BIOFORTIFICATION OF RICE (*Oryza sativa*) WITH ZINC UNDER ORGANIC AND INTEGRATED NUTRIENT MANAGEMENT PRACTICES

WAYOOLANG TALANG

(2017 - 11 – 125)

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE

PADANNAKKAD, KASARGOD - 671 314

KERALA, INDIA 2019

DECLARATION

I, hereby declare that the thesis entitled **"BIOFORTIFICATION OF RICE (*Oryza sativa*) WITH ZINC UNDER ORGANIC AND INTEGRATED NUTRIENT MANAGEMENT PRACTICES"** 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.

18/9/19

Place: PADANNAKKAD **Wayoolang Talang**

3

CERTIFICATE

Certified that this thesis entitled **"BIOFORTIFICATION OF RICE (*Oryza sativa*) WITH ZINC UNDER ORGANIC AND INTEGRATED NUTRIENT MANAGEMENT PRACTICES"** is a record of research work done independently by Mr. Wayoolang Talang under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

18/9/19

Place: PADANNAKKAD

Date: 18/9/19.

Dr. Suresh P. R
(Major Advisor, Advisory Committee)
Professor and Head
Dept. of SSAC
College of Agriculture,
Padannakkad

4

CERTIFICATE

We, the undersigned members of the advisory committee of Mr. Wayoolang Talang, a candidate for the degree of **Master of Science in Agriculture** with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled **"BIOFORTIFICATION OF RICE (*Oryza sativa*) WITH ZINC UNDER ORGANIC AND INTEGRATED NUTRIENT MANAGEMENT PRACTICES"** may be submitted by Mr. Wayoolang Talang, in partial fulfilment of the requirement for the degree.

18/9/19.

Dr. P.R Suresh
(Chairman, Advisory Committee)
Associate Dean,
Professor and Head
Dept. of SSAC
College of Agriculture,
Padannakkad

18/9/19

Dr. N.K. Binitha
(Member, Advisory Committee)
Assistant Professor
Dept. of SSAC
College of Agriculture,
Padannakkad

18/9/19

Dr. Jayraj P.
(Member, Advisory Committee)
Assistant Professor
(Programme Coordinator)
Dept. of SSAC
KVK, Kannur

18/09/19

Sri. Retheesh P.K.
(Member, Advisory Committee)
Assistant Professor
Dept. of Agronomy
Regional Agricultural Research
Station Pilicode, Kasargod

ACKNOWLEDGEMENT

First and foremost I bow my head before the Almighty who have given me the strength, courage and confidence to complete the thesis work successfully on time.

I wish to express my sincere gratitude to **Dr. P. R. Suresh**, *Associate Dean, Professor and Head, Department of Soil science and Agricultural Chemistry, College of Agriculture, Padannakkad and the Chairman of my Advisory Committee for his advice, inspiration, unstinted attention and meticulous guidance and constant encouragement throughout the course of investigation. The keen interest, abundant encouragement, he has imparted to me throughout my research work are invaluable and because of which I have been able to successfully complete the work assigned to me.*

I extend my sincere gratitude and reverence to **Dr. N. K. Binitha**, *Assistant Professor, Department of Soil science and Agricultural Chemistry and Member, Advisory Committee for her constant encouragement, support, technical guidance rendered at every stage of work and timely help throughout the research work and course of study.*

I express my heartfelt gratitude to **Dr. Jayaraj P**, *Assitant Professor and Programme Coordinator, Department of Soil science and Agricultural Chemistry, Krishi Vigyan Kendra, Kannur and Member, Advisory Committee for his timely suggestions and kind guidance throughout the course programme.*

I express my heartfelt gratitude to **Sri Retheesh P. K**, *Assitant Professor, Department of Agronomy, Regional Agricultural Research Station, Pilicode and member for his valuable suggestions and guidance throughout the research work.*

I extend my sincere respect and gratitude to **Dr. K.M. Sreekumar,Dr. Ramesh, Dr. Sujatha. R, Dr. Namboodiri Raji Vasudevan, Dr. G. V. Sudarsana Rao, Dr.Yamini and Dr. Chandran** *who have always given encouragement and support. Their personal involvement at times of need was highly valuable.*

I am gratefully acknowledge the invaluable help I received from ***Mr. Ashique, Mr. Mubarak, Ms. Beena*** *and* ***Ms. Amrutha, Ms. Ramya*** *for the successful completion of my research work.*

I wish to express my sincere gratitude to each and every teaching and non-teaching staff of Agronomy, Horticulture, Agricultural Entomology, Plant Pathology, Agricultural Engineering and Agricultural Extension departments for their suggestions and guidance throughout the research work. I am thankful to my seniors, junior students and research assistants for their help during my research work.

I express my sincere thanks to my dear friends ***Roshni, Amalendu, Aiba, Lapynbiang*** *and* ***Wankit****, my seniors,* ***Mubarak****, and* ***Ashwini*** *and my junior* ***Fousya*** *for their constant help and encouragement that made me confident in difficult situations.*

I wish to acknowledge with gratitude the award of fellowship by the Kerala Agricultural University during the tenure of the M. Sc. (Ag.) programme.

I express my deep sense of gratitude and affection to my father ***Jossly Biam*** *mother Smt.* ***Emelda Talang****, for their affection, constant encouragement, moral support, prayers and blessings without which I would not have completed this research. Above all, for the attention focused and facilities arranged to carry forward my studies.*

Finally I thank all those people who have supported me during my post graduate programme and helped for the successful completion of this thesis.

18/9/19

Wayoolang Talang

CONTENTS

LIST OF TABLES

//

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

%	-	Per cent
@	-	at the rate of
B	-	Boron
BCR	-	Benefit - cost ratio
Ca	-	Calcium
CD	-	Critical difference
Cl	-	Chlorine
cm	-	Centimeter
COA	-	College of Agricultural
Cu	-	Copper
CV	-	Coefficient of variation
DAT	-	Days after transplanting
^0E	-	East
EC	-	Electrical conductivity
et al	-	And others
Fe	-	Iron
Fig.	-	Figure
FUE	-	Fertilizer use efficiency
FYM	-	Farmyard manure
G	-	Gram
ha^{-1}	-	Per hectare
K	-	Potassium
K_2O	-	Potassium oxide
KAU	-	Kerala Agricultural University
kg	-	Kilogram
kg ha^{-1}	-	Kilogram per hectare
M	-	Meter
Mg	-	Magnesium
mg kg^{-1}	-	Milligram per kilogram

ml	-	Millilitre
mm	-	Milli meter
Mn	-	Manganese
Mo	-	Molybdenum
MOP	-	Muriate of Potash
MT/ha	-	Metric tonnes per hectare
N	-	Nitrogen
^{0}N	-	North
NS	-	Not significant
O	-	Oxygen
P	-	Phosphorus
P_2O_5	-	Phosphorus pentoxide
pH	-	Soil reaction
ppm	-	parts per million
POP	-	Package of practices
RARS	-	Regional Agricultural Research Station
RBD	-	Randomised Block Design
RDA	-	Recommended Daily Allowance
RDF	-	Recommended dose of fertilzer
S	-	Sulphur
Si	-	Silicon
Sig	-	Significant
Rs. ha^{-1}	-	Rupees per hectare
t ha^{-1}	-	Tonnes per hectare
viz.	-	Namely
vs.	-	Versus
WS	-	Water soluble
Zn	-	Zinc

Introduction

1. INTRODUCTION

In many developing countries of Asia and Africa cereals are consumed as a staple food which provides about 55 per cent of the daily dietary energy requirement. Among the cereals, rice is consumed as the staple food by more than half of the world's population. Globally, the consumption of rice meets about 21 per cent of the protein and energy requirement of the human population (Maclean *et al.*, 2002). India ranks first in rice cultivation with 433.88 million ha and second in production with 104.32 million tonnes during 2015-16 (Ministry of Agriculture 2015-16). Rice is essentially grown as a kharif crop in most parts of India. It is mostly cultivated in regions with a hot and humid climate with sufficient rainfall. Rice cultivation generally requires an average temperature ranging from 21° C to 37° C and a rainfall of more than 100 cm. It is also cultivated through irrigation in those areas that receives relatively less rainfall. In Kerala, 6.63 per cent of the total cropped area is occupied by rice. It is the staple crop of the state and it is cultivated in all the districts of Kerala. In Wayanad district the cultivation of rice is limited to rainy seasons. During 2016-17 the area under paddy cultivation in Kerala was 1.7 lakh ha and production was 4.3 lakh tonnes.

Soil is the medium in which nearly all plants grow and hence it forms the basis for agriculture. The foundation of our food systems relies on soil health. Healthy soils with sufficient nutrients produce healthy crops that in turn nourish people and animals. In fact, the quality and quantity of food production is the direct indication of soil quality. In India several studies reveal that micronutrient deficiencies occur intensively in cereals, oilseeds, and vegetable grown areas. Among the micronutrients, Zn deficiency is more critical with respect to plant and human nutrition. In Kerala, soil related constraints like iron and aluminum toxicity and high acidity have resulted in a decline in the present status of rice production in the state of Kerala in terms of area and production (Maneesh *et al.*, 2016). These constraints root from the fact that most of the soil in Kerala is lateritic in nature and cultivation in these soils require appropriate management packages. These measures are necessary as these soils are low in organic carbon, primary nutrients like nitrogen and potassium, secondary nutrients like calcium and magnesium and micronutrient such as zinc.

As a result of the above-mentioned soil constraints, the nutritional security of rice is given prime consideration in paddy cultivation in India and other countries where rice is a staple food crop. As such, the nutritional quality indices of rice become an important factor in nutritional budgeting for the Indian population as well as its economy.

In comparison with other cereals, the nutritional value of rice is low. About 31% of the calories of the Indian diet are supplied by the consumption of rice but nutritional analysis in the bioavailability of vitamins like vitamin A and minerals like iron and zinc in rice revealed that rice solely cannot meet the Recommended Daily Allowance (RDA) of vitamins, minerals and protein needs as their levels in rice are fairly low (Stalin *et al.*, 2013). RDA is the dietary intake level in a population that is sufficient to meet the nutrient requirement of nearly all (97 to 98 per cent) healthy individuals in a particular life stage and gender group. In rural areas of India, 75 per cent of the daily calorie intake is satisfied by consumption of rice and wheat alone (Cakmak, 2009) and since the diet is prominently cereal based the population is unable to meet the nutrient requirement. Therefore, there is a need for adequate intake of vitamins and minerals to attain a healthy and productive population. Failure to meet the nutrient requirement as per the RDA will lead to serious issues of malnutrition. Hidden hunger is a form of malnutrition which occurs when intake and absorption of vitamins and minerals (such as zinc, iodine, and iron) are below sufficiency level for sustaining good health and development. One of the major factors leading to hidden hunger is consumption of a poor diet deficient of essential vitamins and minerals. The subclinical deficiencies of vital nutrients go unnoticed by the population despite better understanding and monitoring.

Among the essential minerals required in our body zinc is a standout, being the most scrutinized nutrient in India and all over the world. In India, zinc is considered as the fourth most important nutrient limiting yield in agricultural crops. Plant and soil analysis showed Zn deficiency in 49 per cent of the soil in India (Singh, 2008). Zinc is a major component in the human body and it is also responsible for activating several enzymes that is involved in various metabolic activities (Chaudhary *et al.*, 2007). It is an important component in the cells of a human body and essential for the body's defensive mechanism to function properly. It plays an important role in cell division, cell growth, wound healing, and the breakdown of carbohydrates. Thus deficiency of zinc in human nutrition is widely observed in developing countries of Asia and Africa where cereals are consumed as staple food and intake of meat, poultry, fish, vegetables and fruits are low. Dependence on cereal-based diets accounts for more than 20 million fatalities every year (Kennedy and Burlingame, 2003).

There are several methods to prevent zinc deficiency in the diet which includes diet diversity, zinc supplementation, food fortification, and biofortification. Among the interventions, fortification and supplementation are widely adopted in the developed countries. However, in many developing countries these approaches cannot be easily achieved as they are expensive (Pfeiffer and McClafferty, 2007).

Biofortification is the process by which the nutritional quality of food crops is improved through agronomic practices, conventional plant breeding, or modern biotechnology. Biofortifying staple crop with zinc through these methods depends on available zinc in the soil as well as applied zinc. This method has found to be more effective than other methods for improving zinc status especially in population of remote rural areas with low-income.

Breeding approach is a long-term process requiring substantial effort and resources. A successful breeding program for biofortifying food crops with zinc is highly dependent on zinc pools in the soil available for plant use. The genetic capacity of newly developed (biofortified) cultivars to accumulate zinc through the absorption of a sufficient amount of zinc from soil may not be fully expressed in the grains (Cakmak, 2007). Hence a short-term approach is more favourable in improving zinc concentration in cereal grains. The practice of applying zinc fertilizers or zinc-enriched NPK fertilizers (agronomic biofortification) is the most simple and effective solution to the problem.

So the present study on biofortification of rice (*Oryza sativa*) with zinc under integrated and organic practices was undertaken with the objective:

1. To check the nutrient content of zinc under organic and integrated management practices.

Review of Literature

2. REVIEW OF LITERATURE

Rice is the most extensive staple food consumed by a large part of the human population in the world, predominantly in Asia. It is the third-highest produced crop in the world only after sugarcane and maize. The world's leading rice producer is China with a production volume of over 210 million metric tons in 2017. India ranks second in rice production accounting for about 20 per cent of the worldwide rice production. Rice is consumed as a staple food in India as it flourishes in a hot and humid climate. Most of the Asian countries especially Southeast and South Asian countries are highly dependent on rice for energy requirements. The essential vitamins and minerals required by the bodies are not met as the diets in these countries are predominantly cereal based.

Increasing the concentration of vital vitamins and minerals in rice (*Oryza sativa*) grain has become an important aspect for sustaining a good health in human beings. Among the essential vitamins and minerals, zinc has been one of the most researched nutrients in terms of human nutrition. In developing Asian and African countries where cereal grains are consumed as staple food, zinc deficiencies in human nutrition is a widespread (Prasad *et al.*, 2014).

In perspective on tackling these widespread deficiencies of vitamins and minerals in human nutrition, several interventions like food fortification, consumption of supplements and biofortification have been implemented over the years. Among the interventions mentioned above, biofortification is considered as the most feasible approach in developing countries with low income.

Biofortification is the process which improves the nutritional quality of food crops through practices such as conventional plant breeding, modern biotechnology or agronomic practices. The difference between biofortification and conventional fortification is that biofortification aims to increase nutrient levels in crops during plant growth rather than processing of the crops through manual methods.

Agronomic biofortification through zinc fertilization has resulted in an increased in grain production as well as higher zinc concentration in the grains. zinc fertilization also represents a complementary approach to breeding programs (Prasad, 2009). It also appears that agronomic biofortification strategy maintains a sufficient amount of available zinc in soil solution which in turn helps inadequate transport of zinc to the seeds during the reproductive growth stage. In soils, with low zinc status, soil and foliar application of zinc have increased the bioavailability of zinc in the grains and proved to be an effective practical strategy in overcoming zinc deficiency related problems (Pooniya *et al.*, 2011). There are other encouraging results revealing that foliar or combined soil and foliar application of zinc fertilizers under field conditions maximized the accumulation and uptake of zinc in whole rice.

Literature on the Zn nutrient content on rice and yield response to soil and foliar application of Zn are reviewed in this chapter.

2.1 ZINC

In humans, the number of proteins containing zinc prosthetic group was estimated to be about 2800–3000 (Tapeiro and Tew, 2003). Zinc is the only metal to be involved in all six classes of enzymes: oxidoreductases, transferases, hydrolases, lyases, isomerases, and ligases (Barak and Helmke, 1993). Moreover, zinc is required for activating over 300 enzymes that is essential for the normal functioning of a human body (Gibson, 2012).

Zn ions are neurotransmitters which are found in the cells of the salivary glands, prostate, and the immune system (Herschfinkel *et al.*, 2007). Zn plays several important roles in growth, proper immune system functioning, the health of the reproductive system, sensory functions and neurobehavioral development in humans.

Zinc is a "Type 2" nutrient which means a human body slows down the physiological growth and the excretion process to conserve Zn in the body.

Therefore Zn deficiency in children leads to reduced linear growth or stunting (Graham, 2008). The health issues related to zinc deficiency varied according to various age groups. In infants, low weight gain, diarrhea, anorexia and neurobehavioral disorder are observed. Skin changes and dwarfing are usually observed among toddlers and school children (Hambidge, 1997).

In the elderly age groups, Zn deficiency usually results in hypogeusia (impaired taste sensitivity), chronic ulcers, recurrent infections, and adverse pregnancy outcomes (Brown *et al.*, 2004).

Zn is also necessary for regulating intestinal absorption of Fe, and an adequate amount of Zn and Fe in the human body is crucial for treating Fe deficiency anemia (Graham *et al.*, 2001).

2.2 SOURCES OF ZINC

Zinc sulphate ($ZnSO_4$), zinc oxide (ZnO) and zinc ethylene diamine tetra acetic acid (Zn-EDTA) are the most common sources of zinc. Other inorganic sources of Zn and products of Zn such as Zn chelates and natural organic complexes are also used as Zn fertilizers. The effectiveness of Zn applied fertilizer is measured depending on solubility which is divided into Zn which is water-soluble and weak acid soluble Zn.

Compounds like $ZnNH_4PO_4$ formed as reaction products in ammonium phosphate fertilizers are less available for crop uptake especially on sandy, neutral to alkaline soils under dry conditions. Being a micronutrient the application of Zn to the soil is usually done along with NPK fertilizers in the factory itself or by mixing the granular form with other granular fertilizers. Foliar sprays are used for the application of soluble Zn fertilizers to fruit and vegetable crops. Sources of Zn fertilizer used should be based on the method of application, relative agronomic effectiveness, compatibility, price and convenience in the application.

Biofortification of Zn is considered as a promising strategy to improve the Zn status in cereals. Through biofortification, zinc concentration in rice grains can be enhanced by the addition of Zn fertilizers either through soil or foliar application. Improvement in Zn status was found to be more with this method.

2.3 STATUS OF AVAILABLE ZINC IN INDIAN SOIL

The extensive variation in the availability of Zn in soils is due to the diverse physical and chemical characteristics of soils, management practices which involves growing of high yielding varieties of crops, use of high analysis fertilizers and increasing annual cropping intensity. The available zinc content in Indian soils varies from traces to 22 ppm (Randhawa and Takkar, 1975). Appavu and Ramulu (1981) reported maximum zinc content in laterite soils followed by red, alluvial and black soil in Tamil Nadu.

Katyal (1985) reported that 47 %, 33 % and 58 % of the samples collected from soils of 10 states and 11 union territories in the country were deficient in Zn, Cu, Mg, and Fe, respectively.

Soil analysis performed in soil samples collected from Hissar district of Haryana revealed that available Zn in soil varied from 0.36 to 2.29 ppm which is relative low as compared to the critical value of 0.7 ppm (Singh and Banarjee , 1984).

Rathore *et al.*, (1980) observed a positive correlation between available Zn in soil and organic carbon indicating that low organic carbon content in the soil had low availability of Zn especially in arid and semi-arid regions of India.

Singh *et al.* (1988) found that available Zn in soil was higher at surface horizons and decreases with depth. It was reported that the average value of available Zn in the profile samples was 0.27 ppm.

Similarly, findings were reported by Udo and Fagbami (1979), where DTPA-extractable Zn in Nigerian soils decreases in with depth.

A study conducted by Hazra and Mandal (1988) in some alluvial soils of West Bengal revealed that available Zn in soil ranged between 4.20 and 11.30 ppm. A positive correlation between Zn and clay content was found whereas a negative correlation was with pH thus signifying that the increase in soil pH resulted in a decrease in zinc extractability by DTPA.

Jalali *et al.* (1989) concluded that the available zinc varied from 0.35 to 0.65 ppm in some benchmark soils of Kashmir, the available zinc was in the deficient range of less than 0.6 ppm in all the profile. The amount of DTPA-extractable Zn decreased with soil depth which was positively correlated with organic carbon content in soil followed by pH.

Higher available Zn was observed in soils derived from granites compared to those soils derived from basalts and gneiss. Also, reports showed that higher pH values and higher $CaCO_3$ content were found in Vertisols (basalt) thereby immobilized the available zinc by the process of precipitation thus lowering Zn status of soil (Murthy 1988).

2.4 EFFECT OF PHOSPHORUS AND ZINC INTERACTIONS IN CROPS

Maqsood *et al.* (2004) studied the interaction of zinc and phosphorus in maize and sunflower. The treatments consisted of the application of P (0 and 100 mg kg-1) and Zn (0 and 15 mg kg-1) along with recommended doses of N and K. In maize, application of both P and Zn increased shoot dry matter production, P and K concentration in shoots and improved the uptake compared to control. However antagonistic interactions were observed in the case of sunflower where the application of Zn increased reduced P in the shoot by 66 % over control.

Zhu *et al.* (2001) conducted an experiment to study zinc-phosphorus interaction in two wheat cultivars (Brookton and Krichaue) that differ in P uptake efficiency. It was reported that P uptake efficiency in Brookton was higher than Krichaue under low P conditions. It was concluded that there was no significant effect on tissue P concentration or on either P cultivar on Zn supply but an increase in P availability caused a significant reduction in Zn and tissue concentration of Zn in both cultivars.

In a greenhouse experiment conducted by Haldar and Mandal (1981) to study the effect of P and Zn application revealed that application of P caused a decline in the Zn, Cu, Fe and Mg concentration both in shoots and roots. Zn application similarly lowered the P, Cu, Fe concentration but increased the Mg concentrations in shoots and roots.

2.5 EFFECT OF SOIL APPLICATION OF ZINC ON GROWTH, YIELD AND NUTRIENT CONCENTRATION IN RICE

Savithri *et al.* (1999) and Sharma *et al.* (1999) showed that soil application of $ZnSO_4$ at the rate of 25 kg/ha and with 36 kg $ZnSO_4$/ha recorded the highest yield of grain in the soil in Tamil Nadu and clay loam soils of Rajasthan, respectively.

Kumar *et al.* (1999) reported that soil application of $ZnSO_4$ at the rate of 20 Kg/ha incorporated either with press mud or FYM had significant increase in productive tillers/m^2, which was at par with only soil application of $ZnSO_4$ 40 kg ha^{-1} alone on the sodic soils of the state of Uttar Pradesh.

Sharma *et al.* (1999) concluded the experiment done in Rajasthan by stating that application of $ZnSO_4$ at the rate of 30 Kg ha^{-1} in soil resulted in a considerably higher number of effective tillers /m^2 on soils with clay loam texture.

A field experiment conducted in Bapatla by Jena (1999) reported that soil application of $ZnSO_4$ at the rate of 50 kg/ha on clay loam soils and seedling root dip in 2% ZnO had a significant influence in the grain yield and dry matter production. Similarly, in Bhubaneswar near the coastal areas, soil application of ZnSO4 at the rate of 20 kg/ha significantly increased the grain yield (Katayal and Gangwar, 2000). Channabasavanna *et al.* (2001) reported that soil application of $ZnSO_4$ at the rate of 25 kg/ha on deep black soils of Siriguppa (Karnataka), significantly recorded higher grain yield than control. Sankaran *et al.* (2001) also reported similar results where the soil application of $ZnSO_4$ 50 kg ha^{-1} in red loam soils of Bhavanisagar.

Nirmaladevi (2001) concluded that application of $ZnSO_4$ at the rate of 75 kg/ha had a significant effect on the protein content of rice in vertisols of Bapatla.

Grain yield of rice and straw production was considerably high with the application of 150 per cent recommended doses of NPK fertilizers along with $ZnSO_4$ at the rate of 20 kg/ha and FYM at the rate of10 t/ha in soils of Jammu with clay loam soil texture (Azad and Lehria, 2001).

Rao (2003) concluded in his field experiment that soil application of $ZnSO_4$ at the rate of 30 kg ha^{-1} had a significant increase in the plant height on sandy clay loam soils of Varanasi.

Kulandaiveln *et al.* (2004) on an experiment concerning fertilization of paddy with the soil application of $ZnSO_4$ at the rate of 30 kg ha^{-1} along with 10 kg $FeSO_4$ per which resulted in significantly higher straw yield was significantly higher. Also, in the year 2004, he observed that application of 30 kg $ZnSO_4$ along with 5 kg $FeSO_4$ per ha resulted in elevated production of dry matter, higher tillers/m^2, and a higher number of grains/panicle on sandy clay loam soils of New Delhi.

Soil application of $ZnSO_4$ at the rate of 60 Kg ha^{-1} along with organic and inorganic sources of N significantly improved the physicochemical parameters of rice like hulling and milling per centages, protein content in grain, head rice recovery, amylose and zinc content of rice grain which was grown on sandy clay loam soils of Bapatla (Subba Rao, 2005).

Singh *et al.* (2006) concluded that incorporation of $ZnSO_4$ at the rate of 25 kg/ha along with 100% RDN of nitrogen, phosphorus and potassium fertilizers at the rate of 120 : 60 : 50 kg per ha significantly increased the straw yield of rice over

100% of recommended NPK fertilizers alone on sandy loam soils of Bahraich, Uttar Pradesh.

Jena *et al.* (2006) from a field experiment on sandy loam soils reported that soil application of $ZnSO_4$ at the rate of 50 kg/ha and seedling root dip in ZnO significantly increased the dry matter production.

Khan *et al.* (2007) conducted a pot experiment at Faculty of Agriculture Gomal University, Pakistan during the year 2001 to evaluate the yield and several growth components of rice under the effects of different treatments of soil application of zinc at eight different soil series of D.I. Khan (Pakistan). The source of Zn used was $ZnSO_4.7H_2O$ (21%) which was applied at the rate of 0, 5, 10 and 15 kg ha^{-1} along with the basal doses of NPK fertilizers at the rate of 120:90:60 kg ha^{-1}. The effects of different treatments revealed that treatment receiving 10 kg zinc /ha significantly improved several that growth parameters viz. plant height, numb er of tillers per plant, number of spikelet per panicle, number of panicle per plant and 1000 seed weight of paddy.

Chaudary and Sinha (2007) reported that combined application of nitrogen at the rate of 120 kg ha $^{-1}$ and soil application of $ZnSO_4$ at the rate of 25 kg ha^{-1} resulted in a significant increase in effective tillers/m^2 and dry matter production on silty-clay soil of Pusa (Bihar).

A field experiment conducted by Chaudary *et al.* (2007) on silty-clay soil of Bihar reported that the highest grain yield was recorded when 120 kg N was applied with 50 kg $ZnSO_4$/ha. A significant increase in protein content of 7.6% was recorded with an increase in $ZnSO_4$ level application. Similarly, the numbers of grains per panicle and plant height were significantly increased. On the other hand, according to Jana *et al.* (2009), the highest number of grains/panicle was with the application of 30kg $ZnSO_4$/ha and rice grain yield (67.45 q/ha) was higher with the application of 40 kg $ZnSO_4$/ha on sandy clay loam soils of West Bengal.

In rice-wheat cropping system application of 10 kg zinc per hectare along with the application of 100 per cent of crop residues recorded highest yield of rice (4.35 t/ha) (Prasad *et al.*, 2010).

Shehu *et al.* (2011) in an experiment conducted in Nigeria found that a number of days to heading lowered as the application of 5 kg Zn ha^{-1} was done in soil.

