic treatments and absolute control. Available P was on par for all treatments except T_1. Liming materials significantly increased the soil Ca level whereas soil Mg was increased by application of dolomite. Integrated or organic management increased the soil Fe, Mn and Zn level. In general organic treatment gave significantly lower values for Cu and B.

Economic analysis revealed that foliar application of micronutrients along with KAU PoP (dolomite or lime) significantly increased the B: C ratio with the highest value given by T_8.

Based on the study, it can be concluded that foliar application of micronutrients (sampoorna multimix or micronutrient solution) along with KAU PoP (lime or dolomite) significantly enhances the growth and yield of upland rice. The content and uptake of macro and micronutrients were also significantly influenced by liming and micronutrient supplementation. Organic farming treatments supplemented with micronutrients resulted in significantly higher grain and straw yield compared to pure organic treatment and produced yield on par with the KAU PoP (lime or dolomite) treatments.

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SECONDARY AND MICRONUTRIENT MANAGEMENT FOR ENHANCING SOIL HEALTH AND PRODUCTIVITY IN UPLAND RICE

by

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ABSTRACT

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ABSTRACT

An experiment entitled 'Secondary and micronutrient management for enhancing soil health and productivity in upland rice' was conducted with medium duration rice variety Uma, to investigate the effect of secondary and micronutrient application under organic and integrated nutrient management practices, on nutrient uptake, soil health and productivity of upland rice. The field experiment was carried out at farmer's field, Venganoor, Thiruvananthapuram, during *Virippu,* 2017-'18.

The experiment was laid out in a randomized block design with three replications and ten treatments *viz.* absolute control (T_1), KAU PoP + lime (T_2), KAU PoP + dolomite (T_3), KAU PoP for organic farming (T_4), foliar application of micronutrient solution or KAU sampoorna multimix along with lime (T_5 and T_6), dolomite (T_7 and T_8) and organic farming treatment (T_9 and T_{10}). Foliar sprays of 0.5 % micronutrient solution (containing $FeSO_4.7H_2O$ 0.1%, $ZnSO_4.7H_2O$ 0.25%, borax 0.1%, $MnSO_4.\ H_2O$ 0.025%, and $CuSO_4.\ 5H_2O$ 0.025%) and 1 % KAU sampoorna multimix (containing Zn 7%, B 4.5%, Cu 0.5%, Fe 0.2%, Mn 0.2% and Mo 0.02%) were given during the critical growth stages *viz.* active tillering, panicle initiation and one week after flowering.

The soil of the experimental site before the crop was very strongly acidic with normal EC, sandy clay loam in texture, medium in organic carbon and available N, high in available P and K, sufficient in available Fe, Mn, Cu, Zn, exchangeable Ca and Mg and deficient in available B.

The results of the study revealed that foliar application of micronutrient solution or sampoorna multimix along with KAU PoP (dolomite or lime) significantly increased the total and productive tillers per m^2 with T_7 giving the highest value. Root length, dry weight and volume were highest for all the organic farming treatments.

Foliar application of micronutrients produced significant increase in yield and yield attributes with T_8 recording the highest value for panicle weight (2.41 g), length of panicle (23.43 cm), per cent filled grains (87.17 %) and thousand grain weight (23.53 g) resulting in the highest grain yield (4158 kg ha^{-1}). T_8 was on par with treatments T_5, T_6 and T_7. Highest straw yield was recorded by T_5 (4897 kg ha^{-1}) which was on par with the other micronutrient applied treatments (T_6 to T_8) and KAU PoP receiving lime or dolomite alone.

Application of liming materials alone or along with foliar micronutrients gave significantly higher contents of N, P and K in index leaf at panicle initiation stage with T_6 giving the highest value for N and P and T_7 for K. Treatment T_2 gave the highest Ca content of index leaf, which was also on par with all the micronutrient applied treatments. Mg content was highest in the dolomite applied treatments and was on par with the lime applied ones. Fe, Mn, Cu, Zn and B contents in index leaf were also found to be higher for the treatment receiving foliar micronutrients along with KAU PoP (dolomite or lime), with the highest values recorded by T_5 for Fe, T_7 for Mn and Zn, T_6 for Cu and T_8 for B.

Higher N, P and K content in straw and grain were observed for treatments T_5 to T_8 which were on par with KAU PoP (lime or dolomite). Ca content of straw was highest for T_2 and was on par with all the treatments except T_4 and T_1. Highest grain Ca was observed for T_5 which also gave significantly higher Mg content in grain and straw compared to absolute control and the organic treatments. Uptake of N, P, K, Ca, Mg, Fe, Mn, Cu, Zn and B by straw and grain was also found to be the highest for the treatments receiving micronutrients along with KAU PoP (lime or dolomite).

Soil available N and K were on par for all the treatments except organic treatments and absolute control. Available P was on par for all the treatments except T_1. The increase in organic carbon due to integrated nutrient management was not significant. Liming materials significantly increased the soil Ca level whereas soil Mg was increased by the application of dolomite. Integrated or organic management increased the soil Fe, Mn and Zn levels. In general organic treatments gave significantly lower values for Cu and B.

Foliar application of micronutrients along with KAU PoP (dolomite or lime) was more economical, resulting in significantly higher B: C ratio with the highest value (1.43) given by T_8.

Based on the study, it can be concluded that foliar micronutrient application (sampoorna multimix or micronutrient solution) along with KAU PoP (lime or dolomite) significantly enhanced the growth, yield and nutrient uptake in upland rice.

APPENDIX

Appendix I

Weather data during the cropping period

(May to September, 2017) - Weekly averages of temperature, relative humidity and weekly sum of rainfall

Standard weeks	Temperature (^{0}C)		Rainfall (mm)	Relative Humidity (%)
	Minimum	Maximum		
22	23.9	31.9	187.9	90.9
23	24.6	30.8	31.7	89.8
24	25.2	31.7	11.3	84.5
25	24.4	32.2	18.9	84.0
26	23.7	31.1	140.2	90.6
27	24.6	31.7	10	83.4
28	24.5	31.2	10.3	84.0
29	24.6	31.2	17.0	84.7
30	25.0	32.2	3.1	81.9
31	25.0	32.3	7.2	84.9
32	24.5	31.3	18.5	84.2
33	24.7	31.1	21.4	86.3
34	24.6	30.5	37.7	86.2
35	24.4	31.5	17.9	82.7
36	24.6	32.3	22.9	84.7
37	24.2	31.5	30.0	85.1
38	24.4	30.4	92.7	88.0