A study conducted by Mustafa *et al.* (2011) to evaluate the effect of different methods and timing of zinc application on growth and yield of rice found a significant increase in yield components such as kernel/panicle, number of productive tillers/hill, biological yield, 1000-kernel weight, kernel yield and harvest index. Highest productive tillers/m^2 (249.80) were observed with basal application at the rate 25 kg/ha (21%) $ZnSO_4$ which was at par with foliar application of 0.5% $ZnSO_4$ at 15 DAT and highest kernel yield (220.28) were recorded with foliar application at 60 DAT at the rate of 0.5 % zinc solution. Maximum grain yield (5.21 t/ha) and higher test weight were also observed with the basal application of 25 kg/ha of $ZnSO_4$ which were at par with foliar application of 0.5% $ZnSO_4$ at 15 DAT and root dip treatments with zinc solution.

Keram *et al.* (2012) on an experiment to study the effect of Zn on soil properties and also to evaluate the response of wheat yield, nutrient uptake, protein content by application of zinc at the rate of 0, 1.25, 2.50, 5, 10 and 20 kg/ha as soil application (zinc sulphate) at the time of sowing. The results revealed that the quality of wheat grains significantly improved with the application of the recommended dose of NPK + zinc at the rate of 20 kg/ha as compared to NPK alone. Highest carbohydrate (70.77 %) and gluten (12.37%) content were also found with application of the recommended dose of NPK + zinc at the rate of 20 kg/ha as compared to the control as well as other treatments.

Dixit *et al.* (2012) noted the highest protein content (11.56%) with soil application of 15 kg Zn/ha on sandy loam soils (sodic soil) of Kumarganj, Faizabad.

An experiment conducted by Ram *et al.* (2015) in rice and wheat crop in Punjab which comprises of two treatments in each crops. For rice, the treatment consisted of no zinc and soil application of zinc at the rate of 50 kg $ZnSO_4.7H_2O$/ha. In case of wheat the treatments consisted of 1) no zinc 2) combined soil application of $ZnSO_4.7H_2O$ (50 kg ha^{-1}) and foliar Zn application at 0.5% of $ZnSO_4.7H_2O$ at earing and at milk stage and 3) foliar Zn application at 0.5% of $ZnSO_4.7H_2O$ at earing and at milk stage. In rice soil application of Zn was superior. Similarly, in wheat combined soil application and foliar application of Zn significantly improved grain yield wheat.

2.6 EFFECT OF FOLIAR APPLICATION OF ZINC ON GROWTH, YIELD AND NUTRIENT CONCENTRATION IN RICE

It was reported that two sprayings of 0.5% $ZnSO_4$ at 3rd and 5th weeks after transplanting improved the 1000-grain weight in transplanted rice by Kumar and Singh (1996) the results was on par with one spraying of 0.5% $ZnSO_4$ combined with soil application of 25kg $ZnSO_4$/ha at Sabour, Bihar on silt loam soils.

Farmyard manure application at the rate of 10 t ha^{-1} along with nitrogen fertilizers at the rate of 120 kg ha^{-1} + 20 kg $ZnSO_4$ ha^{-1} as basal + 5 kg $ZnSO_4$ ha^{-1} as foliar application increased the grain yield significantly in Bahraich, Uttar Pradesh on the sandy loam soils, as noticed by Rajput (1997).

Khan *et al.* (2003) found that there was no significant difference in number of tillers m^{-2} and plant height with soil application of 10 kg Zn ha^{-1} compared to foliar spray of 0.2% $ZnSO_4$ on alkaline calcareous soils and 0.20% $ZnSO_4$ and root dipping of 1.0% $ZnSO_4$ on silt loam soils, respectively at Pakistan. However, the highest number of tillers/m^2 and plant height was 415.67 and 101 cm respectively which was recorded with soil application of Zn at the rate of 10 kg ha^{-1} along with folair application. Per centage of filled grains were improved significantly by soil application of Zn, root dipping and foliar application over control on alkaline calcareous soils.

Rao (2003) in his experiment research on rice variety BPT 1768 found that treatment that included of root dip + foliar application of 0.5% $ZnSO_4$ caused a significant increase in the plant height, number of tillers, dry matter production and straw yield of rice variety on sandy clay loam soils of Bapatla.

Ravikiran and Reddy (2004) noticed an increase in the total number of tillers $hill^{-1}$ by foliar application of $ZnSO_4$ at the rate of 0.5 % over control and application of 0.5% Zn along with soil application. However, 0.5 per cent of Zn spray alone showed the highest increase in a pot culture experiment at Bapatla.

At maximum tillering and panicle initiation stage the straw yield was doubled with foliar application of $ZnSO_4$ at the rate of 0.5% on the silty clay loam soils of Nadia (Das *et al.*, 2004).

Application of NPK fertilizers at the rate of 180:80:80 kg ha^{-1} + 0.5 % Zn foliar application + application of farmyard manure at the rate of 10 t ha^{-1} produced the highest grain yield and higher yield attributing characters like number of panicles/m^2 and filled grains/panicle on silty loam soils of Pantnagar as reported by Rathore *et al.* (2004).

Three foliar spray application of Zn and Fe each at the rate of 0.5% at different stages starting from maximum tillering stage till before and after flower initiation stages increased the grain yield of rice significantly on the loamy sand soils in Ludhiana (Dhaliwal *et al.*, 2010).

Significantly higher grain yield was produced with 2% zinc sulphate enriched urea application as compared to application urea only on sandy clay loam of New Delhi (Yadav *et al.*, 2010)

Urea and micronutrient foliar spraying (Fe at the rate of 1.6 kg + zinc at the rate of 0.72 kg + Mn at the rate of 2.4 kg) on wheat showed a significant increase in protein content (13.66%) and 1000 grain weight (47.97) as per the results of an experiment conducted by Yassen *et al.* (2010).

Patel (2011) on his experiment conducted in the loamy sandy soils of Punjab found that grain yield increased significantly when the foliar application of 0.5% $ZnSO_4.7H_2O$ was done three times at different growth stages of rice.

Benedicto *et al.* (2011) found a significant increase in the straw biomass, grain yield, and Zn content in grain when Zn was applied as a foliar application at different growth stages as Zn-EDTA and ZnSO4. The highest grain yield increases with the application of Zn-EDTA.

Stomph *et al.* (2011) reported that when $ZnSO_4$ was applied as a foliar application, it has proven to be an effective technique to improve the concentration of zinc in grains and to overcome the zinc deficiency.

As per reports of Reddy *et al.* (2011) higher number of productive tillers m^{-2}, higher number of filled grains panicle^{-1} and number of panicles m^{-2} was recorded from on application of Biozinc at the rate of 50 kg ha^{-1} as basal application along with foliar spray at the rate of 3g L^{-1} at 30 DAT(during 2008 and 2009 respectively) which had no significant difference from that of $ZnSO_4$ at the rate of 50 kg ha^{-1} as basal application along with foliar spray at the rate of 3g L^{-1} at 30 DAT or sole basal application of Biozinc or $ZnSO_4$ at the rate of50 kg ha^{-1}. Straw yield significantly improved (7042 kg ha^{-1}) with basal application of Biozinc at the rate of 50 kg ha^{-1} + foliar spray of $ZnSO_4$ at the rate of 3 g L^{-1} at 30 DAT and was at a par with basal application of $ZnSO_4$ at the rate of 50 kg ha^{-1} + foliar spray of $ZnSO_4$ at the rate of 3 g L^{-1} at 30 DAT (6696 kg ha^{-1}) and basal application of Biozinc at the rate of 50 kg ha^{-1} (6943 kg ha^{-1}).

Zayed *et al.* (2011) observed that combined application of Zn^{+2} + Fe^{+2} + Mn^{+2} produced the tallest plants with no significant difference between the treatment of commercial compound (14% Mn^{+2} + 12% Fe^{+2} + 16% Zn^{+2}) applied twice at 20 and 45 DAT as a foliar spray on saline soils.

An experiment carried out by Yuan *et al.* (2012) showed that the quality parameters such as protein content and total amino acid content increased significantly when Zn was applied through different foliar applications.

An experiment was carried out by Wei *et al.* (2012) at Longyou, Zhejiang province, China where four different zinc forms were applied as a foliar treatment among rice cultivars. The zinc concentration of grain was increased by foliar zinc fertilization. Foliar Zn fretilization improved the protein content in polished rice.

Boonchuay *et al.* (2013) observed how the concentration of Zn in rice seeds can be improved and consequent seedling growth may be enhanced by foliar zinc application. 0.5% Zinc sulphate ($ZnSO_4.7H_2O$) applied to the rice plant in eight foliar zinc treatments at the different growth stages. Evaluation of zinc in seeding growth was done from the germinated resultant seeds and the results showed that in the early germination stages the seedlings germinated from seeds with 42-67 mg/kg showed longer roots and coleoptiles compared to seeds with 18 mg/kg.

2.7 EFFECT OF APPLICATION OF ZINC UNDER ORGANIC AND INTEGRATED NUTRIENT MANAGEMENT PRACTICES

A pot experiment was conducted by Yoshida *et al.* (1996) in the International Rice Research Institute in 1966. The soil collected from Nene's experimental field in Pantnagar was deficient in zinc. IR-8 variety of rice seedlings were grown in pots with four treatments in which $ZnSO_4$ was applied at the rate 2, 8, 16, 32 ppm with each treatment replicated twice. There was a remarkable increase in dry weight and grain yield associated with an increment in zinc content due with an increase in the rate of Zn application.

Muralidharudu (1991) conducted an experiment in a greenhouse on the soils containing zinc deficiency of Tarai region (U.P.) and reported a significant increase in the uptake of zinc by the application of zinc along with NPK fertilizers in rice.

Sahu *et al.* (1996) conducted a field experiment in Orissa on soils belonging to the soil order of Inceptisol and Vertisol. Application of NPK fertilizers at recommended doses along with Zn application (combined soil and foliar application) recorded a significant increase in zinc uptake rice.

Vasudeva and Ananthanarayana (2001) conducted a field experiment in the acid soils of the Karnataka and reported a significant increase in the uptake of N, P, K and Zn with the application of 20 kg $ZnSO_4$ ha^{-1} + NPK at 75 kg ha^{-1}, 75 kg ha^{-1} and 90 kg ha^{-1}, respectively + farmyard manure at the rate of 5 t ha^{-1}.

Siddhamalai *et al.* (2002) conducted an experiment in Tamil Nadu on soils where rice are cultivated and reported a significant increase in the zinc uptake in the grain and straw of rice with the application of Zn, Cu, Fe, and Mn along with NPK.

Rao (2003) conducted a study on rice grown on the sandy clay loam soils of Bapatla. The experimental results revealed that treatment in which root dip along with the foliar application of 0.5% ZnSO4 considerably improved Zn uptake and Zn content of rice grains.

Das *et al.* (2004) concluded in his work that the content of zinc in straw was significantly highest with Zn- EDTA foliar spray at the rate of 0.05% on silty clay loam soils of Nadia.

Dipanker *et al.* (2007) studied the effect of zinc sources on maize plants and reported that total zinc uptake was maximum in Zn-FA treated plant, followed by Zn-Ha-Fa, Zn-Ha, and $ZnSO_4$. The highest total zinc uptake in Zn-Ha-Fa, Zn-Ha and $ZnSO_4$ treatment were 216.4, 213.25 and 163.25 mg respectively and was found at 10.0 mg zinc/kg soil application.

Patel *et al.* (2009) found that foliar spray of 1% multi-micronutrient mixture having Fe, Mn, Zn, Cu and B of 6%, 1%, 4%, 0.3% and 0.5%, respectively applied at 30, 45 and 60 DAT increased the micronutrient uptake in grain. The uptake of Fe (52.8 g ha^{-1}), Mn (14.2 g ha^{-1}), Zn (51.4 g ha^{-1}), Cu (3.4 g ha^{-1}) were recorded.

Mishra *et al.* (2009) observed the highest concentration of zinc in straw on the application of 50 kg $ZnSO_4$ ha^{-1} along with 100 % NPK at tillering and maturity stage.

Shivay and Prasad (2009) reported that 0.2% $ZnSO_4$ foliar application at different stages of rice cultivated on sandy clay loam soils in New Delhi resulted in Zn concentration increment in both grains as well as a straw of rice.

The results of a field experiment conducted by Dhaliwal *et al.* (2010) at Ludhiana revealed that foliar spraying of 0.5% Zn at maximum tillering stage, before and after the flower initiation stages showed a significant increase in Zn uptake and raised the Zn concentration to 30.42 mg kg^{-1} (PAU 201) and 30.3 mg kg^{-1} (PR 115) attributing to 19.3 % and 18.6 % higher than control and also the concentration of Zn in brown rice improved significantly.

The results of an experiment conducted by Ram *et al.* (2011) revealed that when zinc was applied (Soil + foliar), Zn concentration in grain significantly improved with the application of zinc compared to no zinc application. Foliar application of zinc showed superior results over soil applications alone.

Yadav *et al.* (2011) recorded the highest concentration of Zn (39 ppm) in grain on foliar application of 0.2% $ZnSO_4$ this was at par with $ZnSO_4$ at the rate of 25 kg ha^{-1} applied in the soil. Application of 2.0% zinc-enriched urea (zinc sulphate) did significantly well compared to all other sources of Zn, prilled urea and the control. The uptake of Zn however, was highest with soil application of 25 kg $ZnSO_4$ ha^{-1}.

Jena *et al.* (2011) concluded that application of $ZnSO_4$ at 50 kg ha^{-1} in soil along with a foliar spray of 0.5% $ZnSO_4$ at pre-flowering and pre-milk stage increased the zinc concentrations in rice grain attributing to 12% higher than the control on alluvial soils at Orissa.

Phattarakul *et al.* (2011) reported that foliar spary of Zn significantl increased the grain Zn content significantly in both high and low Zn grain varieties of rice. Foliar application of 0.5% of $CuSO_4$, $ZnSO_4$, $FeSO_4$, $MnSO_4$ + 0.05% Boric acid + 0.010% Sodium molybdate at panicle initiation and flowering stages and 0.25% of $CuSO_4$, $ZnSO_4$, $FeSO_4$, $MnSO_4$ + 0.010% Boric acid + 0.010% Sodium molybdate at active tillering, panicle initiation and flowering stages increased Zn, Cu, Fe, Mn and B content in whole grain (Stalin *et al.*, 2011).

Pooniya *et al.* (2011) observed higher concentration of Zn in straw with 0.2% $ZnSO4.H_2O$ foliar application at maximum tillering, pre-flowering and flowering stages. The Zn concentrations in rice straw were 7-8 times higher than that in the grain because Zn was directly absorbed by plant leaves and finally accumulated into the grain. Higher N, P, K and Zn uptakes by Basmati rice were also recorded with 2.0% zinc enriched urea which was significantly superior to the rest of Zn treatments on sandy clay loam soils at New Delhi.

Shivay *et al.* (2015) conducted two on-farm experiments in different districts of Uttar Pradesh, India. Zinc application in zinc-deficient soils during the rainy season showed improvement in zinc concentration and also zinc uptake by rice. Results also showed an increase in protein content of rice kernels and an increase in concentrations of N, P, K and Fe due to the overall improvement in plant growth.

Saha *et al.* (2015) conducted a field experiment in which rice of different cultivars was raised with no zinc and zinc fertilization ($ZnSO_4.7H_2O$) through basal soil application + two foliar sprays (at maximum tillering and flowering stages). Zinc fertilization recorded grain and straw yield with high zinc content in most of the cultivars.

Yin *et al.* (2016) conducted a field experiment in the soil with low Zn content to determine the effects of zinc fertilization on Zn concentration in grains in different plant tissues of rice in Huainan city of Anhui province, China. The results showed that the combined soil and foliar application of Zn had a large effect on Zn concentration in grains. Furthermore, the Zn concentration in brown rice increased significantly with Zn fertilization.

A field experiment by Gogoi *et al.* (2016) was conducted in AAU, Jorhat, Assam with an aim of enriching grains of popular high yielding varieties of rice with soil and soil plus the foliar application of zinc. Three different levels of zinc viz., 0, 21 kg ha^{-1} as a soil application, and 21 kg ha^{-1} as soil application + foliar spray of 0.5% of $ZnSO_4$ thrice at heading, panicle initiation and flowering stages were evaluated. Irrespective of varieties, highest mean zinc concentration of 34.2 mg kg^{-1} was observed in rice grain with soil + foliar application of zinc. The mean zinc content varied from 17.6 to 34.2 mg kg^{-1} and it increased from 5.8 to 20.3 per cent over control with soil application and 13.2 to 32.3 per cent with soil + foliar application of zinc.

Jaksomsak *et al.* (2018) carried out an experiment which investigated the effect of foliar applied zinc on four rice varieties from Thailand having different grain Zn. Foliar zinc application at 0.5% $ZnSO_4$ applied at flowering and the early milky stage was a more effective approach compared to no foliar application of Zn.

Materials and Methods

3. MATERIALS AND METHODS

The research entitled "Biofortification of rice (*Oryza sativa*) with zinc under organic and integrated nutrient management" was carried out during the "virippu" cropping season (June-October) at Regional Agricultural Research Station (RARS), Pilicode during the period June to October 2018. The objective was to check the nutrient content of zinc in rice grain under organic and integrated nutrient management. The materials and methodologies that were adopted during the period of study are being briefly described in this chapter.

3.1. GENERAL INFORMATION

3.1.1 Experimental site

The experimntal field is located at 12^0 12' N latitude and 75^0 10' E longitudes and it is at an altitude of about 15 meters above mean sea level.

3.1.2 Soil

The soil of the experimental site is sandy clay loam in the texture of the lateritic origin. The soil is very strongly acidic in reaction.

3.1.3 Climate and weather

The region where the experimental field lies experienced a warm humid tropical climate. The average maximum temperature and minimum temperature is 32.1^0 C and 24^0 C respectively during the crop period (June to October).

3.1.4 Season

The field experiment was carried out during the first season crop of 2018. The seeds were sown on the nursery on the month of June and transplanted on the month of July. The crop was harvested in October.

3.2 EXPERIMENTAL DETAILS

3.2.1 Crop variety

The variety used for the research work is Uma (Mo 16). This rice variety was released by the Rice Research Station, Moncompu of Kerala Agricultural University. It is a medium duration variety of about 115 to 120 days. The grain characteristics are red, medium, and bold. The variety is non lodging and resistant to pest like brown planthopper. The variety is suited to three seasons especially to additional crop season of Kuttanad.

3.2.2 Manures and Fertilizers

Farmyard manure containing 0.5% N, 0.22% P_2O_5 and 0.5% K_2O was applied at the rate of 5 t ha^{-1} to each plot as per the treatment requirement. The fertilizer doses for the crop were applied at 90:45:45 kg ha^{-1} of N, P_2O_5, and K_2O, respectively to each plot as per the treatment requirement. The material used was 17-17-17 complex fertilizer, urea, and muriate of potash.

3.2.3 Design and layout

Crop: Rice
Variety: Uma
Spacing : 20 cm x 15 cm
Plot size: 2m x 2m
Design: Randomized Block Design
Duration: 110-120 days
Date of sowing: 31st June 2018
Date of transplanting: 23rd July 2018
Date of harvesting: 21st October 2018

3.2.4 Treatment details

T_1 : Organic POP + soil application of Zn

T_2 : POP(KAU-2016) + soil application of Zn

T_3 : T_1+ single foliar application of Zn

T_4 : T_1+ double foliar application of Zn

T_5 : T_1+ triple foliar application of Zn

T_6 : T_2+ single foliar application of Zn

T_7 : T_2+ double foliar application of Zn

T_8 : T_2+ triple foliar application of Zn

T_9 : Application of zinc in nursery

T_{10} : Control

Note:

1. Single foliar application at the tillering stage.
2. Double foliar application at tillering stage and panicle initiation.
3. Triple foliar application at tillering, panicle initiation and flowering.
4. Zinc will be applied as zinc sulphate at the rate of 1 % and 20 kg/ha as foliar application and soil application, respectively.

3.3 FIELD CULTURE

3.3.1 Nursery

The seedbed was prepared 24 days prior to transplanting. The seedlings were raised by wet nursery method on 31st of June 2018. The seeds were first soaked for 24 hours after which it was incubated in a warm moist condition for 36 to 48 hours. The pre-germinated seeds were then sown at the rate of 80kg ha^{-1} leveled nursery area.

3.3.2 Land preparation and layout

A tractor-drawn iron plough was used to uniformly till the field in order to break and invert the soil either partially or completely until it is suitable for sowing seeds. After ploughing it was followed with puddling done with water. A tractor drawn puddler was used for puddling the field which had standing water of 5 to 10

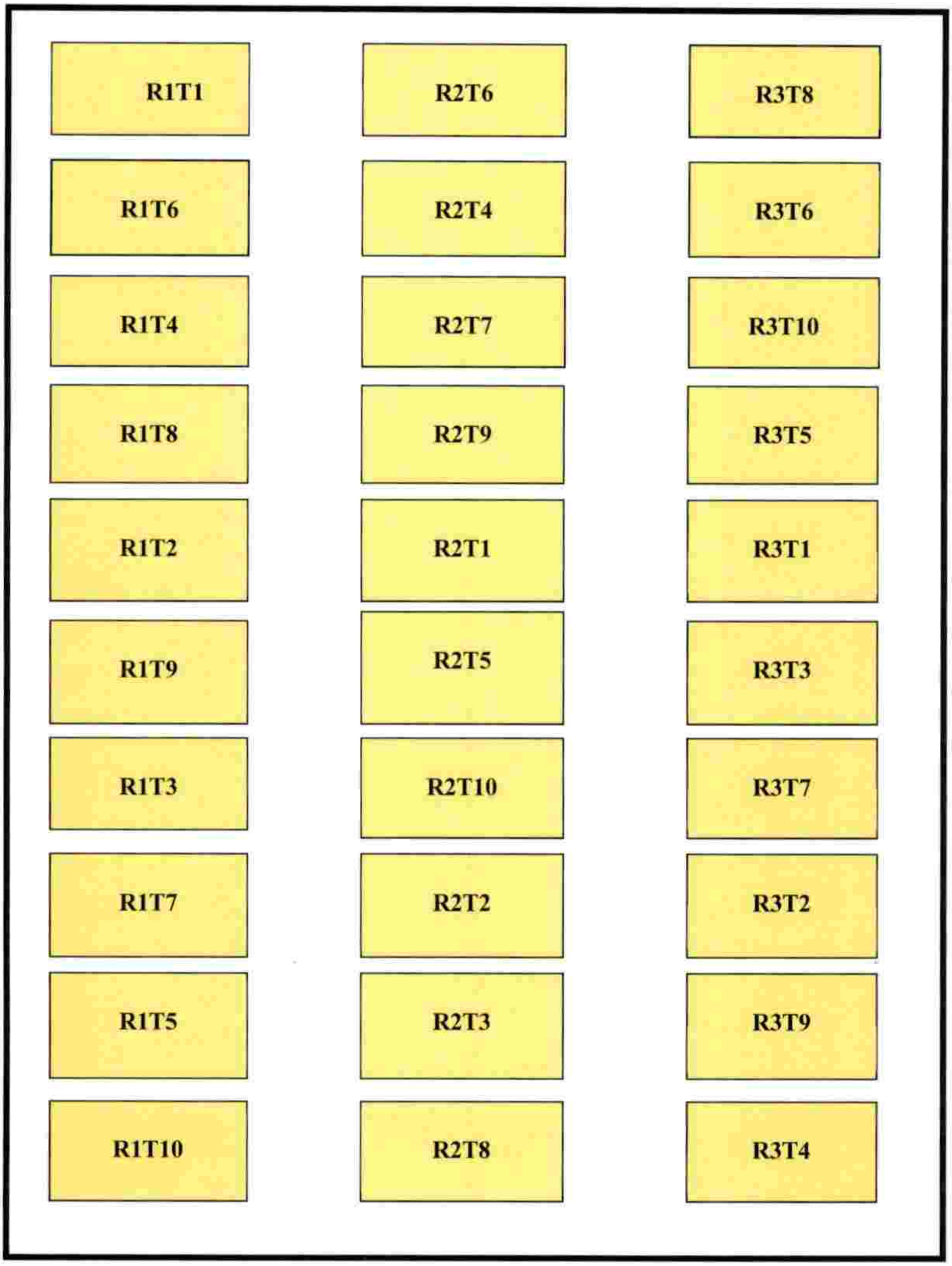


Plate 1: EXPERIMENTAL LAYOUT

cm depth. The plots were laid down as per the technical program. The layout of the field experiment is illustrated in fig 1.

3.3.3 Liming

Split doses of lime at the rate of 600 kg ha^{-1} was done as basal dressing during land preparation and the second doses of about 200 kg ha^{-1} after one month of sowing.

3.3.4 Transplanting of rice

Rice seedlings of 24 days old were transplanted at the rate of 3 seedlings per hill in rows at a spacing of 20 cm x 15 cm on 23rd June 2018.

3.3.5 Manures and Fertilizers

Organic manure in the form of farmyard manure was applied to each experimental plot at the rate of 5 t ha^{-1} prior to transplanting of the seedlings as per the requirements of the treatment. The recommended rates of N, P_2O_5, and K_2O is 90-45-45 kg ha^{-1} where P is applied in full dose as basal and N, K fertilizers were applied in split doses as basal and the remaining were applied at the panicle initiation stage.

Zinc was applied as soil application at the rate of 20 kg ha^{-1} and as a foliar spray at the rate of 1% at nursery, tillering, panicle initiation and flowering stage for each plot as per the requirement of the treatment.

3.3.6 Weeding

The common weeds flora observed in the experimental field were *Echinochloa crusgalli, E. colonum, Cyperus iria, Commelina cummunis, Eclipta alba* and *Ludwigia perennis,* etc. Manual weeding by hand was employed for removing the weeds.

3.3.7 Plant protection

Control measures were taken for controlling of incidence of pests like rice stem borer and rice bugs. Malathion 50% EC at the rate of 1 ml L^{-1} was applied at panicle initiation and at milking stage for controlling rice stem borer and rice bug respectively.

3.3.8 Harvesting

The crop was harvested using a paddy cutter for individual plots when the crop attained maturity. Tagged plants from each plot were collected before the harvest for post-harvest studies.

3.3.9 Threshing

The harvested paddy was sun-dried before threshing. Manual threshing and winnowing were done separately for each plot. The weight of cleaned grains obtained from each plot was taken and converted to tons per hectare.

3.3.10 Plant sampling

Plant samples were collected from each experiment plot at maximum tillering, panicle initiation, flowering and at harvesting stage to determine the nutrient content and uptake by the plant. A random selection of five plants was done and they were tagged for biometric observations.

3.3.11 Soil sampling

Soil samples were collected before land preparation, at 45 days after sowing and at harvesting stage for determination of various soil properties to provide a representative sample of the fertility within the field.

3.4 BIOMETRIC OBSERVATIONS

3.4.1 Observations on growth parameters

From each experimental plot, five plant samples were randomly selected and tagged for recording the observations on growth parameters at different stages of growth and characteristics of yield and its attributes at the harvest stage.

3.4.1.1 Plant height (cm)

Plant height was measured from each experiment plot at the maximum tillering stage, panicle initiation stage, flowering stage and harvest stage. The height of the plant was taken from the base of the stem at ground level to the tip of the last emerged leaf measured in terms of cm.

3.4.1.2 Number of tillers hill^{-1}

The total number of tillers per plant were recorded at different stages *viz*, maximum tillering, panicle initiation stage, flowering stage and harvest stage. The average was calculated and recorded.

3.4.2 Observations on yield and yield attributes

3.4.2.1 No of panicles hill^{-1}

The total number of panicles per hill in each experimental plot was counted from the tagged plants and the average number of panicles per hill was recorded.

3.4.2.2 Total grains panicle^{-1}

The total grains per panicle were counted by counting grains from 10 panicles selected from each experimental plot. The mean value was computed and recorded as total grains per panicle.

3.4.2.3 Test weight (g)

Sample grains were collected from each individual plot, from that 1000 grains were counted and their weight was recorded in gram.

3.4.2.4 Chaffiness (%)

After winnowing the chaffy grains and filled grains were separated and the weight of the chaffy grains was recorded separately for each experimental plot.

3.4.2.5 Grain yield (t ha^{-1})

After threshing and winnowing the grain yield was recorded separately for each treatment and was converted into grain yield tons hectare^{-1}.

3.4.2.6 Straw yield (t ha^{-1})

After threshing, the straw was dried and weighted from each treatment separately in kilogram and converted into straw yield tons hectare^{-1}.

3.4.2.7 Plant analysis

Analysis of plant tissues is done from the plant samples that were collected at maximum tillering stage, panicle initiation stage and at the harvest stage from each experimental plot. The plant samples should be clean and oven dried at 60-70°C. The plant samples were analyzed for N, P, K, Ca, Mg, S, B, Fe, Mn, Si, Zn and Cu using standard procedures listed in Table 1.

3.5 SOIL NUTRIENT ANALYSIS

3.5.1 Initial soil analysis

The soil sample was collected randomly from different places within the prepared experimental field from and it is then pooled and reduced to 500g and air dried. After air drying, the soil sample was sieved using a 2mm sieve and stored in an airtight container.

The soil samples were analyzed for pH, EC, organic carbon, CEC, bulk density, particle density, available macronutrients such as N, P, K and micronutrients such as Fe, Mn, Zn, Cu, B and Mo following the standard procedures in table 2.

3.5.2 Experimental soil analysis

Collection of soil samples for experimental soil analysis was done from each experimental plot at 45 DAS and at harvest. The samples were collected in clean polythene bags, air-dried, ground, sieved with 2 mm sieve and store in an airtight container. The analysis of soil sample was done for pH, EC, organic carbon, particle texture and available nutrients such as N, P, K, Fe, Mn, Zn, Cu, B and Si as per the standard procedures.

3.5.3 Grain analysis

Matured grains were collected from the randomly selected and tagged plants in each experimental plot and oven dried at 60-degree Celsius and then powdered for the analysis of P and Zn content in the grain using standard procedures given in table 1.

3.6 STATISTICAL ANALYSIS

The data obtained from the seed treatment study and field experiment were analyzed statistically using Analysis of Variance (ANOVA) for randomized block design proposed by Panse and Sukhatme in 1985. It is then tested for its significance using WASP software.

Plate 1: Seedbed preparation at nursery

Plate 2: Nursery stage

Plate 3: Foliar spray at nursery

Plate 4: Land preparation

Plate 5: Transplanting

Plate 6: Single foliar spray at tillering stage

Plate 7: Panicle initiation

Plate 8: Flowering stage

Plate 9: Foliar spray of Zn at flowering

51

Plate 10: Harvesting

Plate 11: Threshing

Plate 12: Sun drying of grain and straw

Table 1: Methods used for plant analysis

Sl. No	Parameter	Method	Reference
1.	Total N	Modified kjeldhal digestion method	Jackson (1958)
2.	Total P	Vanadomolybdate yellow colour method	Piper (1966)
3.	Total K	Flame photometry	Jackson (1958)
4.	Total Ca	Atomic absorption spectroscopy	Issac and Kerber (1971)
5.	Total Mg	Atomic absorption spectroscopy	Issac and Kerber (1971)
6.	Total S	Turbidimetric method	Bhargava and Ragupathi (1995)
7.	Total Fe	Atomic absorption spectroscopy	Piper (1966)
8.	Total Mn	Atomic absorption spectroscopy	Piper (1966)
9.	Total Zn	Atomic absorption spectroscopy	Emmel *et al.* (1977)
10.	Total Cu	Atomic absorption spectroscopy	Emmel *et al.* (1977)
11.	Total Si	Blue silicomolybdous acid method	Ma *et al.* (2002)
12.	Total B	Photo electric Colorimetry	Bingham (1982)

Table 2: Methods used for soil analysis

Sl. No.	Parameters	Methods	Reference
1.	pH	pH meter	Jackson (1958)
2.	EC	Conductivity Meter	Jackson (1958)
3.	Organic Carbon	Chromic acid wet digestion Method	Walkley and Black (1934)
5.	Bulk Density	Undisturbed core sample	Black *et al.* (1965)
6.	Textural Analysis	International pipette method	Robinson (1922)
7.	Available N	Alkaline permanganate Method	Subbiah and Asija (1956)
8.	Available P	Bray extraction and photoelectric colorimetry	Jackson (1958)
9.	Available K	Flame Photometry	Pratt (1965)
10.	Available Fe	Atomic absorption spectroscopy	Sims and Johnson (1991)
11.	Available Mn	Atomic absorption spectroscopy	Sims and Johnson (1991)
12.	Available Zn	Atomic absorption spectroscopy	Emmel *et al.* (1977)
13.	Available Cu	Atomic absorption spectroscopy	Emmel *et al.* (1977)
14.	Available B	Photo electric colorimetry	Bingham (1982)
15.	Available Si	Photo electric colorimetry	Gupta (1967)

Results

4. RESULTS

The results that were obtained from the field experiment on the research topic "Biofortification of rice (*Oryza sativa*) with zinc under organic and integrated nutrient management practices" that were conducted in Regional Agricultural Research Station, Pilicode during the first season crop in 2018 are tabulated and statistically analyzed.

4.1 BIOMETRIC OBSERVATION

4.1.1 Plant height

The data on the mean plant height which was recorded on four growth stages of the crop *viz* tillering, panicle initiation, flowering and harvesting stage are presented in table 3.

At tillering stage, significant differences were observed among the treatments. Application of foliar spray of $ZnSO_4$ at the rate of 1% significantly increased the plant height in treatment T_9 which recorded the highest plant height (48.72 cm) and was on par with T_7 and T_8. The least plant height (41.39 cm) was recorded in the control plot T_{10} which was on par with T_1 and T_3.

Similarly, at panicle initiation stage significant differences were observed in plant height. The treatment with the highest plant height (67.07 cm) was T_9 which was on par with T_8 (POP KAU + soil application of Zn + triple foliar application of Zn). The minimum plant height (59.72 cm) was recorded in T_{10} which was on par with T_4 and T_5.

At the flowering stage, foliar application of $ZnSO_4$ at the rate of 1% along with the basal application of N and K fertilizers significantly increased the plant height in treatments under INM practices. Treatment T_7 recorded the highest plant height (97.28 cm) which was on par with T_8 (96.53) and were significantly superior over the other treatments.

At the harvesting stage, triple foliar spray of $ZnSO_4$ at the rate of 1% significantly increased the plant height in T_8 which recorded the highest plant height (99.91 cm) and was on par with T_7, T_6 and T_5. The minimum plant height (92.33 cm) was recorded in control.

4.1.2 Number of tillers hill^{-1}

The total number of tillers per hill under each treatment was recorded at each growth stages of crop *viz* tillering, panicle initiation, flowering and harvesting stage. The values recorded are given in table 4.

In the tillering stage, application of FYM and NPK fertilizers along with soil application of Zn at the rate of 20 Kg ha^{-1} significantly increased the number of tillers per hill. The highest number of tillers (14.7) was recorded in T_6 which was on par with T_8 while T_4 (Organic POP + soil application of Zn + double foliar application of Zn) recorded the minimum number of tillers (9.5) which was on par with control.

At the panicle initiation stage, no significant difference was observed among the treatments. T_8 was superior and recorded the maximum number of tillers (18.66).

In the flowering stage, the treatment with the maximum number of tillers per hill (18.03) is T_8 and the treatment with the minimum number of tillers (14.01) is T_{10}.

At the harvesting stage, there were significant differences among the treatments. The treatment T_8 where the fertilizers were given according to POP KAU and Zn applied as soil application and foliar application at three growth stages *viz* tillering, panicle initiation, flowering and harvesting stage was superior over other treatments recording maximum number of tillers (15.56) followed by T_7. Treatment T_{10} recorded the least number tillers per hill (13.00).

Table 3: Effect of different treatments on plant height (cm) at different growth stages of rice

Treatments	At tillering	At panicle Initiation	At flowering	At harvest
T_1 - Organic POP + soil application of Zn	42.52^{d}	60.95^{cd}	90.54^{f}	92.68^{de}
T_2 - POP(KAU-2016) + soil application of Zn	45.08^{bc}	63.19^{bc}	90.52^{f}	93.71^{cde}
T_3 - T1+ single foliar application of Zn	41.54^{d}	61.23^{cd}	93.78^{cd}	95.92^{bc}
T_4 - T_1+ double foliar application of Zn	45.10^{bc}	60.66^{d}	92.26^{e}	95.84^{bcd}
T_5 - T1+ triple foliar application of Zn	43.49^{cd}	59.94^{d}	92.84^{de}	96.99^{ab}
T_6 - T_2+ single foliar application of Zn	46.13^{b}	63.75^{b}	95.04^{b}	98.51^{ab}
T_7 - T_2+ double foliar application of Zn	46.94^{ab}	64.08^{b}	97.28^{a}	99.76^{a}
T_8 - T_2+ triple foliar application of Zn	46.55^{ab}	65.51^{ab}	96.53^{a}	99.91^{a}
T_9 - Application of zinc in nursery	48.72^{a}	67.07^{a}	94.92^{bc}	95.44^{bcde}
T_{10}- Control	41.39^{d}	59.72^{d}	90.81^{f}	92.33^{e}
SEm ±	**0.78**	**0.79**	**0.41**	**1.08**
CD (0.05)	**2.35**	**2.37**	**1.23**	**3.24**

57

Table 4: Effect of different treatments on the number of tillers hill^{-1} at different growth stages of rice

Treatments	At tillering	At panicle Initiation	At flowering	At harvest
T_1 - Organic POP + soil application of Zn	11.00 ^{c}	15.16	14.41 ^{b}	13.11 ^{ef}
T_2 - POP(KAU-2016) + soil application of Zn	12.33 ^{b}	15.92	14.46 ^{b}	13.61 ^{de}
T_3 - T1+ single foliar application of Zn	10.30 ^{c}	15.51	14.11 ^{b}	13.99 ^{bcd}
T_4 - T_1+ double foliar application of Zn	9.50 ^{d}	15.23	14.33 ^{b}	14.08 ^{bcd}
T_5 - T1+ triple foliar application of Zn	12.53 ^{b}	17.71	16.26 ^{b}	14.33 ^{bc}
T_6 - T_2+ single foliar application of Zn	14.70 ^{a}	18.08	17.18 ^{a}	14.41 ^{b}
T_7 - T_2+ double foliar application of Zn	13.16 ^{b}	17.96	17.66 ^{a}	14.57 ^{b}
T_8 - T_2+ triple foliar application of Zn	14.50 ^{a}	18.66	18.03 ^{a}	15.56 ^{a}
T_9 - Application of zinc in nursery	11.13 ^{c}	17.47	16.33 ^{b}	13.78 ^{cd}
T_{10}- Control	9.70 ^{d}	15.46	14.01 ^{b}	13.00 ^{f}
SEm ±	**0.37**	**0.23**	**0.37**	**0.20**
CD (0.05)	**1.11**	**NS**	**1.10**	**0.59**

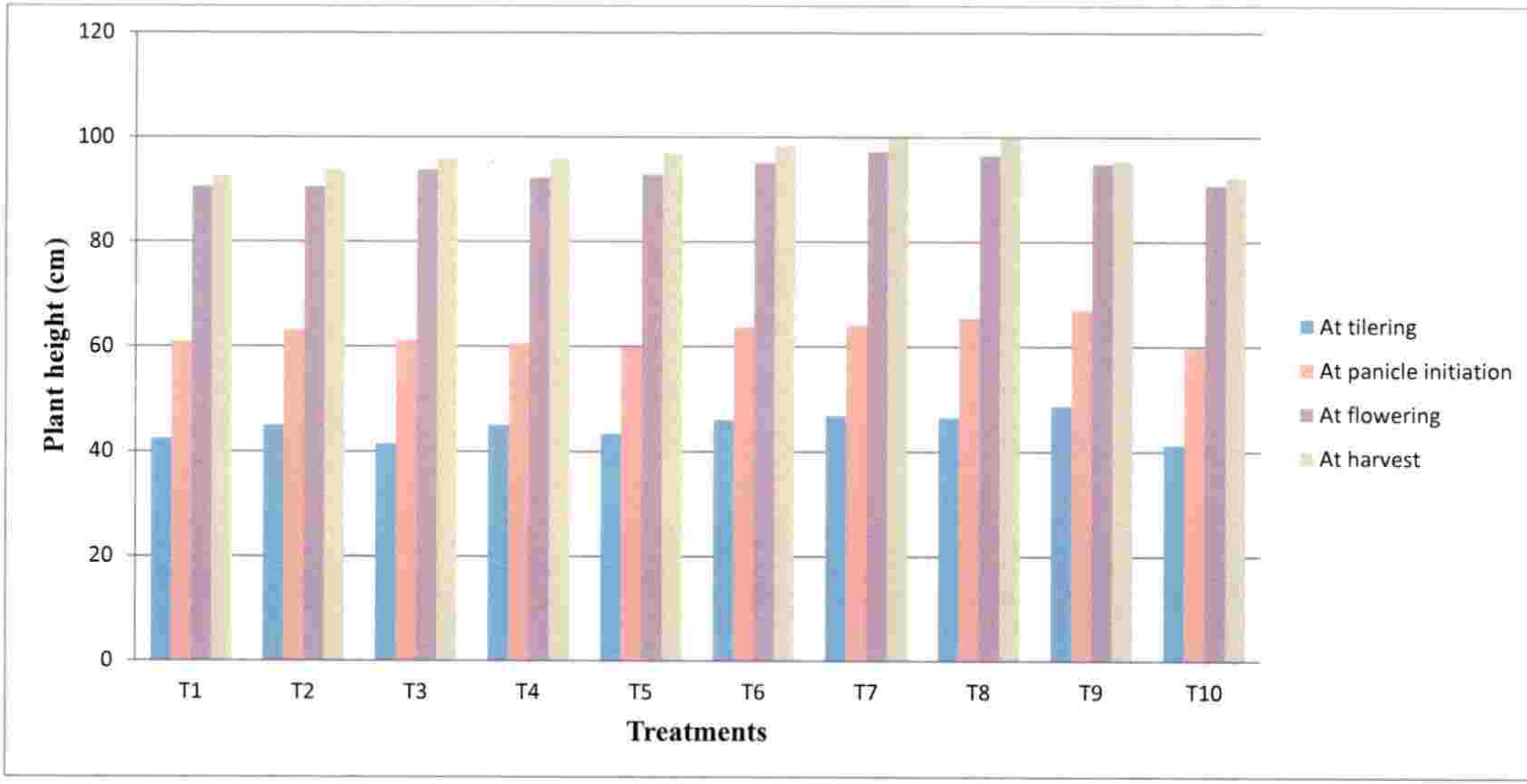


Fig 2: Effect of different treatments on plant height (cm) at different growth stages of rice

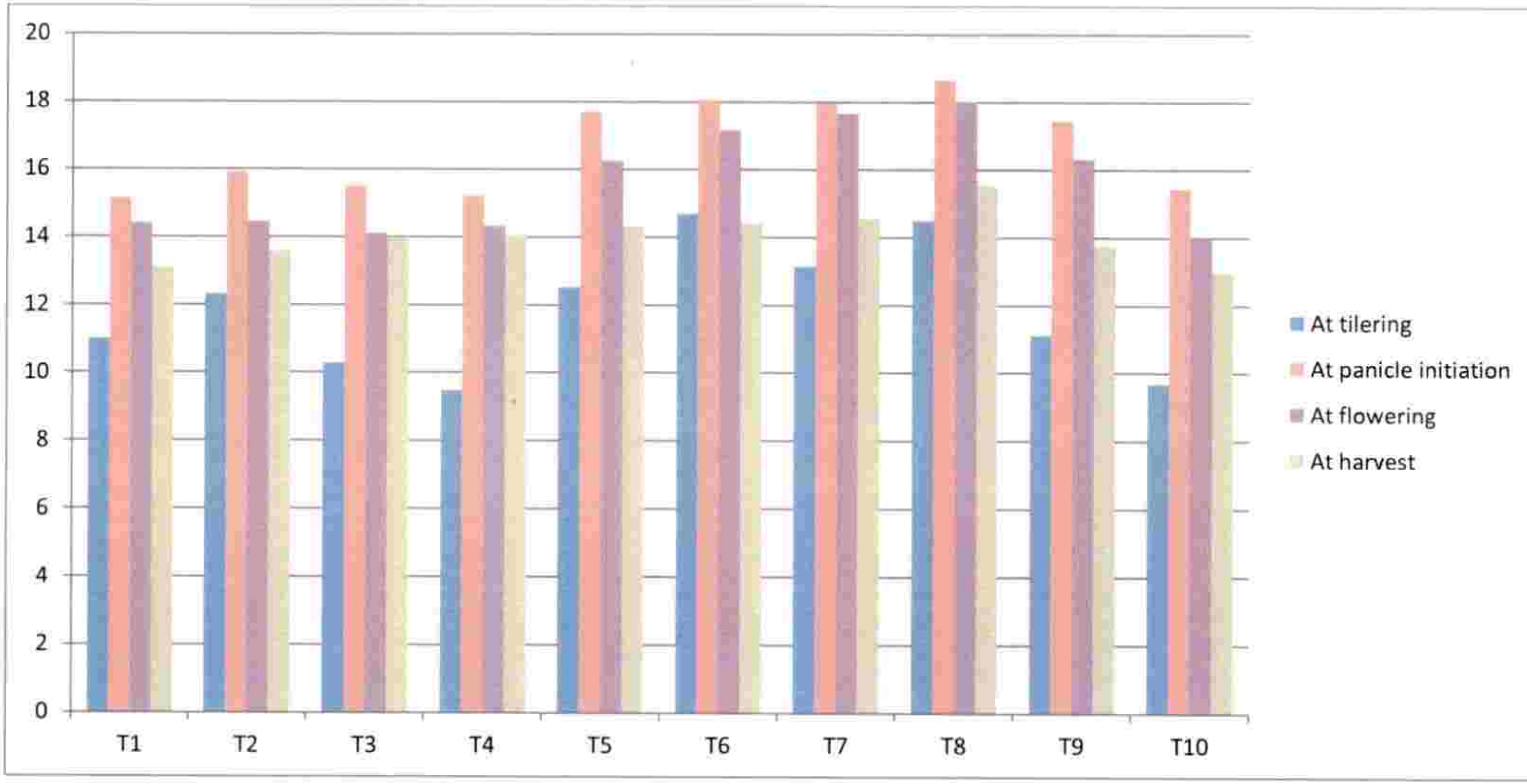


Fig 3: Effect of different treatments on the number of tillers hill^{-1} at different growth stages of rice

4.1.3 Number of panicles hill^{-1}

The mean of the total number of panicles per hill was recorded and presented in table 5. Application of Zn showed significantly influenced the number of panicles hill^{-1}. Among the treatments, T_8 (15.56) was superior compared to other treatments. Treatment T_{10} (13.00) recorded the minimum number of tillers.

4.1.4 Total grains panicle^{-1}

The mean of total grains per panicle was recorded and given in table 5. A significant difference was observed among the treatments. Treatment T_8 recorded the maximum grains per panicle (111.16) and it was superior compared to the other treatment which was followed by T_7 which was on par with T_4, T_5, and T_6. The lowest number of grains per panicle (84.82) was recorded in T_{10}.

4.1.5 Grain yield (t ha^{-1})

The data related to grain yield of rice as influenced by various treatments are presented in Table 5.

The maximum grain yield was obtained in treatment T_8 (6.79 t ha^{-1}) which was significantly superior over the other treatments followed by T_7 which was on par with T_6. The lowest grain yield was obtained in control treatment T_{10} (3.96 t ha^{-1}).

4.1.6 Straw yield (t ha^{-1})

At the harvesting stage, the straw yield obtained from each plot under the effect of different treatments was recorded in table 5.

A significant difference was observed among the treatments, treatment T_8 (6.55 t ha^{-1}) recorded the highest straw yield followed by treatments T_7. Lowest straw yield (3.45 t ha^{-1}) was recorded in treatment T_{10}.

4.1.7 Chaffiness (%)

The effects of different treatments on chaffiness were recorded and given in table 5.

Treatment T_3 recorded the highest chaffiness (15.12 %) which was on par with treatments T_1, T_2, T_5, T_3 and T_{10}. Soil and foliar application of Zn under INM practices resulted in a better quality grain and hence recorded lower chaffy grains. The treatment with the lowest chaffiness is observed in treatment T_6 (12.32 %).

4.1.8 1000 Grain weight

The data pertaining to the test weight or 1000 grain weight was recorded and given in table 5.

The effect of different treatments significantly influenced the test weight of grains. Treatment T_7 (27.10 g) recorded the highest test weight which was on par with treatments T_6 and T_8. Lowest test weight was recorded in treatment T_1 (25.97 g).

4.2 SOIL NUTRIENT ANALYSIS

4.2.1 Initial soil properties

Initial soil samples were collected from the site prepared for the field experiment analyzed for various physicochemical properties of the soil. The soil samples were collected from 10 different areas of the experimental field at a depth of 0-15 cm. The soil physicochemical properties analyzed include pH, EC, organic carbon, particle size, CEC and available content of major nutrients, secondary nutrients and micronutrients following standard procedures and presented in table 6.

Table 5: Effect of different treatments on the number of panicles hill^{-1}, number of grains panicle^{-1}, grain yield, straw yield chaffiness and test weight of grain

Treatments	No of panicles hill^{-1}	Total grains panicle^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Chaffiness (%)	Test weight (g)
T_1 - Organic POP + soil application of Zn	13.11 ^{ef}	87.96 ^{d}	4.26 ^{f}	3.56 ^{e}	15.04 ^{ab}	25.97 ^{e}
T_2 - POP(KAU-2016) + soil application of Zn	13.61 ^{de}	95.06 ^{c}	5.24 ^{e}	5.33 ^{cd}	14.34 ^{abc}	26.28 ^{cde}
T_3 - T1+ single foliar application of Zn	13.99 ^{bcd}	93.94 ^{c}	5.08 ^{e}	4.97 ^{d}	15.12 ^{a}	26.35 ^{bcde}
T_4 - T_1+ double foliar application of Zn	14.08 ^{bcd}	96.48 ^{bc}	5.42 ^{de}	5.48 ^{c}	13.92 ^{abcd}	26.47 ^{bcd}
T_5 - T1+ triple foliar application of Zn	14.33 ^{bc}	97.25 ^{bc}	5.42 ^{de}	5.55 ^{c}	14.55 ^{abc}	26.54 ^{bc}
T_6 - T_2+ single foliar application of Zn	14.41 ^{b}	96.91 ^{bc}	6.49 ^{ab}	5.63 ^{bc}	12.32 ^{d}	26.72 ^{ab}
T_7 - T_2+ double foliar application of Zn	14.57 ^{b}	101.54 ^{b}	6.14 ^{bc}	6.03 ^{b}	12.33 ^{d}	27.10 ^{a}
T_8 - T_2+ triple foliar application of Zn	15.56 ^{a}	111.16 ^{a}	6.79 ^{a}	6.55 ^{a}	12.97 ^{cd}	26.98 ^{a}
T_9 - Application of zinc in nursery	13.78 ^{cd}	94.51 ^{c}	5.70 ^{cd}	5.38 ^{cd}	13.15 ^{bcd}	26.56 ^{bc}
T_{10}- Control	13.00 ^{f}	84.82 ^{d}	3.96 ^{f}	3.45 ^{e}	14.91 ^{abc}	26.09 ^{de}
SEm ±	**0.20**	**1.82**	**0.15**	**0.16**	**0.65**	**0.13**
CD (0.05)	**0.59**	**5.46**	**0.44**	**0.47**	**1.96**	**0.38**

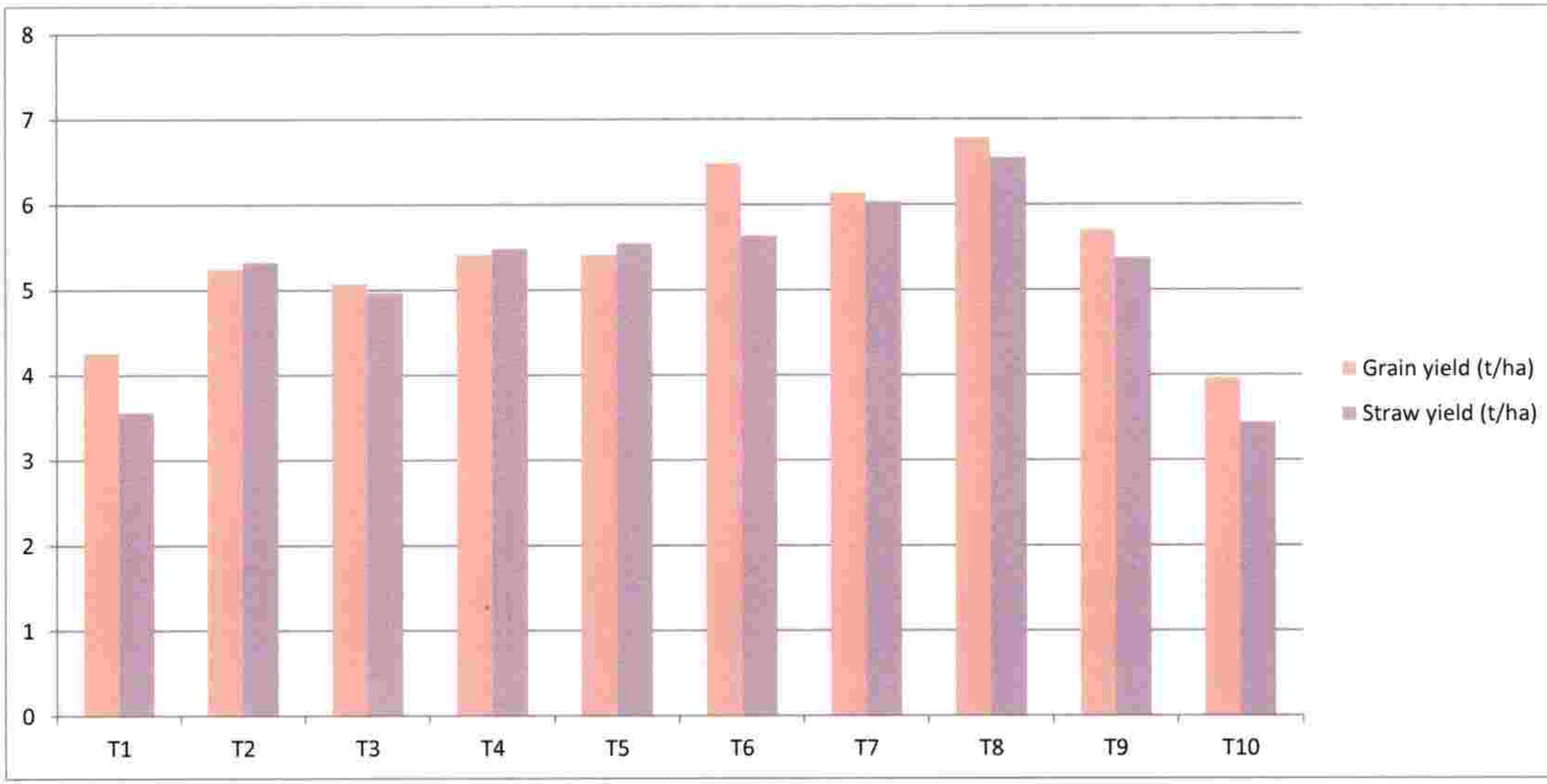


Fig 4: Effect of different treatments on grain yield and straw yield (t ha^{-1})

The soil pH was 4.26 which are categorized as strongly acidic with an electrical conductivity of 0.18 dSm^{-1}. The soil textural class is sandy clay loam and the textural composition is provided in table 6. The organic carbon content of the soil was found to be about 1.18%. With respect to the available major nutrients, secondary nutrients and micronutrients the values are given in table 6.

4.2.2 Soil analysis at 30 days after transplanting and harvest

After 25 days of sowing, transplanting was done at a spacing of 20 x 15 cm. Soil samples were at 30 DAT and at harvest to study the effects of different treatments on various physical properties like pH, EC and particle size and chemical properties like CEC, availability of major nutrients, secondary nutrients, and micronutrients. The analytical results are tabulated and analyzed according to standard statistical techniques.

4.2.2.1 Soil pH

Effects of different treatments on the pH of soil at 30 DAT and at harvest were analyzed and tabulated in table 7.

At 30 DAT, there was a gradual increase in the soil pH in all the treatments after submergence. The treatments with the highest pH (5.04) were T_1 and T_4 which was on par with T_3 and T_5. The lowest pH (4.85) was treatment T_6 and one salient observation is that the treatments with organic practices (T_1, T_3, T_4 and T_5) recorded higher pH as compared to treatments under INM practices (T_2, T_6, T_7 and T_8).

Similarly, at harvest, there was a significant difference observed in soil pH. After harvest, the soil pH decline in all the treatments. The treatment T_5 recorded the highest pH (3.91). The treatment T_7 recorded the lowest pH (3.56) among the treatments.

4.2.2.2 Electrical conductivity

The electrical conductivity of the soil collected from each plot was analyzed to study the effects of different treatments and the data are given in table 7.

Table 6: Initial properties of soil

Sl. No	Parameters	Constituent
	Mechanical composition	
1	Coarse sand (%)	27.4
2	Fine sand (%)	27.2
3	Silt (%)	22.8
4	Clay (%)	22.6
	Textural class	Sandy clay loam
	Chemical composition	
5	pH	4.26
6	EC (dSm^{-1})	0.18
7	Organic C (%)	1.18
8	CEC (meq/100g soil)	4.12
9	Available Nitrogen (kg ha^{-1})	198.24
10	Available Phosphorus (P_2O_5) (kg ha^{-1})	22.63
11	Available Potassium (K_2O) (kg ha^{-1})	150.64
12	Calcium (mg kg^{-1})	152.34
13	Magnesium (mg kg^{-1})	36.42
14	Sulphur (mg kg^{-1})	4.61
15	Iron (mg kg^{-1})	120.61
16	Zinc (mg kg^{-1})	2.12
17	Copper (mg kg^{-1})	1.93
18	Manganese (mg kg^{-1})	5.02
19	Boron (mg kg^{-1})	0.26
20	Silicon (mg kg^{-1})	24.32

At 30 DAT, the EC of soil was significantly influenced by the application of fertilizers. Treatment T_6 (POP KAU+ soil application of Zn + single spray of Zn) recorded the highest EC (0.173 dSm^{-1}) which was on par with T_7 and T_8. Control treatment T_{10} recorded the lowest EC (0.137 dSm^{-1}) among the treatments.

At harvest, there was no significant difference among the treatments and a decline of EC was observed in all the treatments. The EC of soil after harvest ranged from 0.074 dSm^{-1} (T_9) to 0.085 dSm^{-1} (T_1).

4.2.2.3 Organic carbon content

Collected soil samples were analyzed to record the effects of different treatments on the organic carbon content of the soil. The values obtained are tabulated in table 7.

At 30 DAT application of FYM significantly influenced the organic carbon (O.C) content in soil both under organic and INM cultural practices. T_4 recorded the highest OC (1.18 %) content followed by treatment T_8 (1.09 %) while control treatment T_{10} recorded the lowest OC (0.84 %).

At harvest, the organic carbon content in soil was less compared to OC content at 30 DAT. Treatment T_2 (1.04 %) recorded significantly higher OC compared to the other treatments which were on par with T_8, T_4, T_9, T_7, T_6 and T_3. Treatment T_{10} (0.64 %) recorded the least organic carbon content.

4.2.2.4 Cation exchange capacity

The cation exchange capacity of soil at 30 DAT and at harvest was analyzed and the values are given in table 8.

During submergence at 30 DAT, there was an increase in the CEC of soil compared to the initial CEC of soil. Application of FYM and chemical fertilizers as per POP KAU along with soil application of Zn significantly influenced the CEC of soil. Treatment T_2 recorded the highest CEC of 7.97 meq/100g followed by treatment T_7 which was on par with T_8, T_6, T_5 and T_1. The lowest CEC was recorded in treatment T_{10} (6.63 meq/100g).

At harvest, a general reduction in the CEC of soil was observed in all the treatments. A significant difference was observed among the treatments and the treatment T_3 (5.06 meq/100g) recorded the highest CEC at harvest (Organic POP + soil application of Zn along with a single spray of Zn) which was on par with T_4, T_2 and T_7. The treatment that recorded the lowest CEC was treatment T_{10} (4.94 meq/100g).

4.2.2.5 Particle size analysis

The collected soil samples at 30 DAT and at harvest were analyzed for determining the particle size class of soil and the values obtained are given in table 9.

The effects of different treatments had no significant effects on the particle size of sand, silt and clay of soil both at 30 DAT and at harvest.

4.2.2.6 Available nitrogen in the soil

The effects of different treatments on the available N in soil collected at 30 DAT and at harvest were evaluated and recorded in table 10.

At 30 DAT application of FYM and fertilizers as per KAU POP along with soil application of Zn had a significant influence on soil available N. The available N in soil was significantly higher in treatments (T_2, T_6, T_7 and T_8) under INM practices. Highest available N was recorded in treatment T_2 (305.23 Kg ha^{-1}) followed by treatment T_7. Control treatment recorded the lowest (146.33 Kg ha^{-1}) available N content in the soil.

Table 7: Effect of different treatments on pH, electrical conductivity and organic carbon content of the soil at 30 DAT and harvest

Treatments	PH		Electric conductivity(dS m^{-1})		Organic carbon (%)	
	30 DAT	Harvest	30 DAT	Harvest	30 DAT	Harvest
T_1 - Organic POP + soil application of Zn	5.04^{a}	3.73^{b}	0.14^{b}	0.08	0.98^{de}	0.77^{bcd}
T_2 - POP(KAU-2016) + soil application of Zn	4.88^{c}	3.84^{ab}	0.15^{b}	0.07	1.04^{bcde}	1.04^{a}
T_3 - T1+ single foliar application of Zn	5.03^{a}	3.85^{ab}	0.14^{b}	0.08	0.97^{e}	0.90^{abc}
T_4 - T_1+ double foliar application of Zn	5.04^{a}	3.79^{ab}	0.15^{b}	0.07	1.18^{a}	1.03^{a}
T_5 - T1+ triple foliar application of Zn	5.00^{ab}	3.91^{a}	0.15^{b}	0.08	1.03^{bcde}	0.74^{cd}
T_6 - T_2+ single foliar application of Zn	4.85^{c}	3.87^{b}	0.17^{a}	0.08	1.00^{cde}	0.91^{abc}
T_7 - T_2+ double foliar application of Zn	4.88^{c}	3.56^{c}	0.16^{a}	0.07	1.05^{bc}	0.93^{abc}
T_8 - T_2+ triple foliar application of Zn	4.93^{bc}	3.84^{ab}	0.17^{a}	0.08	1.09^{b}	1.03^{a}
T_9 - Application of zinc in nursery	4.90^{c}	3.76^{b}	0.15^{b}	0.07	1.05^{bcd}	1.01^{ab}
T_{10}- Control	4.89^{c}	3.78^{ab}	0.13^{c}	0.08	0.84^{f}	0.64^{d}
SEm ±	**0.03**	**0.05**	**0.00**	**0.01**	**0.02**	**0.08**
CD (0.05)	**0.08**	**0.15**	**0.01**	**NS**	**0.07**	**0.25**

69

Table 8: Effect of different treatments on the cation exchange capacity of soil at 30 DAT and harvest (meq/100g)

Treatment	At 30 DAT	At harvest
T_1 - Organic POP + soil application of Zn	7.23 ^{bc}	5.021 ^{c}
T_2 - POP(KAU-2016) + soil application of Zn	7.97 ^{a}	5.036 ^{abc}
T_3 - T1+ single foliar application of Zn	7.05 ^{cd}	5.067 ^{a}
T_4 - T_1+ double foliar application of Zn	7.04 ^{cd}	5.050 ^{ab}
T_5 - T1+ triple foliar application of Zn	7.24 ^{bc}	5.038 ^{bc}
T_6 - T_2+ single foliar application of Zn	7.35 ^{b}	5.010 ^{c}
T_7 - T_2+ double foliar application of Zn	7.39 ^{b}	5.033 ^{abc}
T_8 - T_2+ triple foliar application of Zn	7.36 ^{b}	5.022 ^{bc}
T_9 - Application of zinc in nursery	6.86 ^{d}	5.021 ^{c}
T_{10}- Control	6.63 ^{e}	4.945 ^{d}
SEm ±	**0.09**	**0.01**
CD (0.05)	**0.27**	**0.032**

Table 9: Effect of different treatments on the particle size of soil at 30 DAT and harvest (%)

Treatments	At 30 DAT				At harvest			
	Coarse sand	Fine Sand	Silt	Clay	Coarse sand	Fine Sand	Silt	Clay
T_1 - Organic POP + soil application of Zn	25.22	29.78	23.25	21.743	25.220	29.78	23.65	21.34
T_2 - POP(KAU-2016) + soil application of Zn	25.97	29.02	22.91	22.08	25.97	29.02	23.25	21.75
T3 - T1+ single foliar application of Zn	26.40	28.58	24.17	20.82	26.42	28.58	24.17	20.82
T_4 - T_1+ double foliar application of Zn	26.78	28.21	23.96	21.03	26.78	28.21	24.38	20.61
T_5 - T1+ triple foliar application of Zn	25.96	29.05	23.45	21.54	25.94	29.05	23.09	21.91
T_6 - T_2+ single foliar application of Zn	26.16	28.83	23.92	21.08	26.23	28.76	23.53	20.90
T_7 - T_2+ double foliar application of Zn	26.86	28.11	24.00	21.38	26.88	28.11	24.46	20.92
T_8 - T_2+ triple foliar application of Zn	25.43	29.52	23.76	21.24	25.98	29.01	23.35	21.65
T_9 - Application of zinc in nursery	25.83	29.16	22.98	22.01	26.45	28.54	23.39	21.61
T_{10}- Control	26.81	28.18	23.19	21.80	25.83	29.16	23.26	21.74
SEm ±	**0.60**	**0.62**	**0.40**	**0.40**	**0.61**	**0.59**	**0.47**	**0.48**
CD (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

71

Similarly at harvest significant difference was observed among the treatments. The treatments under INM practices recorded higher N content in soil compared to other treatments. Highest available N in soil was recorded by T_7 (255.20 Kg ha^{-1}) which was on par with T_8 and T_6. The treatment that recorded the lowest available N content was observed in treatment T_{10} (209.06 Kg ha^{-1}).

4.2.2.7 Available phosphorus in soil

The effects of different treatments on the soil available P was analyzed at 30 DAT and at harvest and the values are presented in table 10.

During submergence at 30 DAT soil available P was high in all the treatments with treatment T_7 (POP KAU + soil application of Zn + double foliar application of Zn) recording highest P (44.36 Kg ha^{-1}) which was statistically on par with T_8 (41.44 Kg ha^{-1}) and significantly higher than other treatments. The treatment with the lowest available P in soil was observed in T_{10} (31.39 Kg ha^{-1}).

However, at harvest different treatments showed no significant difference in the content of soil available P. In general, there is a decline in the value of available P in all the treatments. The soil available P ranged from 8.81 Kg ha^{-1} (T_{10}) to 11.50 Kg ha^{-1} (T_7).

4.2.2.8 Available potassium in soil

Available soil potassium was estimated from soil samples collected at 30 DAT and at harvest and the values are given in table 10.

At 30 DAT the available K in almost all treatments were medium (110-280 Kg ha^{-1}) except for treatment T_2 (POP KAU + soil application of Zn) which recorded the highest available K (248.69 Kg ha^{-1}) in soil and was superior over all other treatments. The lowest soil available K (160.19 Kg ha^{-1}) was observed in control.

After harvesting the soil available K was low (<110 Kg ha^{-1}) in all the treatment. Treatment T_8 (174.12 Kg ha^{-1}) recorded the highest soil available K which was on par with all the treatments except with T_9, T_5, T_1 and T_{10}.

4.2.2.9 Available calcium in the soil

The collected soil samples both at 30 DAT and at harvest were analyzed for available calcium and the values recorded are given in table 11.

During submergence at 30 DAT, a significant difference was observed among the treatment. T_1 (273.33 mg Kg^{-1}) recorded the highest available calcium which was on par with treatments T_5, T_2, and T_7. Lowest available calcium was recorded in treatment T_{10} (193.33 mg Kg^{-1}).

After harvest available Ca in the soil was significantly different among treatments. Highest available calcium was recorded in treatment T_9 (148.66 mg Kg^{-1}) which was on par with all other treatments except treatment T_{10}.

4.2.2.10 Available magnesium in the soil

The effects of different treatments on the available magnesium in soil were evaluated and the values recorded are given in table 11.

The treatments showed no significant difference in the available magnesium in the soil at 30 DAT. The available magnesium in soil ranged from 39.33 mg Kg^{-1} (T_1) to 41.73 mg Kg^{-1} (T_8).

After harvest, no significant difference was observed among the treatments in the available magnesium in the soil. Highest available magnesium content was observed in treatment T_6 (40.73 mg Kg^{-1}). Treatment T_4 recorded the lowest value of 37.03 mg Kg^{-1}.

Table10: Effect of different treatments on available nitrogen, phosphorus and potassium in the soil at 30DAT and harvest (Kg ha^{-1})

Treatments	Nitrogen		Phosphorus		Potassium	
	30 DAT	Harvest	30 DAT	Harvest	30 DAT	Harvest
T_1 - Organic POP + soil application of Zn	156.80^{de}	217.74^{cd}	32.10^{bc}	9.76	174.49^{de}	140.38^{b}
T_2 - POP(KAU-2016) + soil application of Zn	305.23^{a}	220.32^{bcd}	31.93^{c}	10.733	248.69^{a}	172.64^{a}
T_3 - T1+ single foliar application of Zn	186.06^{cd}	213.77^{d}	34.57^{bc}	10.443	207.23^{bc}	170.24^{ab}
T_4 - T_1+ double foliar application of Zn	250.79^{c}	234.40^{bc}	38.08^{bc}	10.533	198.61^{cd}	170.86^{ab}
T_5 - T1+ triple foliar application of Zn	171.43^{de}	221.48^{bcd}	32.40^{bc}	10.070	175.09^{de}	143.06^{b}
T_6 - T_2+ single foliar application of Zn	250.88^{b}	236.74^{ab}	38.82^{bc}	11.033	214.29^{bc}	173.40^{a}
T_7 - T_2+ double foliar application of Zn	269.69^{b}	255.20^{a}	44.36^{a}	11.506	232.06^{b}	172.87^{a}
T_8 - T_2+ triple foliar application of Zn	252.97^{b}	253.26^{a}	41.44^{ab}	10.400	212.80^{bc}	174.12^{a}
T_9 - Application of zinc in nursery	146.34^{e}	222.23^{bcd}	31.95	10.300	169.10^{e}	148.27^{b}
T_{10}- Control	146.33^{e}	209.06^{d}	31.39^{c}	8.816	160.19^{e}	133.86^{c}
SEm ±	**10.19**	**6.25**	**3.15**	**0.94**	**9.46**	**1.32**
CD (0.05)	**30.58**	**18.74**	**9.46**	**NS**	**28.37**	**3.97**

4.2.2.11 Available sulphur in soil

At 30 DAT and at harvest, soil samples were collected to analyze the effects of the different treatments on the available sulphur content in the soil. The values were recorded and given in table 11.

Soil application of $ZnSO_4$ at the rate of 25 Kg ha^{-1} significantly resulted in an increase in the S content of the soil at 30 DAT as compared to treatments where soil application of $ZnSO_4$ was not done. Treatment T_6 (POP KAU + soil application of Zn + single foliar application of Zn) recorded the highest available sulphur (7.26 mg Kg^{-1}) in the soil which was on par with all other treatments except treatments T_9 and T_{10} (Control).

However, after cultivation treatments made no significant difference in soil available S. The available sulphur in soil ranged from 3.60 mg Kg^{-1}(T_1) to 5.8 mg Kg^{-1} (T_7).

4.2.2.12 Available iron in the soil

The effects of different treatments on available iron in soil were evaluated from soil samples collected at 30 DAT and at harvest and the data recorded are given in table 12.

During submergence at 30 DAT, the concentration of soil available iron (Fe^{2+}) was high. The effect of treatments showed no significant difference in the concentration of soil available iron. The treatment that recorded the highest value of soil available (298.93 mg Kg^{-1}) iron is treatment T_9 (application of Zn at nursery) followed by T_{10} while the lowest soil available iron was recorded in treatment T_7 (250.50 mg Kg^{-1}).

After harvest soil available Fe was observed to be decreased in soil. The treatments showed significant difference with treatment T_3 (175.00 mg Kg^{-1}) recording the highest value which was on par with T_5, T_9 and T_4. Treatment T_2 (167.33 mg Kg^{-1}) recorded the lowest value.

Table 11: Effect of different treatments on available calcium, magnesium and sulphur in the soil at 30 DAT and harvest (mg Kg^{-1})

Treatments	Calcium		Magnesium		Sulphur	
	30 DAS	Harvest	30 DAS	Harvest	30 DAS	Harvest
T_1 - Organic POP + soil application of Zn	273.33^{a}	144.33^{a}	39.33	37.33	7.250^{a}	3.60
T_2 - POP(KAU-2016) + soil application of Zn	250.00^{ab}	145.00^{a}	40.33	39.33	7.220^{a}	5.36
T_3 - T1+ single foliar application of Zn	216.67^{cd}	144.33^{a}	41.50	37.50	7.256^{a}	5.03
T_4 - T_1+ double foliar application of Zn	216.66^{cd}	140.00^{a}	41.03	37.03	7.246^{a}	5.50
T_5 - T1+ triple foliar application of Zn	253.33^{ab}	141.33^{a}	40.33	38.33	7.256^{a}	5.38
T_6 - T_2+ single foliar application of Zn	206.66^{d}	144.00^{a}	41.33	40.73	7.266^{a}	5.33
T_7 - T_2+ double foliar application of Zn	250.00^{ab}	145.67^{a}	41.00	40.00	7.260^{a}	5.80
T_8 - T_2+ triple foliar application of Zn	240.00^{bc}	144.66^{a}	41.73	39.73	7.203^{a}	5.30
T_9 - Application of zinc in nursery	210.00^{d}	148.66^{a}	39.66	38.66	7.100^{b}	5.20
T_{10}- Control	193.33^{d}	137.00^{b}	40.33	38.33	7.003^{c}	5.23
SEm ±	**1.71**	**1.63**	**0.86**	**1.3**	**0.03**	**0.8**
CD (0.05)	**5.14**	**4.88**	**NS**	**NS**	**0.089**	**NS**

4.2.2.13 Available zinc in soil

Similarly, for available zinc, soil samples collected at 30 DAT and harvest were evaluated and the values are recorded and given in table 12.

At 30 DAT the treatment that recorded the highest available Zn in soil was treatment T_8 (4.96 mg Kg) which was on par with T_6, T_4, T_7, T_5 and T_3 while T_9 (3.513 mg Kg^{-1}) recorded the lowest soil available Zn.

At harvest Zn content in soil was lower in treatments under INM practices as compared to other treatments. The soil available Zn was highest in treatment T_4 (3.26 mg Kg^{-1}) which was on par with T_3. The treatment that recorded the lowest soil available Zn was treatment T_7 (2.50 mg Kg^{-1}) which was on par with T_2 and T_8.

4.2.2.14 Available copper in soil

The soil samples collected at 30 DAT and at harvest were analyzed for available copper in the soil. The values are given in table 12.

At 30 DAT available Cu was significantly different among the treatments with highest available copper in treatment T_7 (1.66 mg Kg^{-1}) which was on par with T_1, T_8, T_6, T_3, T_4, and T_5. Control treatment recorded the lowest available copper (1.23 mg Kg^{-1}) in soil.

After harvest, there was a significant difference in copper in the soil among the treatments. The treatment that recorded the highest available copper in soil was treatment T_2 (2.61 mg Kg^{-1}) which was on par with T_6 and T_5. Treatment T_9 (1.29 mg Kg^{-1}) recorded the lowest soil, available copper.

4.2.2.15 Available manganese in soil

In the table, the content of available manganese in soil recorded at 30 DAT and at harvest are given 13.

At 30 DAT the content of soil available Mn was relatively higher as compared to the initial Mn status in soil. Application of FYM in treatments under organic and INM practices resulted in an increase in Mn concentration as compared to treatments T_{10} and T_9 where FYM was not incorporated. Treatment T_2 and T_3 recorded the highest available Mn (14.00 mg Kg^{-1}) in soil. Lowest soil available manganese (11.00 mg Kg^{-1}) was recorded in treatment T_9.

However, at harvest, Mn concentration in soil decreased to a certain extent. There was no significant difference among the treatments and the soil available manganese ranged from 8.03 mg Kg^{-1} (T_7) to 8.90 mg Kg^{-1} (T_4).

4.2.2.16 Available boron in the soil

The effect of different treatments on soil available boron in soil samples collected at 30 DAT and at harvest was evaluated and the values are given in table 13.

At 30 DAT the effect of different treatments had no significant difference in the concentration of available B in soil. The concentration of the available soil B ranged from 0.22 mg Kg^{-1} (T_2) to 0.25 mg Kg^{-1}(T_1) which was generally low.

At harvest, a significant difference was observed among the treatments and treatment T_1 (0.23 mg Kg^{-1}) recorded the highest soil available boron followed by T_5. The treatment that recorded the lowest soil available boron was treatment T_6 (0.17 mg Kg^{-1}).

4.2.2.17 Available silicon in the soil

The collected soil samples at 30 DAT and at harvest were analyzed for soil available silicon to study the effects of different treatments. The values were given in table 13.

Table 12: Effect of different treatments on soil available iron, zinc, and copper at 30 DAT and at harvest (mg Kg^{-1})

Treatments	Iron		Zinc		Copper	
	30 DAT	Harvest	30 DAT	Harvest	30 DAT	Harvest
T_1 - Organic POP + soil application of Zn	254.56	170.66^{cd}	3.76^{c}	3.03^{cd}	1.63^{ab}	2.32^{abc}
T_2 - POP(KAU-2016) + soil application of Zn	255.66	167.33^{e}	4.29^{b}	2.733^{e}	1.33^{cd}	2.61^{a}
T_3 - T1+ single foliar application of Zn	258.93	175.00^{a}	4.56^{ab}	3.23^{a}	1.56^{abc}	2.14^{c}
T_4 - T_1+ double foliar application of Zn	251.96	173.33^{ab}	4.86^{ab}	3.26^{a}	1.53^{abc}	2.17^{bc}
T_5 - T1+ triple foliar application of Zn	257.56	174.00^{a}	4.66^{ab}	3.60^{b}	1.43^{abcd}	2.14^{ab}
T_6 - T_2+ single foliar application of Zn	258.33	170.00^{cd}	4.93^{ab}	2.80^{e}	1.60^{ab}	2.51^{ab}
T_7 - T_2+ double foliar application of Zn	250.50	169.00^{de}	4.70^{ab}	2.50^{e}	1.66^{a}	1.99^{c}
T_8 - T_2+ triple foliar application of Zn	255.83	171.66^{bc}	4.96^{a}	2.73^{e}	1.63^{ab}	2.12^{c}
T_9 - Application of zinc in nursery	258.93	174.00^{a}	3.51^{d}	3.14^{d}	1.40^{bcd}	1.29^{d}
T_{10}- Control	257.33	171.66^{bc}	3.75^{c}	3.46^{bc}	1.23^{d}	1.45^{d}
SEm ±	**2.94**	**0.63**	**0.48**	**0.10**	**0.08**	**0.11**
CD (0.05)	**NS**	**1.89**	**1.45**	**0.31**	**0.23**	**0.34**

The effect of treatments on soil available silicon at 30 DAT was observed to be non significant. The soil available Si ranged from 29.78 mg Kg^{-1} to 31.68 mg Kg^{-1}.

The effects of treatments at harvest were observed to be significantly higher in treatment T_3 (22.68 mg Kg^{-1}) which was on par with T_5 and treatment T_6 (17.68 mg Kg^{-1}) recorded the lowest soil available Si.

4.3 NUTRIENT CONTENT IN PLANT

4.3.1 Nitrogen

The nitrogen content in shoots was analyzed at different given growth stages and the values are presented in table 14.

There were significant differences observed among the treatments in the three growth stages of rice *viz* tillering, panicle initiation and harvest stage. At tillering, stage treatment T_7 recorded the highest N content in shoots with a value of 4.01% which was on par with T_6, T_8 and T_2.

Similarly, at panicle initiation stage the treatment that recorded the highest N content in shoots was treatment T_7 (2.54 %) which was on par with T_6 and T_8 while treatment T_{10} recorded the lowest N content (1.03 %).

At harvest treatment T_7 (0.62 %) was superior over all the other treatments. Lowest N content in straw was seen in T_{10} (0.35 %).

4.3.2 Phosphorus

The phosphorus content in shoots was analyzed at different given growth stages and the values are presented in table 15.

Table 13: Effect of different treatments on soil available manganese, boron and silicon at 30 DAT and at harvest (mg Kg^{-1})

Treatments	Manganese		Boron		Silicon	
	30 DAT	Harvest	30 DAT	Harvest	30 DAT	Harvest
T_1 - Organic POP + soil application of Zn	13.00^{ab}	8.47	0.25	0.23^{a}	31.06	20.75^{c}
T_2 - POP(KAU-2016) + soil application of Zn	14.00^{a}	8.76	0.22	0.19^{cd}	30.83	18.57^{d}
T_3 - T1+ single foliar application of Zn	14.00^{a}	8.60	0.23	0.20^{bc}	31.68	22.68^{a}
T_4 - T_1+ double foliar application of Zn	12.80^{ab}	8.90	0.24	0.21^{ab}	30.50	21.06^{bc}
T_5 - T1+ triple foliar application of Zn	12.00^{bc}	8.38	0.23	0.21^{b}	31.46	22.02^{ab}
T_6 - T_2+ single foliar application of Zn	12.00^{bc}	8.43	0.24	0.17^{e}	31.05	17.68^{d}
T_7 - T_2+ double foliar application of Zn	11.33^{bc}	8.03	0.23	0.18^{de}	31.06	17.70^{d}
T_8 - T_2+ triple foliar application of Zn	11.66^{bc}	8.50	0.24	0.19^{cd}	30.80	17.69^{d}
T_9 - Application of zinc in nursery	11.00^{c}	8.19	0.24	0.20^{bcd}	30.37	21.35^{bc}
T_{10}- Control	12.66^{abc}	8.21	0.24	0.19^{cd}	29.78	21.00^{c}
SEm ±	**0.62**	**0.25**	**0.02**	**0.003**	**0.7**	**0.33**
CD (0.05)	**1.87**	**NS**	**NS**	**0.01**	**NS**	**1.00**

Table 14: Effect of different treatments on nitrogen content in shoots in different growth stages of rice (%)

Treatments	Nitrogen		
	At Tillering	At panicle Initiation	At harvest
T_1 - Organic POP + soil application of Zn	2.36 [b]	1.25 [d]	0.39 [e]
T_2 - POP(KAU-2016) + soil application of Zn	3.89 [a]	2.20 [b]	0.51 [c]
T_3 - T1+ single foliar application of Zn	2.24 [b]	1.46 [c]	0.43 [d]
T_4 - T_1+ double foliar application of Zn	2.22 [b]	1.50 [c]	0.41 [e]
T_5 - T1+ triple foliar application of Zn	2.26 [b]	1.54 [c]	0.49 [c]
T_6 - T_2+ single foliar application of Zn	3.98 [a]	2.48 [a]	0.61 [ab]
T_7 - T_2+ double foliar application of Zn	4.01 [a]	2.54 [a]	0.62 [a]
T_8 - T_2+ triple foliar application of Zn	3.94 [a]	2.49 [a]	0.57 [ab]
T_9 - Application of zinc in nursery	2.38 [b]	1.18 [d]	0.40 [e]
T_{10}- Control	1.75 [c]	1.03 [e]	0.35 [f]
SEm ±	**0.05**	**0.04**	**0.007**
CD (0.05)	**0.15**	**0.11**	**0.02**

At tillering stage, treatment T_2 (POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1}) recorded the highest P content in shoots (0.42 %) which was on par with treatment T_8. The treatment that recorded the lowest P content in shoots was treatment T_{10} (0.26 %).

At panicle initiation, treatment T_6 (applying fertilizers and manures as per POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1} + single spray of $ZnSO_4$ at 1%) recorded the highest P content (0.36 %). Lowest P content (0.22 %) in the shoot was recorded in treatment T_4 (applying manures as organic POP + soil application of Zn at the rate of 20 Kg ha^{-1} + triple spray of $ZnSO_4$ at 1%).

At harvest stage P content in straw was significant higher in treatment T_2 (0.26 %) (applying fertilizers as per KAU POP + soil application of Zn at the rate of 20 Kg ha^{-1}) and the lowest content of P in straw (0.19%) was recorded in T_5 (applying manures as per POP (KAU-2016) + soil application of Zn at the rate of 20 Kg ha^{-1} + triple spray of $ZnSO_4$ at 1%)

4.3.3 Potassium

The potassium content in shoots was analyzed at different given growth stages and the values are presented in table 16.

At the tillering stage, T_6 (2.82 %) recorded the highest K content in shoots which was significantly superior over the other treatments followed by T_7 which was on par with T_8 and T_2. The lowest K content in shoots was recorded in treatment T_{10} (2.14 %).

Similarly at panicle initiation T_6 (application of manures and fertilizers as per POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1} + single spray of $ZnSO_4$ at 1%) recorded the highest K content in shoots. The K content in shoots ranged from 1.43 % (T_{10}) to 1.77 %.

Table 15: Effect of different treatments on phosphorus content in shoots in different growth stages of rice (%)

Treatments	Phosphorus		
	At Tillering	At panicle Initiation	At harvest
T_1 - Organic POP + soil application of Zn	0.31 [b]	0.26 [bc]	0.21 [b]
T_2 - POP(KAU-2016) + soil application of Zn	0.42 [a]	0.28 [b]	0.26 [a]
T_3 - T1+ single foliar application of Zn	0.29 [b]	0.24 [cd]	0.24 [a]
T_4 - T_1+ double foliar application of Zn	0.29 [b]	0.22 [d]	0.21 [b]
T_5 - T1+ triple foliar application of Zn	0.29 [b]	0.24 [cd]	0.19 [c]
T_6 - T_2+ single foliar application of Zn	0.28 [b]	0.36 [a]	0.24 [a]
T_7 - T_2+ double foliar application of Zn	0.30 [b]	0.25 [bcd]	0.24 [a]
T_8 - T_2+ triple foliar application of Zn	0.39 [a]	0.26 [bc]	0.21 [b]
T_9 - Application of zinc in nursery	0.29 [b]	0.25 [bcd]	0.21 [b]
T_{10}- Control	0.26 [b]	0.25[bcd]	0.20 [c]
SEm ±	**0.02**	**0.01**	**0.003**
CD (0.05)	**0.06**	**0.03**	**0.01**

Table 16: Effect of different treatments on potassium content in shoots in different growth stages of rice (%)

Treatments	Potassium		
	At Tillering	At panicle Initiation	At harvest
T_1 - Organic POP + soil application of Zn	2.47 ^{c}	1.48 ^{def}	1.547 ^{e}
T_2 - POP(KAU-2016) + soil application of Zn	2.69 ^{b}	1.26 ^{c}	1.93 ^{ab}
T_3 - T1+ single foliar application of Zn	2.46 ^{c}	1.51 ^{de}	1.59 ^{de}
T_4 - T_1+ double foliar application of Zn	2.40 ^{c}	1.47 ^{def}	1.56 ^{e}
T_5 - T1+ triple foliar application of Zn	2.40 ^{c}	1.44 ^{ef}	1.63 ^{d}
T_6 - T_2+ single foliar application of Zn	2.82 ^{a}	1.77 ^{a}	1.92 ^{b}
T_7 - T_2+ double foliar application of Zn	2.75 ^{ab}	1.67 ^{bc}	1.93 ^{ab}
T_8 - T_2+ triple foliar application of Zn	2.71 ^{b}	1.70 ^{ab}	1.99 ^{a}
T_9 - Application of zinc in nursery	2.30 ^{d}	1.54 ^{d}	1.70 ^{c}
T_{10}- Control	2.14 ^{e}	1.43 ^{f}	1.54 ^{e}
SEm ±	**0.03**	**0.023**	**0.02**
CD (0.05)	**0.08**	**0.07**	**0.06**

At harvest highest K content in straw was recorded in treatment T_8 (1.99 %) (application manures and fertilizers as per POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1} + triple spray of $ZnSO_4$ at 1%) which was on par with treatments T_2 and T_7.

4.3.4 Calcium

The plant samples collected at different growth stages were analyzed for Ca content. The values are presented in table 17.

At tillering stage, significant different was recorded in Ca with treatment T_6 (1.10 %) recording the highest Ca content in shoots followed by treatment T_2 (POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1}). The treatment that recorded the lowest Ca content in shoots was T_{10} (0.74 %).

Similarly, at panicle initiation stage significant difference was observed among the treatments with T_6 (Organic POP + soil application of Zn) recording the highest Ca content (1.40 %) followed by treatment T_8. Like in the tillering stage, application of zinc at nursery recorded the lowest Ca content (0.63 %) in shoots.

At harvest, the effect of different treatments on Ca content on straw was seen to be significantly different. Treatment T_6 (applying fertilizers and manures as per POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1} + single spray of $ZnSO_4$ at 1%) recorded the highest Ca content (2.08 %) which was on par with treatment T_7.

4.3.5 Sulphur

The sulphur content in plant samples analyzed at different growth stages was recorded and given in table 18.

At tillering stage, the treatments showed no significant difference in terms of S content in shoots.

Table 17: Effect of different treatments on calcium content in shoots in different growth stages of rice (%)

Treatments	Calcium		
	At Tillering	At panicle Initiation	At harvest
T_1 - Organic POP + soil application of Zn	1.06[bc]	0.90[d]	1.33[cd]
T_2 - POP(KAU-2016) + soil application of Zn	1.01[ab]	1.21[b]	1.67[b]
T_3 - T1+ single foliar application of Zn	0.98[c]	0.96[cd]	1.43[bc]
T_4 - T_1+ double foliar application of Zn	1.04[bc]	0.77[e]	1.20[d]
T_5 - T1+ triple foliar application of Zn	0.96[cd]	0.93[cd]	1.20[d]
T_6 - T_2+ single foliar application of Zn	1.10[a]	1.40[a]	2.08[a]
T_7 - T_2+ double foliar application of Zn	0.93[c]	1.16[bc]	2.01[a]
T_8 - T_2+ triple foliar application of Zn	1.06[bc]	1.28[ab]	1.73[b]
T_9 - Application of zinc in nursery	0.98[c]	0.63[e]	1.46[bcd]
T_{10}- Control	0.74[d]	0.96[cd]	1.41[cd]
SEm (±)	**1.91**	**0.71**	**1.01**
CD (0.05)	**5.74**	**2.13**	**3.04**

The treatment that recorded the highest S content was observed in treatment T_2 (0.52 %) while the lowest S content (0.49 %) was recorded in treatment T_{10}. However, at panicle initiation stage the treatments showed a significant difference in S content in shoots.

Treatment T_7 (0.47 %) recorded the highest S content in shoots (applying fertilizers and manures as per POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1} + double spray of $ZnSO_4$ at 1%) which was on par with T_8, T_6 and T_2. The treatment that recorded the lowest S content in shoots was treatment T_{10} (0.25 %).

Similarly at harvest significant difference was observed among the treatments. T_8 recorded the highest S content (0.11 %) on par with T_7. The lowest S content was recorded in control (0.01 %).

4.3.6 Magnesium

The sulphur content in plant samples analyzed at different growth stages was recorded and given in table 19.

At tillering, stage treatment T_2 (POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1}) recorded the highest Mg content in shoots (0.67 %) which was significantly superior over the other treatments. The treatment that recorded the lowest Mg content in shoots was treatment T_{10} (0.27 %).

Similarly, at panicle initiation stage significant differences were observed among the treatments with treatment T_7(KAU POP + soil application of Zn + double spray of $ZnSO_4$) was significantly superior over the other treatments recording Mg content in shoots of 0.5 % which was on par with T_2 and T_8. Lowest Mg content in the shoots was recorded in treatment T_3 (0.25 %)

At harvest Mg content in straw was seen to be significantly different with treatment T_8 (0.44 %) recording the highest value which was superior over the other treatments followed by treatment T_4.

Table 18: Effect of different treatments on sulphur content in shoots in different growth stages of rice (%)

Treatments	Sulphur		
	At Tillering	At panicle Initiation	At harvest
T_1 - Organic POP + soil application of Zn	0.50	0.30 ^{b}	0.03 ^{ef}
T_2 - POP(KAU-2016) + soil application of Zn	0.52	0.42 ^{a}	0.06 ^{bcd}
T_3 - T1+ single foliar application of Zn	0.51	0.32 ^{b}	0.04 ^{de}
T_4 - T_1+ double foliar application of Zn	0.50	0.32 ^{b}	0.05 ^{cd}
T_5 - T1+ triple foliar application of Zn	0.51	0.32 ^{b}	0.06 ^{bcd}
T_6 - T_2+ single foliar application of Zn	0.51	0.44 ^{a}	0.07 ^{bc}
T_7 - T_2+ double foliar application of Zn	0.50	0.47 ^{a}	0.08 ^{ab}
T_8 - T_2+ triple foliar application of Zn	0.51	0.45 ^{a}	0.11 ^{a}
T_9 - Application of zinc in nursery	0.51	0.31 ^{b}	0.02 ^{ef}
T_{10}- Control	0.49	0.25 ^{c}	0.01 ^{f}
SEm ±	**0.02**	**0.01**	**0.007**
CD (0.05)	**NS**	**0.03**	**0.02**

Table 19: Effect of different treatments on magnesium content in shoots in different growth stages of rice (%)

Treatments	Magnesium		
	At Tillering	At panicle Initiation	At harvest
T_1 - Organic POP + soil application of Zn	0.38 [d]	0.29 [c]	0.27
T_2 - POP(KAU-2016) + soil application of Zn	0.67 [a]	0.53 [a]	0.24
T_3 - T1+ single foliar application of Zn	0.32 [f]	0.25 [d]	0.23
T_4 - T_1+ double foliar application of Zn	0.36 [e]	0.26 [d]	0.42
T_5 - T1+ triple foliar application of Zn	0.48 [c]	0.35 [b]	0.31
T_6 - T_2+ single foliar application of Zn	0.48 [c]	0.37 [b]	0.31
T_7 - T_2+ double foliar application of Zn	0.60 [b]	0.54 [a]	0.42
T_8 - T_2+ triple foliar application of Zn	0.59 [b]	0.53 [a]	0.44
T_9 - Application of zinc in nursery	0.47 [c]	0.26 [d]	0.26
T_{10}- Control	0.27 [g]	0.37 [b]	0.22
SEm ±	**0.37**	**2.4**	**0.14**
CD (0.05)	**1.12**	**7.28**	**NS**

4.3.7 Iron

The iron content in plant samples analyzed at different growth stages was recorded and given in table 20.

A significant difference in Fe content in shoots was observed among the treatments at tillering stage. The treatment that recorded the highest Fe content was treatment T_{10} (1168.55 mg Kg^{-1}). The lowest Fe content in shoots was recorded in treatment T_2 (1151.27 mg Kg^{-1}).

Similarly, at panicle initiation the treatments showed significant difference with treatment T_{10} (660.91 mg Kg^{-1}).

Likewise at harvest stage treatment T_{10} recorded the highest (459.176 mg Kg^{-1}). The lowest Fe content in straw was recorded in treatment T_8 (application of manures and fertilizers as per POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1} + triple spray of $ZnSO_4$ at 1%).

4.3.8 Zinc

The zinc content in plant samples analyzed at different growth stages was recorded and given in table 21.

At tillering stage the treatment showed a significant difference in Zn content in shoots with treatment T_9 recording the highest Zn content of 76.67 mg Kg^{-1} which was on par with treatment T_9, T_8 and T_5. The lowest Zn content (39.00 mg Kg^{-1}) in shoots was recorded in treatment T_{10} (Control).

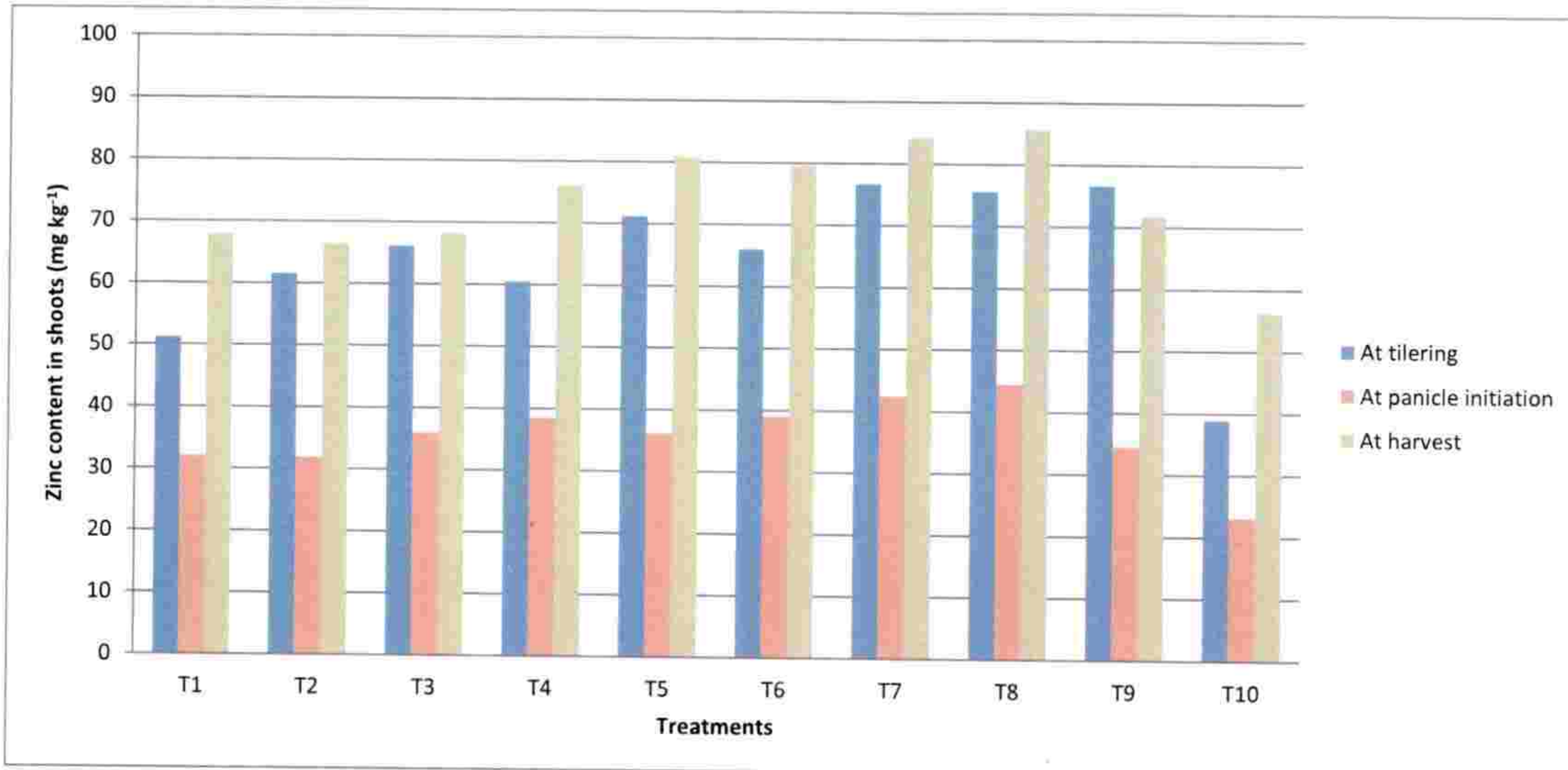
Table 20: Effect of different treatments on the iron content in shoots in different growth stages of rice (mg/Kg)

Treatments	Iron		
	At Tillering	At panicle Initiation	A t harvest
T_1 - Organic POP + soil application of Zn	1152.37	651.66	455.691
T_2 - POP(KAU-2016) + soil application of Zn	1151.27	650.95	458.546
T_3 - T_1+ single foliar application of Zn	1161.93	650.28	456.333
T_4 - T_1+ double foliar application of Zn	1160.70	651.98	454.925
T_5 - T_1+ triple foliar application of Zn	1156.30	656.36	457.933
T_6 - T_2+ single foliar application of Zn	1154.76	651.67	456.325
T_7 - T_2+ double foliar application of Zn	1158.23	658.76	454.313
T_8 - T_2+ triple foliar application of Zn	1153.12	651.02	451.080
T_9 - Application of zinc in nursery	1158.42	658.89	453.489
T_{10}- Control	1168.55	660.91	459.176
SEm ±	5.81	3.34	2.75
CD (0.05)	**17.75**	**10.12**	**8.24**

Table 21: Effect of different treatments on zinc content in shoots in different growth stages of rice (mg/Kg)

Treatments	Zinc		
	At Tillering	At panicle Initiation	At harvest
T_1 - Organic POP + soil application of Zn	51.33 ^{d}	32.07 ^{e}	67.93 ^{cde}
T_2 - POP(KAU-2016) + soil application of Zn	61.60 ^{c}	31.87 ^{e}	66.53 ^{de}
T_3 - T1+ single foliar application of Zn	66.20 ^{bc}	35.93 ^{cde}	68.33 ^{cde}
T_4 - T_1+ double foliar application of Zn	60.53 ^{c}	38.53 ^{bcd}	76.06 ^{abcd}
T_5 - T1+ triple foliar application of Zn	71.27 ^{ab}	36.13 ^{cde}	80.86 ^{abc}
T_6 - T_2+ single foliar application of Zn	66.07 ^{bc}	39.06 ^{bc}	79.66 ^{abcd}
T_7 - T_2+ double foliar application of Zn	76.73 ^{a}	42.46 ^{ab}	84.26 ^{ab}
T_8 - T_2+ triple foliar application of Zn	75.67 ^{a}	44.53 ^{a}	85.73 ^{a}
T_9 - Application of zinc in nursery	76.67 ^{a}	34.53 ^{de}	71.80 ^{bcd}
T_{10}- Control	39.00 ^{e}	23.20 ^{f}	56.26 ^{e}
SEm ±	**2.487**	**1.425**	**4.62**
CD (0.05)	**7.461**	**4.277**	**13.86**

Fig 5: Effect of different treatments on zinc content in shoots in different growth stages of rice (mg/Kg)



Similarly at panicle initiation, significant difference was observed among the treatments. Treatment T_8 (44.53 mg Kg^{-1}) recorded the highest Zn content in the shoot which was on par with T_7. The treatment that recorded the lowest Zn content was treatment T_{10} (23.20 mg Kg^{-1}). At harvest stage treatment T_8 was significantly superior compared to the other treatments. The Zn content in T_8 was 85.73 mg Kg^{-1} followed by treatment T_7. Lowest Zn content in straw was recorded in treatment control with 56.2 mg Kg^{-1}.

4.3.9 Copper

The experimental effects of different treatments on Cu content in plant samples analyzed at different growth stages were recorded and given in table 22.

The treatments showed no significant difference in terms of Cu content in shoots at tillering stage. The Cu content in shoots ranged from 8.43 mg Kg^{-1} (T_9) to 12.66 mg Kg^{-1} (T_{10}).

At panicle initiation, the treatments showed significant difference with treatment T_{10} (Control) recording the highest Cu content (10.40 mg Kg^{-1}) in shoots. The treatment that recorded the lowest Cu content (6.35 mg Kg^{-1}) in shoots was T_3 (Organic POP + soil application of Zn + single spray of $ZnSO_4$).

Similarly at the harvest stage, a significant difference was observed in Cu content in straw. The highest Cu content (43.75 mg Kg^{-1}) was observed in treatment T_2 followed by T_6. The treatment that recorded the lowest the Cu content (18.91 mg Kg^{-1}) was T_5.

4.3.10 Manganese

The experimental effects of different treatments on Mn content in plant samples analyzed at different growth stages were recorded and given in table 23.

Table 22: Effect of different treatments on copper content in shoots in different growth stages of rice (mg/Kg)

Treatments	Copper		
	At Tillering	At panicle Initiation	At harvest
T_1 - Organic POP + soil application of Zn	10.60	7.74 ^{cd}	23.84 ^{d}
T_2 - POP(KAU-2016) + soil application of Zn	10.04	8.56^{bcd}	43.75 ^{a}
T_3 - T1+ single foliar application of Zn	9.06	6.35 ^{d}	21.32 ^{e}
T_4 - T_1+ double foliar application of Zn	9.11	7.44 ^{cd}	19.01 ^{f}
T_5 - T1+ triple foliar application of Zn	10.46	6.47 ^{d}	18.91 ^{f}
T_6 - T_2+ single foliar application of Zn	11.65	8.83^{abc}	40.21 ^{b}
T_7 - T_2+ double foliar application of Zn	10.16	6.47 ^{d}	31.71 ^{c}
T_8 - T_2+ triple foliar application of Zn	8.54	6.63 ^{cd}	19.71 ^{ef}
T_9 - Application of zinc in nursery	8.43	9.06 ^{ab}	23.78 ^{d}
T_{10}- Control	12.66	10.40 ^{a}	19.82^{ef}
SEm ±	**1.47**	**0.77**	**0.76**
CD (0.05)	**NS**	**2.32**	**2.29**

Table 23: Effect of different treatments on manganese content in shoots in different growth stages of rice (mg/Kg)

Treatments	Manganese		
	At Tillering	At panicle Initiation	At harvest
T_1 - Organic POP + soil application of Zn	405.33 c	220.33 bc	401.96 d
T_2 - POP(KAU-2016) + soil application of Zn	382.00 c	171.40 ef	477.26 cd
T_3 - T1+ single foliar application of Zn	492.66 c	223.66 bc	530.93 bc
T_4 - T_1+ double foliar application of Zn	456.00 f	150.66 fg	444.26 cd
T_5 - T1+ triple foliar application of Zn	325.33 e	239.33 b	524.43 bc
T_6 - T_2+ single foliar application of Zn	401.33 c	189.06 de	607.46 ab
T_7 - T_2+ double foliar application of Zn	356.00 d	208.73 cd	609.16 ab
T_8 - T_2+ triple foliar application of Zn	388.00 c	151.93 fg	650.26 a
T_9 - Application of zinc in nursery	492.66 a	269.66 a	521.08 bc
T_{10}- Control	277.33 b	139.66 g	387.19 d
SEm ±	**8.64**	**7.57**	**8.82**
CD (0.05)	**25.92**	**22.70**	**26.45**

The treatment in which Zn was applied at nursery stage recorded the highest Mn content (492.66 mg Kg^{-1}) in shoots and the lowest Mn content (277.33 mg Kg^{-1}) was recorded in T_{10}.

Similarly, at panicle initiation stage the treatments showed significant difference, with treatment T_9 recorded the highest Mn content (269.66 mg Kg^{-1}) in shoots which was also followed by treatment T_5. The lowest Mn content was recorded in treatment T_{10} with 139.66 mg Kg^{-1}.

At harvest stage the highest Mn content (650.26 mg Kg^{-1}) was in treatment T_8 where fertilization was done as per POP KAU along with soil Zn application and triple foliar spray of Zn which was followed by T_7 and T_6 and the lowest Mn content was recorded in control (387.19 mg Kg^{-1}).

4.3.11 Boron

The data pertaining to B content in plant samples recorded at different growth stages are given in table 24.

At the tillering stage the treatments showed significant difference among the treatments. The treatment T_2 in which application of fertilizers was done as per the POP KAU along with soil application of Zn at the rate of 20 Kg ha^{-1} recorded the highest B content (4.97 mg Kg^{-1}) in shoots. B content was recorded to be lowest in treatment T_{10} (4.31 mg Kg^{-1}).

Similarly, at panicle initiation stage significant difference were observed among the treatments. B content was observed to be highest in treatment T_4 with a value of 5.67 mg Kg^{-1} which was on par with treatment T_3 and the treatment that recorded the lowest B content was treatment T_9 (4.30 mg Kg^{-1}).

At harvest treatment T_1 (Organic POP + soil application of Zn) recorded the highest B content (6.80 mg Kg^{-1}) in straw followed by treatment T_5. The treatment that recorded the lowest B content in straws is treatment T_{10} (3.50 mg Kg^{-1}).

Table 24: Effect of different treatments on boron content in shoots in different growth stages of rice (mg/Kg)

Treatments	Boron		
	At Tillering	At panicle Initiation	At harvest
T_1 - Organic POP + soil application of Zn	4.96 [a]	4.50 [b]	6.80 [a]
T_2 - POP(KAU-2016) + soil application of Zn	4.97 [a]	5.47 [b]	4.71 [bc]
T_3 - T1+ single foliar application of Zn	4.76 [ab]	5.65 [a]	4.26 [cd]
T_4 - T_1+ double foliar application of Zn	4.80 [ab]	5.67 [a]	4.52 [bcd]
T_5 - T1+ triple foliar application of Zn	4.87 [ab]	5.45 [b]	4.06 [b]
T_6 - T_2+ single foliar application of Zn	4.96 [a]	4.73 [d]	4.03 [de]
T_7 - T_2+ double foliar application of Zn	4.64 [b]	4.87 [c]	4.50 [bcd]
T_8 - T_2+ triple foliar application of Zn	4.86 [ab]	4.88 [c]	4.04 [de]
T_9 - Application of zinc in nursery	4.88 [ab]	4.30 [f]	4.70 [bc]
T_{10}- Control	4.31 [c]	4.48 [e]	3.50 [e]
SEm ±	**0.087**	**0.03**	**0.2**
CD (0.05)	**0.26**	**0.09**	**0.61**

4.3.12 Silicon

The effects of different treatments on Si content on plant samples at different growth stages were recorded and given in table 25.

The effect of different treatment on Si content on plant shoots at tillering and panicle initiation stage were non significant. At tillering stage the Si content in shoots ranged from 6.32 to 6.54 %. At panicle initiation Si content ranged from in 4.65 to 5.03 % shoots.

At harvest, the effect of treatments significantly improved the Si content in straw as compared to control. The highest Si content was recorded in treatment T_2 (4.34 %) which was on par with all other treatments except control.

4.4 GRAIN ANALYSIS

4.4.1 Zinc

The Zn content on grain was analyzed after harvest and the values are presented in table 26.

The results showed a significant difference in the treatments, with treatment T_8 (application of manures and fertilizers as per POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1} + triple spray of $ZnSO_4$ at 1%) recorded the highest Zn content in the grain (49.86 mg Kg^{-1}). Treatment T_7 recorded the second highest Zn concentration in the grain.

Among the organic treatments, T_5 (Organic POP + soil application of Zn at the rate of 20 Kg ha^{-1} + triple spray of $ZnSO_4$ at 1%) recorded higher zinc content (24.33 %) as compared to T_3 and T_5. The treatment that recorded the lowest Zn content was T_{10} (18.20 %).

4.4.2 Phosphorus

Grain analysis was also done to study the effects of different treatments on the P content in the grain. The analysis was done after harvest and the values are given in table 26.

The effects of the treatments on P content in the grains showed a significant difference among the treatments. The treatment that recorded the highest P content in the grain was T_2 (POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1}) with a value of 0.61 mg Kg^{-1} followed by treatment T_6. The treatment that recorded the lowest P concentration was T_5 with a value of 0.44 mg Kg^{-1}.

4.5 ZINC CONTENT IN COOKED RICE

Zinc content was also analyzed from 30 sample cooked rice and the values were given in mg Kg^{-1} given on table 26.

There was a significant decreased in the Zn content ingrains after the cooking process in all the treatments. The highest Zn content was recorded in treatment T_8 (28.52 mg Kg^{-1}) which also recorded the highest Zn content in grain before cooking, followed by T_7 and T_6 and the lowest Zn content in cooked rice was recorded in control (3.93 %).

Table 25: Effect of different treatments on silicon content in shoots in different growth stages of rice (%)

Treatments	Silicon		
	At Tillering	At panicle Initiation	At harvest
T_1 - Organic POP + soil application of Zn	6.54	4.97	4.21 [a]
T_2 - POP(KAU-2016) + soil application of Zn	6.45	4.67	4.34 [a]
T_3 - T1+ single foliar application of Zn	6.41	4.97	4.23 [a]
T_4 - T_1+ double foliar application of Zn	6.34	4.65	4.20 [a]
T_5 - T1+ triple foliar application of Zn	6.32	4.91	4.16 [a]
T_6 - T_2+ single foliar application of Zn	6.32	4.87	4.30 [a]
T_7 - T_2+ double foliar application of Zn	6.44	4.99	4.16 [a]
T_8 - T_2+ triple foliar application of Zn	6.35	5.03	4.25 [a]
T_9 - Application of zinc in nursery	6.42	4.94	4.15 [a]
T_{10}- Control	6.38	4.98	3.74 [b]
SEm ±	**0.12**	**0.17**	**0.09**
CD (0.05)	**NS**	**NS**	**0.27**

Table 26: Effect of different treatments on zinc, phosphorus content in grains and zinc content in cooked rice

Treatments	Grain		Cooked rice
	Zinc (mg/Kg)	Phosphorus (%)	Zinc (mg kg^{-1})
T_1 - Organic POP + soil application of Zn	20.53^{e}	0.53^{c}	5.33^{gh}
T_2 - POP(KAU-2016) + soil application of Zn	25.36^{d}	0.61^{a}	12.22^{cd}
T_3 - T1+ single foliar application of Zn	18.93^{e}	0.52^{cd}	5.82^{fgh}
T_4 - T_1+ double foliar application of Zn	20.70^{e}	0.48^{e}	8.36^{ef}
T_5 - T1+ triple foliar application of Zn	24.33^{d}	0.44^{g}	7.79^{fg}
T_6 - T_2+ single foliar application of Zn	32.66^{c}	0.55^{b}	13.11^{c}
T_7 - T_2+ double foliar application of Zn	40.00^{b}	0.46^{fg}	21.57^{b}
T_8 - T_2+ triple foliar application of Zn	49.86^{a}	0.46^{f}	28.52^{a}
T_9 - Application of zinc in nursery	26.40^{d}	0.51^{d}	10.48^{de}
T_{10}- Control	18.20^{e}	0.48^{e}	3.93^{h}
SEm ±	**1.11**	**0.06**	**0.857**
CD (0.05)	**3.33**	**0.18**	**2.57**

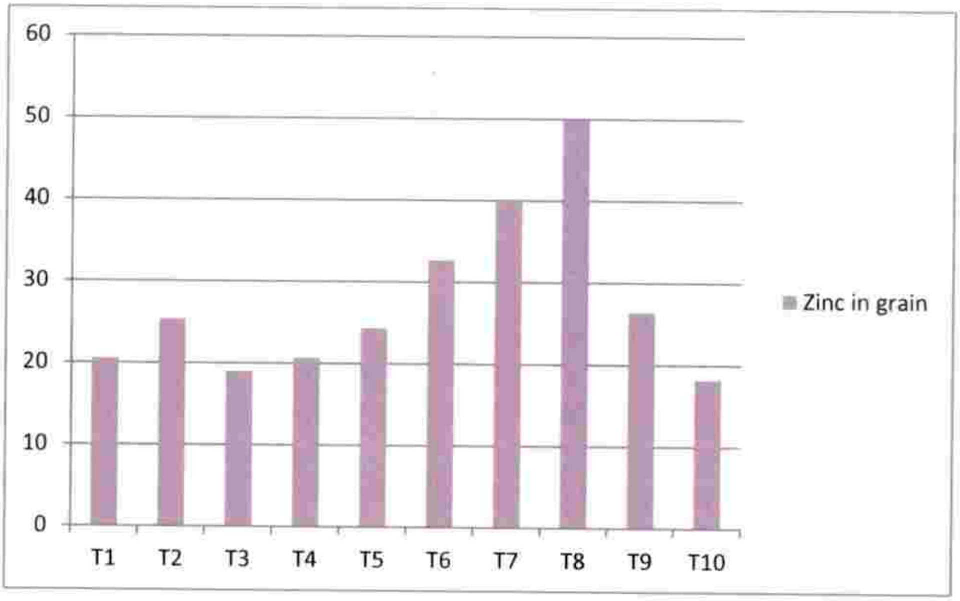


Fig 6: Effect of different treatments on zinc content in grains (mg Kg^{-1})

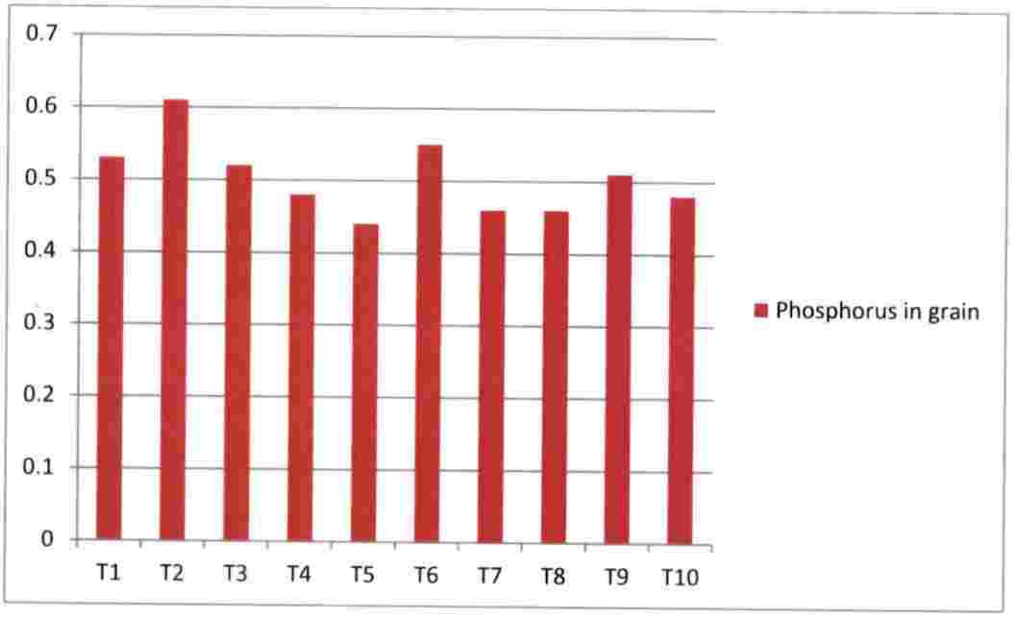


Fig 7: Effect of different treatments on phosphorus content in grains (%)

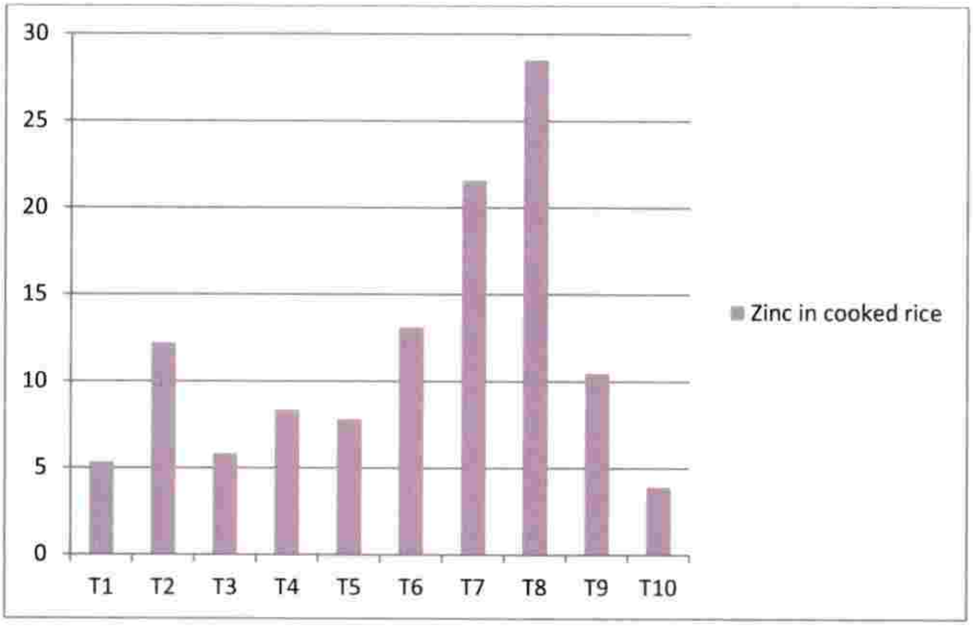


Fig 8: Effect of different treatment in zinc in cooked rice (mg Kg^{-1})

Discussion

5. DISCUSSION

The discussion of the results of the experimental research "Biofortification of rice (*Oryza sativa*) with zinc under organic and integrated nutrient management practices" carried out at Regional Agricultural Research, Pilicode during the first crop season is presented below.

5.1 EFFECT OF TREATMENTS ON PLANT GROWTH PARAMETERS

Application of Zn at nursery as a foliar spray at the rate of 1% was found to significantly increase plant height at the tillering stage as compared to other treatments. At other growth stages of the crop soil and foliar application of zinc significantly influenced the plant height in rice. Zn application along with NPK fertilizers recorded higher plant height compared to treatments under organic practices. The plant height increased with an increase in the number of foliar spray of Zn. At tillering and panicle initiation T_9 recorded the maximum height as compared to other treatments and at harvest T_8 recorded the maximum plant height on par with T_7, T_6 and T_5. The increase in plant height under zinc treatment might be due to its effect in the metabolism of growing plants as zinc is a major component of many enzymes, which may effectively explain the response of zinc application.

The increase in the height of paddy with zinc application corroborates with the findings of Kadam *et al.* (2018). Maximum plant height up to 32.33 cm was found with soil application of RDF + $ZnSO_4$ at the rate of 25 kg ha^{-1}. Khan *et al.* (2007) also had similar findings which suggested that zinc application increases the plant height.

The production of tillers in paddy is a direct measure of plant growth. Therefore, counting the number of tillers per hill provides an adequate basis for measuring the treatment differences owing to various treatments. Treatments with combined soil and foliar application along with NPK fertilizers as per POP KAU recorded a higher number of tillers per hill as compared to treatments under organic practices. Among the treatments under organic practices, the highest number of tillers per hill was recorded in plants with a triple spray of Zn. At harvest treatment T_8 was superior as compared to other treatments and recorded the maximum number of tillers per hill. The zinc treatments along with NPK fertilizers as per POP KAU might have increased the nutrient use efficiency and promoted various physiological activities in the plant which are vital for proper growth and development. Zinc also plays an important role in the formation of growth hormones and auxin metabolism which enhanced the number of tillers. Similar results were found by Kadam *et al.* (2018) and Khan *et al.* (2007) who showed a considerable increase in the number of tillers by Zn application compared to the control.

5.2 EFFECT OF TREATMENTS ON YIELD AND PLANT YIELD PARAMETERS

The effect of soil application and foliar spray of Zn along with the application of NPK fertilizers as per POP KAU has shown a marked difference in plant yield parameters like the total number of grains per panicle, 1000 grain weight, chaffiness, grain yield and straw yield.

A signifiant increase in the total grain per panicle was observed in the treatments with foliar application of Zn over control. Treatment T_8 (application of manures and fertilizers per POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1} + triple spray of $ZnSO_4$ at 1%) was superior compared to other treatments recording maximum grains per panicle followed by T_7. In a research conducted by Abid *et al.* (2015) treatment (NPK + Mn + Zn) recorded the highest number of grains $panicle^{-1}$ (118.66 g), 1000 grain weight (23.93 g) and maximum paddy yield (78.73 g). The lowest yield (20.53 g) was in control. This may be due to the balanced nutrient ratio, which improved the yield and yield contributing characteristics of rice.

The test weight of grain is a vital yield component that contributes towards grain yield of rice. The higher the test weight of grain the higher is the efficacy of grain to store more photosynthates. Application of foliar spray of $ZnSO_4$ at the rate of 1% showed higher grains with higher test weight both under organic and integrated nutrient management practices as compared to control. The maximum test weight in grains was recorded with treatment T_7 on par with treatment T_8 and T_6. However, the test weight of grain recorded with INM practices was higher as compared to organic practices. According to Naik and Das (2008), the effects of nitrogen and zinc fertilization were responsible for higher test weight of grain because nitrogen increased the crude protein content in grains.

The effects of Zn application on chaffiness showed a significant difference among the treatments. The chaffiness per centage was relatively higher in treatments where NPK fertilizers were not applied. Application of NPK fertilizers along with Zn significantly improved the physiological quality of grains. Treatment T_3 recorded highest chaffiness which was at par with treatments T_1, T_2, T_4, T_5, and T_{10}. The treatment with the lowest chaffiness is observed in treatment T_6.

The effects of Zn fertilization as soil application and combined soil and foliar application showed a significant increase in grain yield as compared to control. Application of Zn under INM practices recorded higher grain yield as compared to the application of Zn under organic practices. The highest grain yield was in treatment T_8 (6.79 t ha^{-1}) which was significantly higher than the other treatments followed by T_7 which was at par with T_6. The lowest grain yield was obtained in treatment T_{10} (3.90 t ha^{-1}). The increase in grain yield with Zn treatment might be due to the increased number of tillers, grains per panicle and improved nutrient use efficiency in these treatments. Another major reason for increased grain and straw yield under Zn application may be because Zn is a major constituent in several enzymes and plant hormones such as auxin that promotes seed maturation and starch formation.

Hussain *et al.* (2018) observed an increase in the grain yield of paddy with soil application of Zn, whereas Saha *et al.* (2015) reported that grain yield of paddy increased with both soil and foliar Zn application. Shivay *et al.* (2015) reported that zinc application in rice had a positive effect on yield and yield attributing characters. It was reported that combined soil and foliar application of Zn recorded the highest grain yield and were superior to soil application of Zn alone.

5.3 EFFECT OF TREATMENTS ON PHYSICAL, CHEMICAL PROPERTIES AND NUTRIENT STATUS IN SOIL AT 30 DAT AND AT HARVEST

5.3.1 Soil pH

The data given on the table showed there was an increase in the pH of the soil at 30 DAT as compared to initial soil sample analysis. This increase in pH may be attributed to the proton consumption in reduction process which occurs during submergence. However, the pH values of soil decline after harvest with treatment T_5 recording the highest pH. Ponnamperuma (1972) reported that during submergence, acid soils tend to increase in pH and in the case of calcareous soil there is a drop in pH to attain neutrality. At harvest treatment under INM practices recorded lower pH values at harvest as compared to organic practices. This might be attributed to the residual acidity caused by the use of fertilizers such as urea and $ZnSO_4$.

5.3.2 Electrical conductivity

The EC of soil at 30 DAT showed a significant difference among treatments under organic practices and under INM practices with treatment T_6 recording the highest EC which was on par, with treatments T_7 and T_8. Treatment T_{10} recorded the lowest EC among the treatments. The increase in EC might be due to the increase in total soluble salts after application of fertilizers under INM practices. At harvest, the EC of soil declined in all the treatments and no significant difference was observed among treatments.

In strong acid soils, the EC of soil usually has low initial conductance. During the first 4 weeks of flooding the EC of soil tend to increases about 2-4 mmhos cm^{-1} after which it declines sharply after draining the flood water (Poonamperuma 1972)

5.3.3 Organic carbon content

At 30 DAT the soil was under submergence and soil analysis was done to determine the organic carbon content in the soil. There was a significant difference among the treatments with treatment T_4 having the highest organic carbon content. Treatment T_{10} (Control) recorded the lowest organic carbon content among the treatments. The organic carbon content in soil at harvest was again analyzed and the values were lower as compared to Organic carbon content at 30 DAT. This might be due to the fact that submergence of soil slows down the decomposition process of organic matter added as FYM.

Sahrawat (2004) reported that in tropical humid climate application of organic manures in wetland rice cultivation significantly improved the OC content as compared to soils under arable cropping under similar conditions owing to the slow decomposition process under submergence.

5.3.4 Particle size

The particle size of soil analyzed at the initial stage, 30 DAT and after harvest indicated that the soil belonged to sandy clay loam texture with no significant differences in their sizes under the effect of different treatments attributing to the fact that soil texture is a property of the soil that does not undergo changes easily.

5.3.5 Cation exchange capacity

The initial CEC of soil was very low with a value of 4.32 and at 30 DAT the CEC gradually increased and then decreased after submergence. The increase in CEC of soil during submergence may be due to the rise in pH in the soil. In a laterite soil with a 1:1 kalonitic group the charges developed are pH dependent, at higher pH, the CEC of soil is relatively higher.

5.3.6 Nitrogen

At 30 DAT highest available N was observed in treatment T_2 followed by treatment T_7. The lowest available N content was observed in treatment T_{10}. At harvest, the treatment that recorded the highest available N was T_7 which was at par with T_6 and T_8 and the lowest available N content was in treatment T_{10}. The results indicated that soil available N was higher in treatments under INM which might be due to the application of fertilizers along with soil application of $ZnSO_4$ at the rate of 20 Kg ha^{-1}. The soil available N increased when N was added in the form of fertilizers and FYM (Chandrapala *et al.*, 2010)

Adel (2016) reported that the highest N content in the soil after harvest was recorded in treatments where soil application of zinc was done as compared to control plots.

5.3.7 Phosphorus

At 30 DAT the treatments revealed a significant difference in the available P in soil with treatment T_7 having the highest available P content which was on par with T_8. The treatment with the lowest available P in soil was observed in T_{10}. However, at harvest no significant difference was observed among the treatments. In general, there is a decline in soil available P in all the treatments. The soil available P ranged from 8.81 Kg ha^{-1} (T_{10}) to 11.50 Kg ha^{-1} (T_7). At both 30 DAT and harvest treatment T_{10} recorded significantly lower soil available P as compared to treatments with Zn application. This result was in agreement with the findings of Singh *et al.* (2013) who reported that available phosphorous content was seemingly increased with the application of zinc.

Amanullah and Inamullah (2016) concluded that after the harvest of paddy the highest soil residual P concentration was recorded in treatments with 15 kg Zn ha^{-1} and the lowest P concentration was in control plots.

The available P in the soil at harvest was lower as compared to the available P in the soil at 30 DAT both under organic and INM practices. This might be due to the drop in pH at harvest which may lead to fixation of P (Dixit, 2006).

5.3.8 Potassium

The effects of Zn application on the availability of soil potassium were significantly higher in treatments under Zn application as compared to control at both 30 DAT and harvest. The K content was higher in treatments under INM practices as compared to organic practices and control treatment. At 30 DAT a significant difference was observed among the treatments and treatment T_2 recorded the highest available K in the soil. Lowest soil available K was recorded in T_{10}. Similarly, at harvest the treatments showed a significant difference in the soil available K with treatment T_8 having the highest soil available K which was at par with T_2 and T_6. This might be attributed to the application of K fertilizers in these treatments. The treatment that received the lowest soil available K was control. At harvest the soil available K was lower as compared to the 30 DAT which may be due to the uptake of K^+ ion by the crops.

Adel (2016) reported in his experiment that the K content in the soil after the harvest of rice was higher with soil application of Zn and the lowest K content was in the plots where Zn fertilization was not done.

Chavan *et al.* (2018) reported that increasing dose of zinc sulphate from 10 to 30 kg ha^{-1} increased the available potassium linearly. This result was supported by Singh *et al.* (2013).

5.3.9 Calcium

The availability of Zn in soil was higher at 30 DAT as compared to harvest. At 30 DAT the soil available Ca ranged from 193.33 mg Kg^{-1} to 273.33 mg Kg^{-1} and at harvest it ranged from 137 mg Kg^{-1} to 148.6 mg Kg^{-1}. According to Islam and Islam (1973) submergence of soil during rice cultivation led to the increase in the Ca, Mg and K concentration in soil.

5.3.10 Magnesium

At 30 DAT the treatments revealed no significant difference in the availability of magnesium in the soil. The available magnesium in soil ranged from 39.33 mg Kg^{-1} (T_1) to 41.73 mg Kg^{-1} (T_8). At harvest, there was a decline in available Mg in soil. Highest available magnesium content was observed in treatment T_6. Treatment T_1 recorded the lowest available value of 37.33 mg kg^{-1}. The increase in available Mg at 30 DAT might be due to the increase in the solubilty of Mg^{2+} ions in the soil during submergence.

5.3.11 Sulphur

At 30 DAT the soil application of Zn in the form of $ZnSO_4$ at the rate of 20 Kg ha^{-1} had a significant effect on the availability of S in all the treatments except treatment T_9 and T_{10}. Treatment T_6 had the highest available sulphur in the soil which was at par with all other treatments except with T_9 and T_{10} (Control). This might be because the soil application of $ZnSO_4$ has a residual effect on soil. However there was no significant difference among the treatments at harvest. The available sulphur in soil ranged from 3.60 mg Kg^{-1}(T_1) to 5.8 mg Kg^{-1} (T_7). Sulphur content in zinc sulphate might be the reason to increase the available sulphur content in the soil.

These observations made were in agreement with the results found by Chavan *et al.* (2018) and Singh *et al.* (2013).

5.3.12 Iron

At 30 DAT the treatments showed no significant difference in terms of availability of iron in soil. The soil available Fe was higher at 30 DAT compared to harvest. This might be attributed to the fact that when a soil is submerged there is a reduction of iron (Fe^{3+} to Fe^{2+}) and the accompanying increase in its solubility. It is evident that the concentration of Fe ion increases initially to some peak value and thereafter decreases slowly with the period of soil submergence. At harvest the treatments showed significant difference with treatment T_3 recording the highest value which was at par with T_5, T_9 and T_4.

5.3.13 Zinc

The effects of different treatment on the availability of Zn in the soil at 30 DAT were significant. At 30 DAT the soil application of $ZnSO_4$ at the rate of 20 Kg ha^{-1} increased the available Zn in soil significantly in almost all the treatments except for treatment T_9 and control. The highest Zn concentration in soil was in treatment T_8 which was at par with T_6, T_4, T_7, T_5 and T_3 while T_9 recorded the least Zn availability in soil. Similar results were reported by Husain *et al*, (2009) where he reported that Zn being mobile in soil accumulates in the soil after its application.

At harvest also the treatments were seen to be significantly different. The treatment that recorded the highest available Zn was treatment T_4 which was on par with T_3. The treatment showed the lowest soil available Zn in T_7 which were on par with T_2 and T_8. The treatments under INM practices recorded lower Zn content in the soil as compared to treatments under organic practices. This may be because of higher Zn uptake by the plants when applied along with NPK fertilizers and FYM.

5.3.13 Copper

The effect of different treatments showed significant difference in soil available Cu at 30 DAT and harvest. At harvest, the soil available Cu was higher as compared to soil available Cu at 30 DAT. This may be due to the reason that when an acid soil is submerged, the release of copper decreases due to the gradual increase in soil pH.

The present values were in accordance to findings of Saha and Mandal, (2000) where it was reported that submergence of soil causes the rise of pH in acid soils and drop in the redox potential of soil which reduces the water soluble and exchangeable copper in the soil.

5.3.14 Manganese

The soil available Mn at 30 DAT was higher as compared to Mn content in the soil prior to cultivation and after harvest. The initial increase in the concentration of Mn^{2+} recorded during submergence at 30 DAT may be due to a drop in the redox potential of soil and subsequent reduction of Mn^{4+} to Mn^{2+}. After submergence, there is a decrease of the Mn^{2+} which may be because of the precipitation of Mn^{2+} on $MnCO_3$ and Mn $(OH)_2$ in the soil solution.

The reduction of Mn (IV) oxides to Mn (II), in submerged soils is responsible for major transformations of manganese thereby increasing the concentration of water-soluble Mn^{2+} ions. Within 1-4 weeks of submergence almost all the EDTA-dithionate extractable manganese present in soils is reduced, increasing the concentration of water soluble Mn^{2+}. Following submergence, after the flooded water is drained precipitation of manganous carbonate and reoxidation of Mn^{2+} occurs by diffusion or mass flow to oxygenated interfaces in the soil (IRRI, 1964).

5.3.15 Boron

The B content in the soil gradually increases as compared to the initial B content following submergence and then followed by a gradual decrease in the content of B in the soil at harvest. This may be due to the rise in pH in acid soils during submergence which increases the readily soluble B content in the soil. The results were similar to the findings of Kalokhe (2017) who concluded that there was a significant increase in the average value of readily soluble B as compared with an initial status of B at 30 days during submergence.

5.3.16 Silicon

At 30 DAT the silicon content in soil was higher compared to the initial Si content and it gradually decreased after submergence. At harvest, the Si content was even lower than the initial Si content in the soil.

In submerged conditions silica concentration in the soil solution showed a slight increase after flooding as compared to the initial concentration and then followed by a gradual decrease, and after submerging for several months the concentration of silica may even be lower than the initial concentration prior to flooding. After flooding the increase in the concentration of silica in soil solutions may be attributed to the reduction of hydrous oxides of Fe (III) followed by the release of silica (IRRI, 1964).

5.4 EFFECTS OF TREATMENTS ON PLANT NUTRIENT ANALYSIS

Zn fertilization with soil and foliar application under organic and integrated nutrient management practices showed significant effects on the nutrients content in the plant samples at different growth stages. The N content in shoots (tillering and panicle initiation stage) and straw (harvest stage) showed considerable difference between organic and INM practices. This may be due to the application of both organic and inorganic sources of N under INM practices. At tillering and panicle initiation treatment T_7 recorded the highest N content, however at harvest stage T_8 recorded the highest N content which indicates the effectiveness of foliar spray of Zn at flowering stage. Similar trends were observed in treatments (T_1, T_3, T_4 and T_5) under organic practices but recorded lower N content as compared to treatments under INM practices. This was in accordance with the findings of (Potarzycki and Grzebisz.,2009) and (Keram *et al.*,2012) who concluded that the increase in N content in shoots and straw may be due to the synergistic effect between N and Zn which in turn may be because of the increase in enzymatic activity on application of Zn. The results were also supported by the findings of (Ashoka *et al.*, 2008), (Morshedi and Farahbeksha, 2010) and (Khan *et al.*, 2002)

An experiment conducted by Rahman *et al.* (2002) showed higher nitrogen content (straw and grain) in paddy with the application of zinc sulphate along with urea compared to the sole application of urea. Mollah *et al.* (2009) found significantly higher nitrogen content in plants with the application of Zn. The finding of Dash *et al.* (2015), Singh *et al.* (2013) and Ghasal *et al.* (2017) also showed a similar trend with zinc application. Pooniya and Shivay (2013) observed superior results with 2.0% $ZnSO_4$ enriched urea which yielded significantly higher uptake in straw, grain as well as total uptake by the plant (straw + grain). The increase in uptake attributed to an increase in concentrations of the nutrients in rice and also due to the increase in grain and straw yield. It is evident that there is a positive interaction between Zn and N which consequently led to the increase in uptake of N by rice.

P content in shoots analyzed at the tillering stage was highest in treatment T_2 which was under the effect of soil application Zn, FYM, neem cake and NPK fertilizers. This might due to the application of P nutrient both in organic and inorganic for which may lead to the higher uptake of P by plants. However, the P content in shoots (panicle initiation stage) and straw (harvest stage) was lower in those treatments with the increase in the number of foliar application of Zn. At harvest, treatment T_5 recorded the lowest P content which may be due to the reason that no fertilizers were added and triple foliar spray of Zn was applied in this treatment. The results indicate that soil application of Zn did not affect the decrease of P content in plant samples as much as the foliar application of Zn with increase number of Zn applications. The antagonistic effect between P and Zn may be the reason for the decline in P concentration in straw and grain. Zn has the ability to control the absorption of P by roots which inhibited the P translocation from the roots to the above plant parts through functional links in the membrane of the cell. By decreasing the amount of P absorbed by the roots and inhibiting transport it directly interferes with the P metabolism. Similar findings were reported by Keram *et al.*(2012) and Fageria *et al.* (2008). Further, the decline in P uptake on the application of higher Zn levels may be due to the antagonistic effect of Zn reported by (Khan *et al.*, 2007) and Alam *et al.* (2000). Similarly, Singh *et al.* (2009) reported the antagonistic effect of phosphorous with zinc application and further observed that soil application of zinc did not affect the decrease in phosphorous content as much as foliar treatments.

The effect of soil and foliar application of Zn treatments on K content in the plant samples showed a significant improvement both under organic and INM practices as compared to control. At tillering stage basal application of zinc under INM practices recorded the highest K content in T_6 which was on par with T_7. The potassium content in shoots (panicle initiation stage) and straw (harvest stage) increased with the increased number of foliar spray in treatments under INM practices. This may be due to the synergistic interactions between K and Zn which were similar to the results of (Srivastava *et al.*, 1999., Yaseen, 1999., Khan *et al.*, 2007 and Keram, 2012). Several enzymes in the plants which require Zn are associated with the metabolism of carbohydrates in the plant tissues particularly leaves by maintaining water balance in the soil-plant-atmosphere continuum, imparting K in stomata regulation, phloem export of assimilation from the leaves into the sink organs. Zn sufficiency is also positively correlated with potassium efflux from roots, shoots into the growth medium. Zn uptake facilitates the K movement in the guard cells of stomata (Ali *et al.*, 2011).

Keram *et al.* (2012) found that in comparison to the control, the recommended dose of NPK along with Zn application at the rate of 20 kg ha^{-1} resulted in maximum uptake of N, K and Zn with 123.19, 90.96 and 327.74 kg ha^{-1}, respectively. However, the highest total uptake of P was recorded in the control attributing to 19.27 kg ha^{-1} and increasing Zn levels resulted in a decline in the value of P uptake. The increase in total N uptake by the plants could be due to the synergistic effect with Zn whereas the increase in K may be due to the positive interaction of K and Zn.

In terms of secondary nutrients content in plants, application of Zn showed a significant difference in almost all the growth stages. Comparatively, the effects of combined soil and foliar application of Zn along with NPK showed higher Ca contents in plant samples at all the growth stages. Treatment T_6 recorded the highest Ca content in shoots (tillering and panicle initiation stage) and straws (harvest stage). A study conducted by Singh and Singh (2005) showed that the application of $ZnSO_4$ at the rate of 25 Kg ha^{-1} increased the Ca content in rice compared to the control.

Similarly, Mg content in plants samples was enhanced with Zn fertilization at all the three stages of the crop growth as compared to treatment with no Zn application. At tillering, T_2 (soil application of 20 kg Zn ha^{-1} along with NPK fertilizers as per POP KAU) recorded the highest Mg content in shoots. Treatments T_7 and T_8 recorded the highest Mg content at panicle initiation and at harvest stage respectively, which shows that Zn fertilization enhanced uptake of Mg. Positive interactions of Zn and Mg in plants was also observed by Merrill *et al*. (1953) and Singh and Singh (2005).

The effects of Zn fertilization on the S content in shoots and straw was more significant in those treatments with more than once the foliar application of $ZnSO_4$ at the rate of 1%. At tillering stage no significant difference was observed in S content in the shoots. At panicle initiation and harvest, a significant increase in S content was observed in treatments with double spray and triple spray of $ZnSO_4$ under organic and INM practices.

Iron toxicity is often related to zinc deficiency in rice cultivation. Dissolved ferrous iron is taken up by the plant especially at low oxygen levels and pH. A high concentration of ferrous iron in the root zone forms iron plaques which prevent the plant from taking up other nutrients such as Zn (Hägnesten, 2006). Combined soil and foliar application of Zn along with NPK fertilizers as per POP KAU recorded lower Fe content in shoots and straw as compared to control treatment at all growth stages. Treatment T_2 recorded the lowest Fe content at tillering and panicle initiation and treatment T_{10} (Control) recorded the highest Fe content in shoots and straw at tillering and harvest stage. This may be a result of a balanced nutrient application of NPK fertilizers with Zn fertilization along with soil amendments like liming. Shahid *et al.* (2014) reported that Fe toxicity in rice is corrected through the application of certain plant nutrients such as Zn, K and Mn along with recommended doses of NPK fertilizers which in turn increases the yield of rice cultivars. Similar results were also reported by Sedberry *et al.*, 1971.

Zn application either as soil application or combined soil and foliar Zn application showed significant uptake of Zn by shoots and straw both under organic as well as INM practices as compared to the control. At tillering stage T_7 recorded maximum Zn content in the shoot which was on par with treatment T_9, T_8 and T_5. At both panicle initiation and harvest treatment T_8 recorded the maximum Zn content. This might be due to the availability of Zn at all growth stages either from soil or from foliage. Zn fertilization showed higher Zn uptake with INM practices as compared to the treatments with organic practices. This might have resulted due to a balanced application of nutrients which increases Zn uptake by rice. The lowest Zn uptake was observed in control. The experiment conducted by Sahu *et al.* (1996) on Inceptisol and Vertisol showed a significant increase in the Zn uptake by rice with Zn application and recommended NPK doses. Foliar application of Zn at tillering, panicle initiation and flowering stage gave the highest result in the uptake of Zn by paddy. The highest Zn concentration in paddy was achieved with foliar Zn spray that was applied at four stages *viz* panicle initiation, booting, 1 to 2 WAF reported by Cakmak (2007).

The effects of Zn fertilization particularly the foliar application of Zn seemed to show an antagonistic effect with Cu uptake by plants. At tillering stage no significant difference was observed among the treatments but treatment T_9 (application of foliar spray of Zn at nursery) recorded the lowest Cu content. At panicle initiation, the treatment that recorded the lowest Cu content was T_3 (organic POP + soil application of Zn +single spray of Zn) which was on par with T_8 (POP

KAU + soil application of Zn + triple spray of Zn). The results indicate that Cu content in shoots and straws were lower with an increase in Zn fertilization.

Similar observations were made by Ping *et al.* (2008) who reported a decline in copper content with increase in zinc content and this result appeared to be at par with the observations made by Mollah *et al.* (2009).

Chaudhry *et al.* (1972) reported that although zinc application increased the zinc status of plants it was responsible for the reduction of copper contents in the plants. Therefore Zn can also reduce the rice yield due to this antagonistic effect of zinc on copper.

Soil and foliar application of Zn with organic and INM practices showed significant differences in all the treatments. Treatment T_{10} (control) had the lowest Mn content at all the growth stages of rice. The result shows that the application of zinc affects the manganese content linearly. Meena *et al.* (2017) also reported a synergetic effect of Zn on Mg content in plants.

Application of Zn individually as a soil application or combined soil and foliar application enhanced B uptake in plants in most treatments. At tillering, the highest boron content in shoots and plants was recorded in T_2 (Zn treatment along with application of NPK fertilizers done as per the POP KAU along with soil application of zinc at the rate of 20 kg ha^{-1}) gave the highest B concentration in shoots and was at par with all the treatment except T_7 and T_{10} and the lowest B content was recorded in T_{10}. Similarly at panicle initiation, T_9 recorded the lowest B content. The results indicate that Zn is beneficial for the uptake of B especially with increased numbers of application. Uptake of boron by plants with sufficient stores increased with Zn application (Rengel *et al.*, 1998)

At tillering and panicle initiation no significant difference was recorded among the treatments. At harvest significant difference was recorded in the silicon content in the straw. The maximum silicon content was recorded in treatment T_2 which was on par with all the treatments except control. A significant increase in silicon content in straw was observed when zinc was applied at the rate of 7.5 kg

ha^{-1} compared to control. A similar trend was observed in grains and roots. Application of zinc fertilizer may lead to better plant growth by enhancing auxin production and thereby increased nutrient uptake. The highest silicon uptake was recorded with application of zinc at the rate of 7.5 kg ha^{-1}. The results were on par with the observations made by Ghasemi *et al.* (2013).

5.6 EFFECTS OF TREATMENTS ON GRAIN AND COOKED RICE

Grain analysis was done to test the effect of different treatments of zinc and its effect on phosphorus content in grain which generally show an antagonistic effect in grains.

The effects ofdifferent treatments showed a significant increase in Zn content on grain except for the control. The results revealed that application of foliar spray of $ZnSO_4$ at the rate of 1% done at tillering, panicle initiation and flowering recorded the highest Zn content on grain. The Zn content was lower with organic practices as compared to INM practices. This might be due to the application of NPK fertilizers along with FYM at a recommended dose as per POP KAU which increased the uptake of Zn.

The phosphorus content on grain was highest in treatment T_2 and lowest P content was in treatment T_5. This might have resulted because of increase in the number of application of foliar spray of Zn. Similar results were also reported in the finding of Hoseinzade *et al,* (2014) who concluded that fertilization of paddy with Zn fertilizers significantly decreased the uptake of phosphorus by rice in straw and grain. Comparatively, the treatment that recorded the highest concentration of phosphorus in straw (11.85%) and grain (0.44%) was in control.

The cooking of rice is always accompanied by the reduction of several key nutrients, especially in vital vitamins and minerals. Similar trends were also observed in the Zn content of cooked rice where the reduction of the amount of Zn after cooking accounted for nearly about 40 per cent. Jena *et al.*, (2006) also reported similar results that cooking of rice resulted in a reduction in Zn content which accounted for 36 per cent. The highest Zn content after cooking was in T_8 and the lowest was recorded in control.

Summary

6. SUMMARY

The salient findings of the present research study entitled "Biofortification of rice (*Oryza sativa*) with zinc under organic and integrated nutrient management practice" are summarized in this chapter.

The field experiment was conducted in Regional Agricultural Research Station, Pilicode during June 2018 to October 2018 with the main objective to study the effects of zinc fertilization on nutrient zinc content in the rice grains. The investigation was carried out using Uma variety which is one of the leading consumed rice variety in the state of Kerala. The experiment was conducted using RBD consisting of ten treatments having three replications. The treatments consisted of zinc fertilization as soil application and combined soil and foliar application under organic (organic POP) and INM (POP KAU) practices. The layout of the experimental field was planned in such a way that three plots each of 4 m^2 were maintained in a single row and the entire experimental plot consisted of 10 such rows. After land preparation, application of lime was done followed by incorporation of FYM. Prior to the transplanting, the seedlings were maintained in the nursery for 24 days. At nursery stage, a portion of the seedlings was maintained separately for the application of foliar spray of $ZnSO_4$ at the rate of 1 % for treatment T_9. After transplanting basal application of recommended dose of NPK fertilizers was done as per POP KAU which was then followed by soil application of $ZnSO_4$ at the rate of 25 Kg ha^{-1} at 7 days after application of NPK fertilizers. Foliar spray of $ZnSO_4$ at the rate of 1 % was done at tillering, panicle initiation and flowering stages of the crop growth.

Soil analysis was conducted before rice cultivation, at 30 DAT and after harvest to study the effects of different treatments on various physical and chemical properties of soil and its fertility status.

The soil analysis results obtained at 30 DAT showed a gradual increase in the soil pH compared to the initial pH. The organic carbon content in soil was also highest during this stage as compared to the initial OC content of the soil. The concentration of available major nutrients (N, P and K) in soil was significantly higher in those treatments where soil application of $ZnSO_4$ at the rate of 25 Kg ha^{-1} was carried out under INM practices. Similarly, the concentration of soil available Zn was significantly increased in all the treatments except for treatment T_9 (application of Zn at nursery) and control. Due to the rise in pH during flooding several nutrients like Fe, Mn and Si in soil were improved significantly except for Cu.

At the harvest stage, soil analysis results revealed a decline in pH and OC content which was even lower than the respective initial value. This drop in pH and OC content of the soil was also accompanied by a decline in the concentration of most soil available nutrients (except copper) as compared to the concentration of nutrients at 30 DAT.

Biometric observations were also taken at tillering, panicle initiation, flowering and harvest stage to check the effects of different treatments on growth and yield parameters of rice. Observations like plant height and number of tillers per hill were taken at different growth stages. Other observations like the number of panicles, test weight of grains, straw and grain yield were taken at harvest stage.

Soil and foliar application of Zn significantly enhanced plant growth parameters like plant height and number of tillers per hill however, Zn fertilization under INM practices were more effective as compared to treatments under organic practices. At harvest stage, the highest plant height (99.91 cm) and the maximum number of tillers per hill (15.66) were recorded in treatment T_8.

Similar trends were recorded in other observations like the number of panicles, test weight of grains, straw and grain yield where Zn treatment under INM practices showed better yield than organic practices and control. The treatments that recorded the maximum number of panicles and test weight were T_8 (15.56) and T_7 (27.10 g) respectively. Highest grain yield among the treatments was recorded in treatment T_7 (6.79 t ha^{-1}).

The effect of different treatments on the nutrient content in shoot, straw and grain were also studied at different stages of crop growth. Plant analysis results revealed that Zn fertilization under INM practices significantly enhanced N, K and Zn content in plants. The treatments that recorded the highest N content in the straw at harvest stage was treatment T_8 which was superior over all the other treatments. Lowest N content in straw was recorded in T_{10} (Control). At harvest highest K content in straw was recorded in treatment T_8 (applying fertilizers and manures as per POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1} + triple spray of $ZnSO_4$ at 1%) which was on par with treatments T_2 and T_7. At harvest stage treatment T_8 was significantly superior over all the other treatments in terms of Zn concentration it recorded a value of 85.73 mg Kg^{-1} in straw followed by treatment T_7. Lowest Zn concentration in straw was recorded in treatment T_{10} with a value of 56.26 mg Kg^{-1}.

Antagonistic interactions between P and Zn were observed from the plant analysis results. An increase in the Zn application resulted in lower P content in shoot and straw. At harvest stage P content in straw was significant higher in treatment T_2 (applying fertilizers as per POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1}) and the lowest content of P in straw was recorded in T_5 (applying manures as per POP KAU + soil application of Zn at the rate of 20 Kg ha^{-1} + triple spray of $ZnSO_4$ at 1%)

One of the main objectives of this experiment is to check the Zn nutrient content in rice grain under the effect of different Zn treatments. Zn analysis was done to check its content in the grain and cooked rice. The results revealed that triple foliar spray of $ZnSO_4$ along with soil application of $ZnSO_4$ under INM practices recorded the highest Zn content in grain (49.86 mg kg^{-1}) as well as cooked rice (28.52 mg kg^{-1}) and was superior compared to other treatments.

References

7. REFERENCES

Abid, M., Khan, I., Mahmood, F., Ashraf, U., Imran, M., and Anjum, S. 2015. Response of hybrid rice to various transplanting dates and nitrogen application rates. *Philipp. Agric.* 98: 98-104.

Adel, G. 2016. Effect of Different Methods of Zn Application on Rice Growth, Yield and Nutrients Dynamics in Plant and Soil. *J. Agric. Ecol. Res. Intl.* 6: 1-9.

Alam, S.M., Zafar, I., and Latif, A. 2000. Effect of P and Zn application by fertigation on P use efficiency and yield of wheat. *Int. J. Agric. Res. Ext.* 3(2):17-20.

Ali, S., Said, A., Saeed, B., Ahmad, I., and Ali, K. 2011. Response of yield and yield components of wheat towards foliar spray of nitrogen, potassium and zinc. *J. Agric. Biol. Sci.* 5: 23-25.

Amanullah. and Inamullah. 2016. Residual phosphorus and zinc influence wheat productivity under rice–wheat cropping system. *Springerplus*. 5: 255.

Appavu, K. and Ramulu, U.S. 1981. Froms of zinc and their distribution in some soil profile of Tamil Nadu. *Agric. J.* 68(5): 325.

Ashoka, Mudalagiriyappa, P., and Desai, B.K. 2008. Effect of micronutrients with or without organic manures on yield of baby corn-chickpea sequence. *Karnataka J. Agric. Sci.* 21(4): 485-487.

Azad, B.S. and Lehria, S.K. 2001. Yield maximization of rice through integrated nutrient management under irrigated conditions. *Ann. Agric. Res.* 22(4): 471-475.

Barak, P. and Helmke, P.A. 1993. The chemistry of zinc. In: Robson, A.D. (ed.), *Zinc in soils and plants*, Kluwer Academic Publishers, Dordrecht, pp 90-106.

Benedicto,A., Hernández-Apaolaza, L., Rivas, I., and Lucena, J.J. 2011. Determination of ^{67}Zn distribution in navy bean (Phaseolus vulgaris L.) after foliar application of ^{67}Zn–lignosulfonates using isotope pattern deconvolution. *J. Agric. Food Chem*. 59: 8829–8838.

Bhargava, B. S. and Raghupathi, H. B. 1995. Analysis of plant material for macro and micronutrients. In: Tandon, H.L.S. (ed.), *Methods of analysis of soils, plants, water and fertilizers*. Malhotra publishing house, New Delhi, pp. 61-62.

Bingham, F. T. 1982. Boron. In: Page, A. L. (ed.), *Methods of soil analysis* (2nd ed.). *Am. Soc. of Agron*. Madison, USA, p.438.

Black, C. A., Evans, D. D., Ensminger, L. E., White, J. L., and Clark, F. E. 1965. *Methods of soil analysis*. *Am. Soc. Agron.* Madison, USA, p.156.

Boonchuay, P., Cakmak, I., Rerkasem, B., and Prom-u-Thai, C. 2013. Effect of different foliar Zn application at different growth stages on seed Zn concentration and its impact on seedling vigor in rice. *Soil Sci. Plant Nutr.* 59: 180-188.

Brown, K.H., Rivera, J.A., Bhutta, Z., Gibson, R.S., King, J.C., Lönnerdal, B., Ruel, M.T., Sandtröm, B., Wasantwisut, E., and Hotz, C. 2004. Assessment of the risk of zinc deficiency in populations and options for its control. *Food Nutr. Bull.* 25(1 & 2): 99-203.

Cakmak, I. 2007. Enrichment of cereal grains with zinc: Agronomic or genetic biofortification. *Plant Soil*. 302: 1-17.

132

Cakmak, I. 2009. Enrichment of fertilizers with zinc: An excellent investment for humanity and crop production in India. *J. Trace Elements Med. Biol.* 23(4): 281–289.

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

Channabasavanna, A.S., Yelamali, S.G., and Biradar, D.P. 2001. Response of rice (*Oryza sativa* L.) to sources of organic manures and levels of zinc sulphate in deep black soils. *Indian J. Agron*. 46(3): 458-461.

Chaudary, S.K. and Sinha, N.K. 2007. Effect of levels of nitrogen and zinc on grain yield and their uptake in transplanted rice. *Oryza*. 44(1): 44-47.

Chaudary, S.K., Thakur, S.K., and Pandey, A.K. 2007. Response of wetland rice (*Oryza sativa* L.) to nitrogen and zinc. *Oryza*. 44(1):31-34.

Chaudhary, F.M. and Loneragan, J.F. 1972. Zinc absorption by wheat seedlings and the nature of its inhibition by alkaline earth cations. *J. Exp. Bot.* 23: 552-560.

Chaudhary, S. K., Thakur, S. K., and Pandey, A. K. 2007. Response of wetland rice to nitrogen and zinc. *Oryza.* 44(1): 31-34.

Chavan, R. S., Katkar, R. N., and Bhende, R. K. 2018. Effect of zinc application on utilization of nutrient uptake, yield and quality of chickpea in inceptisol. *Res. J. Agric. Sci.* 9(1): 14-18

Chouhan, N., Sharma, G.D., Khamparia, R.S., and Sahu, R.K.2012. Status of sulphur and micronutrients in medium black soils of Dewas district, Madhya Pradesh. *Agropedology*. 22(1): 66-68.

Das, D.K., Karak, T., and Maiti, D. 2004. Effect of foliar application of different sources of Zn on the changes in Zn content, uptake and yield of rice (*Oryza sativa* L.). *Ann. Agric. Res. Ser*. 25(2): 253-256.

Dash, A.K., Singh, H.K., Mahakud, T., Pradhan, K.C., and Jena, D. 2015. Interaction effect of nitrogen, phosphorous, potassium with sulphur, boron and zinc on yield and nutrient uptake by rice under rice-rice cropping system in Inceptisols of coastal odisha. *Int. Res. J. Agric. Sci. Soil Sci*. 5(1): 14-21.

Dhaliwal, S.S., Sadana, U.S., Khurana, M.P.S., Dhadli, H.S., and Manchanda, S. 2010. Effect of foliar application of Zn and Fe on rice yield. *Indian J. Fertil*. 6 (7): 28-35.

Dipankar, K., Ghosh, D., and Srivastava, P.C. 2007. Efficacy evaluation of different zinc-oegano complexes in zinc to maize. *Plant J. Indian Soc. Soil Sci*. 55(1): 67-72.

Dixit, V., Parihar, A.K.S., and Ganesh, S. 2012. Effect of sulphur and Zinc on yield, quality and nutrient uptake of hybrid rice in sodic soil. *J. Agric. Sci. Tech*. 1(2):26-30.

Dixit, V., Parihar, A.K.S., Kumar, A., Singh, D., and Rahi, T.S. 2012. Effect of Sulphur and Zinc on Yield Quality and Nutrient Uptake of Hybrid Rice in Sodic Soil. *Int. J. Environ. Sci. Tech*. 1 (1): 53-57.

Emmel, R. H., Solera, J. J., and Stux, R. L. 1977. *Atomic absorption methods manual*. Instrumentation Laboratory Inc., Wilmington, pp. 67-190.

Fageria, N.K., Barbosa, M.P., and Santos, A.B. 2008. Growth and zinc uptake and use efficiency in food crops. *Commun. Soil Sci. Plant Anal*. 39: 2258–2269.

Ghasal, P.C., Shivay, Y.S., Pooniya, V., Choudhary, M., and Varma, R.K. 2017. Zinc fertilization effect on macro and micronutrients concentrations and uptake in Wheat (*Triticum aestivum*) varieties. *Indian J. Agron*. 62(4): 470-475.

Ghassemi-Golezani, K., Saleh, J., Najafi, N., Oustan, S. and Aliasgharzad, N. 2013. Effects of silicon, salinity and water-logging on the extractable Zn, Cu, K, and Na in a sandy loam soil. *Int. J. Agric. Res. Rev.* 3: 56–64.

Gibson, R.S. 2006. Zinc: the missing link in combating micronutrient malnutrition in developing countries. *Proc. Nutr. Soc*. 65(1): 51-60.

Gogoi, N., Basumatary, A., Gayatri, G., Hazarika, D.B., and Medhi, B.K. 2016. Enrichment of rice grains with zinc through agronomic Bio-fortification. *J. Indian. Soc. Sci*. 64(4): 414-418.

Graham, R.D. 2008. Micronutrient deficiencies in crops and their global significance. In: Alloway, B.J. (ed.), *Micronutrient deficiencies in global crop production*. Vol. 105. Springer, Dordrecht, pp 41–61.

Graham, R.D., Welch, R.M., and Bouis, H.E. 2001. Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: Principles, perspectives and knowledge gaps. *Adv. Agron*. 70:77–142.

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

Hagnesten, H. 2006. Zinc deficiency and iron toxicity in rice soils of Office du Niger, Mali. M.Sc.(Ag) thesis, Sweden University of Agricultural Sciences, Sweden.

Haldar, M. and Mandal, L.N. 1981. Effect of phosphorus and zinc on the growth and phosphorus, zinc, copper, iron and manganese nutrition of rice. *Plant Soil.* 59: 415-425.

Hambidge, M. 1997. Zinc deficiency in young children. *Am. J. Clin. Nutr.* 65(1): 160.

Hazra, G.V. and Mandal, B. 1988. Distribution of DTPA extractable Fe, Mn, Cu and Zn in some acid alluvial soils of West Bengal and the effect of submergence on their contents. *Indian J. Soc. Soil Sci.* 36: 169-172.

Herschfinkel, M., Silverman, W.F., and Sekler, I. 2007. The zinc sensing receptor, a link between zinc and cell signaling. *Mol. Med.* 13: 331–336.

Hoseinzade, H., Mobaleghi, M., Maleki, Y., Mashayekhi, S., and Divsalar, N. 2014. Investigating the effect of zinc sulfate chelate application on phosphorous uptake in rice cv. 'Shirodi'. *Agric. Commun.* 3(2): 28-33.

Hussain, S.T., Hussain, A., and Showkat, A.D. 2018. Biofortificational benefits of zinc application to rice genotypes. *J. Pharma. Phytochem.* 7(1): 1555-1558.

IRRI. 1964. *Annu. Rep. Int. Rice Res. Inst.*, Los Bafios, Philippines.

Islam, A. and Islam, W. 1973. Chemistry of submerged soils and growth and yield of rice. *Plant and soil.* 39(3): 555-565.

Issac, R. A. and Kerber, J. D. 1971. Atomic absorption and flame photometry techniques and uses in soil, plant and water analysis. In: Walsh, L. M. (ed.). *Instrumental methods for analysis of soil and plant tissue*. Soil Science Society America, Madison, USA, pp. 17-37.

Jackson, M. L. 1958. Soil chemical analysis. In Cliffs, E. N. J. (ed.). Soil Science University of Wisconsin, USA, Madison, pp. 89-102.

Jaksomsak, P., Tuiwong, P., Rerkasem, B., Guild, G., Palmer, L., Stangoulis, J., and Prom-U-Thai, C.T. 2018. The impact of foliar applied zinc fertilizer on zinc and phytate accumulation in dorsal and ventral grain sections of four Thai rice varieties with different grain zinc. *J. Cereal Sci.* 79: 6-12.

Jalali, V.K., Talib, A.R., and Takkar, P.N. 1989. Distribution of micronutrients in some bench marked soils of Kashmir at different altitudes. *J. Indian Soc. Soil Sci*. 32: 3754-3577

Jana, P.K., Ghatak, R., Sounda, G., Ghosh, R.K., and Bandyopadhyay, P. 2009. Effect of zinc fertilization on yield, N, P, K and Zn uptake by transplanted rice at farmer's field of red and laterite soils of West Bengal. *Indian Agric*. 53 (3&4): 129-132.

Jena, D., Pal, A.K., Bansal, S.K., and Cakmak, I. 2011. Zinc Biofortification of rice grown in an iron toxic soil of Orissa, India. Available: *www.Zinccrops2011. org/presentations/2011*. [3 Dec2018]

Jena, P.K. 1999. Zinc management in transplanted rice. M. Sc. (Ag) thesis, Acharya N G Ranga Agricultural University, Hyderabad, India. p 74.

Jena, P.K., Rao, C.P., and Subbiah G. 2006. Effect of zinc management practices on growth, yield economics in transplanted rice. *Oryza*. 43: 326-328.

Kadam, S.R., S.R., Bhale, V.M., Kubade, K.J., and Deshmukh M.R. 2018. Effect of zinc and iron fortification on growth and developmental stages of upland irrigated rice (*Oryza sativa* L.) cultivars. *Int. J. Curr. Microbiol. App. Sci*. *7*(1): 1950-1958.

Kalokhe, D.P. 2017. Fractionation of boron and effect of submergence on different boron fractions in soils of Konkan. Ph.D. thesis, DBSKKV, Dapoli, Maharashtra.

Katayal, V and Gangwar, B. 2000. Long term effect of integrated nutrient management on crop productivity of rice-rice system. *Indian J. Agric. Sci*. 70(2): 110-113.

Katyal, J.C. 1985. Research assessment of all India coordinated scheme of micronutrients in soils and plants. *Fertil. News*. 30: 67-80.

Kennedy, G. and Burlingame, B. 2003. Analysis of food composition data on rice from a plant genetic resource s perspective. *Food Chem.* 80: 589-596.

Keram, K.S., Sharma, B.L., and Sawarkar, S.D. 2012. Impact of Zn application on yield, quality, nutrients uptake and soil fertility in a medium deep black soil (Vertisol). *Int. J. Sci. Environ. Tech.* 1(5): 563-571.

Khan, M.U., Qasim, M., and Jamil, M. 2002. Effect of different levels of Zinc on the extractable Zinc content of soil and chemical composition of rice. Asian J. Plant Sci. 1: 20-21.

Khan, M.U., Qasim, M., and Khan, I. 2007. Effect of Zn fertilizer on rice grown in different soils of Dera Ismail Khan. *Sarhad J. Agric.* 23(4): 72-75.

Khan, M.U., Qasim, M., Subhan, M., Jamil, M., and Ahmad, R.D. 2003. Response of rice to different methods of zinc application in calcareous soil. *Pakist. J. Appl. Sci.* 3(7): 524-529.

Khan, R., Gurmani, A.R., Khan, M.S., and Gurmani A.H. 2007. Effect of zinc application on rice yield under wheat rice system. *Pakist. J. Biol. Sci.* 10: 235-239.

Kulandaivel, S., Mishra, B.N., Gangaiah, B., and Mishra, P.K. 2004. Effect of levels of zinc and iron and their chelation on yield and soil micronutrient status in hybrid rice (*Oryza sativa*) - wheat (*Triticum aestivum*) cropping system. *Indian J. Agron.* 49(2): 80-83.

Kumar, B. and Singh, S.P. 1996. Zinc management in nursery and transplanted rice (*Oryza sativa*). *Indian J. Agron.* 41 (1):153-154.

Kumar, D., Chauhan, R.P.S., Singh, B.B., and Singh, V.P. 1999. Response of rice (*Oryza sativa*) to zinc sulphate incubated and blended with organic materials in sodic soil. *Indian J. Agric. Sci.* 69(6): 402-405.

Ma, J.F., Tamai, K., Ichii, M., and Wu, G.F. 2002. A rice mutant defective in Si uptake. *Plant Physiology*. 130: 2111– 2117.

Maclean, J.L., Dawe, D.C., Hardy, B., and Hettel, G.P. 2002. *Rice Almanac* (3rd Edition). CABI Publishing, Wallingord, UK, 10 pp.

Maneesh, P. and Deepa, N.R. 2016. Trend analysis of area, production and productivity of rice in kerala in the context of food security. *Int. J. Agric. Res. Rev*. 4(8): 538-546.

Maqsood, A.G., Kanwal, S., and Rahmathullah. 2004, Differences in phosphorus-zinc interaction among sunflower *(Helianthus Annuus* L.), Brassica *(Brassica Napus* L.) and Maize *(Zea Mays* L.). *Pakist. J. Agri. Sci.* 41(1-2): 29-35.

Meena, R.S., Prasad, S.K. Layek, A., Singh, M.K., and Hingonia, K. 2017. Nitrogen and zinc scheduling for productivity and profitability in direct-seeded rice (*Oryza sativa*). *Indian J. Agron*. 62(4): 525-527.

Merrill, S. Jr., Potter, G.F., and Brown, R.T. 1953. Responses of tung trees on lakeland fine sand to less common elements. *Proc. Am. Soc. Hort. Sci.* 62: 94-102.

Mishra, P., Singh, R., Srivastava, P.C., and Ram, B. 2009 Effect of continuous cropping and fertilization on zinc fractions and their contribution to plant uptake under rice-wheat system. *J. Indian Soc. Soil Sci.* 57: 167-71.

Mollah, M.Z.I., Talukder, N.M., Islam, M.N., and Ferdous, Z. 2009. Effect of nutrients content in rice as influenced by zinc fertilization. *World Appl. Sci. J.* 6(8): 1082–1089.

Morshedia, A. and Farahbakhsh, H. 2010.Effects of potassium and zinc on grain protein contents and yield of two wheat genotypes under soil and water salinity and alkalinity stress. *Plant Ecophysiol*. 2: 67-72.

Muralidarudu, Y. 1991. Studies on availability of zinc applied through chelated forms to rice. *J. Indian Soc. Soil Sci.* 39(1): 114-117.

Murthy, A.S.P. 1988. Distribution, properties and management of vertisols of India (En). *Adv. in Soil Sci.* 8: 151-214.

Mustafa, G., Akbar, N., S.A., Iqbal, A., Khan, H.Z., Khawar, Z., Chattha, A.A., and Trethowan, R., 2011. Effect of Zinc application on growth and yield of rice (*Oryza sativa* L.). *Int. J. Agro. Vet. Med. Sci.* 5(6): 530-535.

Naik, S.K. and Das, D.K. 2008. Relative performance of chelated zinc and zinc sulphate for lowland rice (*Oryza sativa* L.). *Nutr. Cycl. Agroecosys.* 81: 219–227.

Nirmaladevi, P. 2001. Zinc use efficiency in rice hybrids. M.Sc. (Ag) thesis, Acharya N G Ranga Agricultural University, Hyderabad, India. p 67.

Panse, V.G. and Sukhatme, P.V. (1985) Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research Publication, 87-89.

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

Patel, M.M., Patel, I.C., Patel, P.H., Patel, A.G., Acharya, S., and Tikka, S.B. 2009. Impact of foliar nutrition of zinc and iron on productivity of cowpea under rainfed condition. *J. Arid Legumes*. 6(1): 49-51.

Pfeiffer, W.H. and McClafferty, B. 2007. HarvestPlus: Breeding crops for better nutrition. *Crop Sci.* 47: 88–105.

Phattarakul, N., Mongon, J., and Rerkasem, B. 2011. Variation in rice grain zinc and their response to zinc fertilizer. Available: www.fertilizer.org [7 Nov 2018].

Ping, L., Wang, X., Zhang, T. Zhou, D., and Yuanqiu, H.E. 2008. Effect of several amendments on rice growth and uptake of copper and cadmium from contaminated soil. *J. Environ. Sci.* 20: 449-455.

Piper. 1966. Aging of crystalline precipitates. *Analyst* 77: 1000-1001.

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

Pooniya, V., Shivay, Y.S., and Bana, R.S. 2011. Effects of zinc fertilization on productivity and Zn concentrations in Basmati rice (*Oryza sativa* L.). Available: www.zinccrops.org. [28 Nov 2018]

Pooniya,V. and Shivay, V.S. 2013. Enrichment of Basmati rice grain and straw with Zinc and Nitrogen through ferti-fortification and summer green manuring under Indo- Gangetic plains of India. *J. Plant Nutr.* 36: 91–117.

Potarzycki, J. and Grzebisz, W. 2009. Effect of zinc foliar application on grain yield of maize and its yielding components. *Plant Soil Environ.* 55(12): 519-527.

Prasad, A.S. 2009. Zinc: role in immunity, oxidative stress and chronic inflammation. *Curr. Opinion Clin. Nutr. Metabolic Care*. 12(6): 646-652.

Prasad, R., Shivay, Y.S., and Kumar, D. 2014. Agronomic biofortification of cereal grains with iron and zinc. *Adv. in Agron.* 125, 55-91.

Prasad, R.K., Vipin, K., Prasad, B., and Singh, A.P. 2010. Long-term effect of crop residues and zinc fertilizer on crop yield, nutrient uptake and fertility buildup under rice-wheat cropping system in calciorthents. *J. Indian Soc. Soil Sci.* 58: 205-211.

Pratt, P. F. 1965. *Potassium in methods of soil analysis*. (2nd Ed.). American Society of Agronomy, Madison, USA, pp. 1019-1021.

Rahman, A., Yasin, M., Akram, M., and Awan, Z.I. 2002. Response of rice to zinc-application and different N-sources in calcareous soil. *Sci. Vision*. 8(1): 12-15.

Rajput, A.L. 1997. Effect of nitrogen and zinc split application on wheat (*Triticum aestivum*) and their residual effect on rice (*Oryza sativa*). *Indian J. Agron*. 42(1): 22-25.

Ram, H., Sohu, V.S., Cakmak, I., Singh, K., Buttar, G.S., Sodhi, G.P.S., Gill, H.S., Bhagat, I., Singh, P., Dhaliwal, S.S., and Mavi, G.S. 2015. Agronomic fortification of rice and wheat grains with Zn for nutritional security. *Current Sci*. 109(6): 1171-1176.

Ram, H., Sohu, V.S., Singh, K., Cakmak, I., Buttar, G.S., Sodhi, G.P.S., Gill, H.S., Bhagat, I., Singh, P., Dhaliwal, S.S., and Mavi, G.S. 2011. Agronomic fortification of rice and wheat grains for improving human health. In: Third International Zinc Symposium: '*Improving crop production and human health*', October 10-14, Hyderabad, Andhra Pradesh, India.

Randhawa, N.S. and Takkar, P.N. 1975. Micronutrient research in India. *Fertil. News*. 20: 11–19.

Rao, C.P. 2003. Nutrient utilization efficiency of rice influenced by different sources and levels of phosphorus and rates of zinc. *Ann. Agric. Res. New Ser*. 24(1): 7-11.

Rathore, G.S., Khamparia, R.S., Gupta, G.P., and Sinha, S.B. 1980. Availability of micronutrients in some alluvial soils and their effect on wheat. *J. Indian Soc. Soil Sci*. 28:248-250.

Rathore, R.S., Lal, P., Pandey, P.C., and Bisht, P.S. 2004. Effect of long term application of fertilizers and farmyard manure on soil fertility and rice productivity under rice-wheat system. *Oryza*. 41(2): 45-47.

Ravikiran, S. and Reddy, G.L.N. 2004. Invivo fortification of zinc in rice (*Oryza sativa* L.). *Andhra Agric. J.* 51(2): 184-187.

Reddy, M., Padmaja, B., Reddy, R.U., and Reddy, D.V.V. 2011. Response of low land rice to source, time and method of zinc application. *J. Res. Angrau.* 39(1): 14-19.

Rengel, Z., Romheld, V., and Marschner, H. 1998. Uptake of zinc and iron by wheat genotypes differing in tolerance to zinc deficiency. *J. Plant Physiol.* 142: 433-438.

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

Saha, J. and Mandal, B. 2000. Redistribution of copper in Alfisols under submergence. I. Native copper. *Communications in Soil Science and Plant Analysis*. 31: 1121-1127.

Saha, S.B., Mandal, G.C., Hazra, A., Dey, M., Chakraborty, B., Adhikari, S.K., and Sadhukhan, R. 2015. Can agronomic biofortification of zinc be benign for iron in cereals? *J. Cereal Sci.* 65: 186-191.

Sahrawat, K.L. 2004. Organic matter accumulation in submerged soils. *Adv. Agron.* 81: 169-201.

Sahu, S.K., Mitra, G.N., and Pani, S.C. 1996. Effect of Zn application on uptake of nutrients by rice on an Inceptisol. *J. Indian Soc. Soil Sci.* 44(4): 795-796.

Sankaran, M.S., Mani, S., and Savithri, P. 2001. Effect of teprosyn and zinc sources on yield and nutrient uptake in rice (*Oryza sativa* L.). *Madras Agric. J.* 88 (10-12): 715-716.

Savithri, P., Perumal, R., and Nagarajan, R. 1999. Soil and crop management technologies for enhancing rice production under micronutrient constraints nutrient. *Nutr. Cycl.* 53(1): 83-92.

Sedberry, J.E., Peterson, F.J., Wilson, E., Nugent, A.L., Engler, R.M. and Brapbackor, R.H. 1971. Effects of zinc and other elements on the yield of rice and nutrient content of rice plants. *Louisiana Agr. Exp. Sta. Bull.* 653p.

Shahid, M., Nayak, A.K., Shukla, A.K., Tripathi, R., Kumar, A., Raja, R., Panda, B.B., Meher, J., Bhattacharyya, P., and Dash, D. 2014. Mitigation of iron toxicity and iron, zinc, and manganese nutrition ofwetland rice cultivars (*Oryza sativa* L.) grown in iron-toxic soil. *Soil Air Water.* 42: 1604–1609.

Sharma, S.K., Bhunia, S.R., and Pathan, A.R.K. 1999. Effect of zinc fertilization on transplanted rice in Ghaggar flood plains of North-West Rajasthan. *Crop Res.* 20(2): 245-247.

Shehu, H.E., Jamala, G.Y., and Musa, A.M. 2011. Response of transplanted irrigated rice (Faro, 44) to applied zinc by nursery enrichment of fadama soil in Adamawa State, Nigeria. *World J. Agric. Sci.* 7(2): 143-148.

Shivay, Y.S. and Prasad, R. 2009. Zinc fertilization for higher yield and quality in basmati rice. *Indian Farming.* 59(6): 36-37 & 52.

Shivay, Y.S., Prasad, R., Singh, R.K., and Pal, M. 2015. Relative efficiency of zinc-coated urea and soil and foliar application of zinc sulphate on yield, nitrogen, phosphorus, potassium, zinc and iron biofortification in grains and uptake by basmati rice (*Oryza sativa* L.). *J. Agri. Sci.* 7(2): 161-173.

Siddhamalai, A., Appavu, K., and Poongothai, S. 2002. Distribution of DTPA-extractable Zn, Cu, Fe and Mn in rice soils of Tamil Nadu. *Madras Agric. J.* 89: 737- 740.

Sims, J. R. and Johnson, G. V. 1991. Micronutrient soil tests. In: Mortvedt, J. J. (ed.), *Micronutrients in Agriculture* (2nd ed.). Soil Science Society of America, Madison, USA, pp. 427-476.

Singh, G., Singh, O.P., Singh, R.G., Mehta, R.K., Kumar, V., and Singh, R.P. 2006. Effect of integrated nutrient management on yield and nutrient uptake of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system in lowlands of eastern Uttar Pradesh. *Indian J. Agron*. 51(2): 85-88.

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

Singh, J.P., Karwasra, S.P.S., and Singh, M. 1988. Distribution and forms of copper, iron, manganese, and zinc in calcareous soils of India. *Soil Science*, 146(5): 359-366.

Singh, K. and Banarjee, N.K. 1984. Available micronutrient status of some desert soils of Haryana. *Ann. of Arid Zone*. 23(l): 21-24.

Singh, M.V. 2008. Micronutrient fertility mapping of Indian soil, Technical Bulletin. AICRP Micronutrients, vol, 7. IISS, Bhopal, pp. 1-60.

Singh, M.V., Naraval, R.P., Patel K.P., and Sadana, U.S. 2009.Changing scenario of micronutrient deficiencies in India during four decades and its impact on crop responses and nutritional health of human and animals. *Indian J. Fertil.* 5(4) 11-26.

Singh. R., Prasad, S.K., and Singh, M.K. 2013. Effect of nitrogen and zinc fertilizer on zinc biofortification in pearlmillet (*Pennisitum glaucum*). *Indian. J. Agron*. 59(3): 474-476.

Srivastava, P.C., Gosh, D., and Singh, V.P. 1999. Evaluation of different Zn sources for lowland rice production. *Biol. Fertil. Soils*. 30 (1-2): 168-172.

Stalin, P., Bazroy, J., Dimri, D., Singh, Z., Senthil, V., and Narayanan, S. 2013. Prevalence of under-weight and its risk factors among under-five children in a rural area of Kancheepuram District, Tamil Nadu. *J. Dental Med. Sci.* 3 (6):71-4.

Stalin, P., Das, T., Muthumanickam, D., Chitdeshwari, T., and Velu, V. 2011. Foliar nutrition of rice to enhance micronutrient concentration in grains. *Int. Rice Res. Notes*. 1170-1176.

Stomph, T.J., Hoebe, N., and Spaans, E. 2011. The relative contribution of post-flowering uptake of Zn to rice grain Zn density. 3rd International Zn Symposium; 2011 Oct 10–14; Hyderabad, India. Available: https://doi.org/10.3389/fpls.2014.00008 [20 Nov 2018]

Subba, R.A. 2005. Nitrogen and zinc effects on productivity and quality of rice (*Oryza sativa* L.) with and without farm yard manure. M.Sc. (Ag) thesis, Acharya N G Ranga Agricultural University, Hyderabad, India. 68p.

Subbiah, B. V. and Asija, G. L. A. 1956. A rapid procedure for the estimation of available nitrogen in soil. *Curr. Sci*. 32: 325-327.

Tapeiro, H. and Tew, K. D. 2003. Trace elements in human physiology and pathology: Zinc and metallothioneins. *Biomed Pharmacother*. 57(9):399-411.

Udo, E.J. and Fagbemi, A.A. 1979. The Profile Distribution of Total and extractable Zinc in Selected Nigerian Soils. *Commun. Soil Sci. Plant Anal*. 10: 1141-1161.

Vasudeva and Ananthanarayana, R. 2001. Response of paddy to different levels of zinc application based on adsorption maxima in acid soils of Karnataka. *Madras Agric. J*. 88(7-9): 498-500.

Walkley, A. J. and Black, I. A. 1934. Estimation of soil organic carbon by chromic acid and titration method. *Soil Sci*. 31: 21-38.

Wei, Y.Y., Shohag, M.J.I., and Yang, X.E. 2012. Biofortification and bioavailability of rice grain zinc as affected by different forms of foliar zinc fertilization. Available: doi:10.1371/journal.pone.0045428. [05 Nov 2018].

Yadav, G.S., Kumar, D., Shivay, Y.S., and Singh, H.D. 2010. Zinc-enriched urea improves grain yield and quality of aromatic rice. *Better Crops*. 94(2): 6-7.

Yadav, G.S., Kumar, D., Shivay, Y.S., and Singh, N. 2011. Agronomic evaluation of zinc-enriched urea formulation in scented rice (*Oryza sativa*). *Indian J. Agric. Sci.* 81(4): 366-370.

Yaseen, M., Hussain, T., Hakeem, A., and Ahmad, S. 1999. Integrated nutrient use including Zn for rice. *Pakist. J. Biol. Sci.* 2: 614-616.

Yassen, A., Abou, E.A., El-Nour, A., and Shedeed, S. 2010. Response of wheat to foliar spray with urea and micronutrients. *J. Am. Sci*. 6(9): 14-22.

Yin, H., Gao, X.P. Stomph, T., Li, L., Zhang, F.S., and Zou, C.Q. 2016. Zinc concentration in rice (*Oryza sativa* L.) grains and allocation in plants as affected by different zinc fertilization strategies. *Commu. Soil Sci. Plant Anal*. 47(6): 761-768.

Yoshida, S. and Tanaka, A. 1969. Zinc deficiency of the rice plant in calcareous soils. *Soil Sci Plant Nutr*. 15: 75–80.

Yuan, L., Wu, L., Yang, C., and Lv, Q. 2012. Effects of Iron and Zn foliar applications on rice plants and their grain accumulation and grain nutritional quality. *J. Sci. Food Agric*. 93: 254-261.

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

Zhu, Y., G., Smith, S. E., and Smith, F. A. 2001, Plant growth and cation composition of two wheat cultivars of spring wheat differing in P uptake efficiency. *J. Exp.bot.* 52(359):1277-82.

BIOFORTIFICATION OF RICE (*Oryza sativa*) WITH ZINC UNDER ORGANIC AND INTEGRATED NUTRIENT MANAGEMENT PRACTICES

By

WAYOOLANG TALANG
(2017 - 11 - 125)

ABSTRACT OF THESIS

Submitted in partial fulfillment of the requirement for the degree

MASTER OF SCIENCE IN AGRICULTURE

In

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE PADANNAKKAD, KASARGOD – 671 314
KERALA, INDIA 2019

8. ABSTRACT

An investigation entitled "Biofortification of rice (*Oryza sativa*) with zinc under organic and integrated nutrient management practices" was carried out in Regional Agricultural Research Station (RARS), Pilicode during June to October 2018. The study was conducted in rice variety Uma (MO 16). The main objective of this research was to check the zinc nutrient content under organic and integrated nutrient management practices (INM).

The field experiment was laid out under Randomized Block Design (RBD) with nine treatments and one control each replicated three times. The treatments consisted of soil application of Zn and combined soil and foliar application of Zn under organic (Organic Package Of Practice) and INM practices (Package Of Practice Kerala Agricultural University). Zn was applied as zinc sulphate ($ZnSO_4$) at the rate of 1 per cent and 20 kg ha^{-1} as foliar application and soil application respectively. Foliar application of $ZnSO_4$ was done at three growth stages of rice viz tillering, panicle initiation and flowering stage. Single foliar application of Zn was done at only tillering stage. Double foliar application of Zn was done at tillering and panicle initiation stages and triple foliar application of Zn was done at all the three growth stages.

The effect of different treatments significantly influenced plant growth attributes like plant height, number of tillers per hill and panicles per hill. At harvest stage, the highest plant height (99.9 cm) was recorded in T_8 (POP KAU + soil application of Zn + triple foliar spray of Zn) which was on par with T_7. The minimum plant height was recorded in control (92.3 cm). Similarly, the maximum number of tillers per hill (15.5) and maximum number of panicles per hill (15.5) was recorded in T_8 at harvest stage. Soil and foliar application of Zn along with soil application of NPK fertilizers as per POP KAU significantly improved the grain yield and other crop yield attributes. The treatment that recorded the highest grain yield was T_8 (6.7 t ha^{-1}) which was superior as compared to other treatments. The treatments that recorded the highest straw yield (6.5 t ha^{-1}) and highest 1000 grain weight (27.1g) was with treatment T_7.

The nutrient content in the plant samples (shoot and straw) analyzed at different growth stages of paddy was studied. The results revealed that nutrient content of N, K and Zn was highly improved in treatments under INM practices. At the harvest stage, treatments T_7 recorded the highest N (0.62 %) and K (1.9 %) whereas Zn (85.7 mg kg^{-1}) content in straw was highest with treatment T_8. However, the nutrient content of P in plant samples declined with the increase in the number of foliar application of Zn. The treatment that recorded the lowest P content (0.19 %) in the straw at harvest was T_5 (Organic POP + soil application of Zn + triple foliar application of Zn).

The effect of treatments on Zn and P content in rice grains were also studied. Grain analysis results revealed that the treatment that recorded the highest Zn content (49.8 mg kg^{-1}) was in T_8 and the lowest Zn content (18.2 mg kg^{-1}) was recorded in T_{10} (control). Similarly, P content was also analyzed in rice grains to study the interaction between Zn and P. The treatment that recorded the highest P content (0.61 %) in the grain was T_2 and lowest P content (0.44%) was recorded in T_5.

APPENDIX – I

Effect of soil and foliar application of zinc under organic and integrated nutrient management practices on B:C ratio

Treatments	Cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	B:C ratio
T_1 - Organic POP + soil application of Zn	128590	128000	1.04
T_2 - POP(KAU-2016) + soil application of Zn	165780	132000	1.26
T_3 - T1+ single foliar application of Zn	159140	128800	1.24
T_4 - T_1+ double foliar application of Zn	171210	129550	1.32
T_5 - T1+ triple foliar application of Zn	171770	130350	1.32
T_6 - T_2+ single foliar application of Zn	197555	137800	1.43
T_7 - T_2+ double foliar application of Zn	192530	138600	1.39
T_8 - T_2+ triple foliar application of Zn	211965	139400	1.52
T_9 - Application of zinc in nursery	176990	128000	1.38