RELATIVE PERFORMANCE OF ZINC SULPHATE AND CHELATED ZINC ON ZINC FORTIFICATION OF RICE

by
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(J-20-M-767)

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SOIL SCIENCE AND AGRICULTURE CHEMISTRY

Division of Soil Science and Agriculture Chemistry
Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu
Main Campus, Chatha, Jammu-180009
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CERTIFICATE-I

This is to certify that the thesis entitled **"Relative Performance of Zinc sulphate and Chelated Zinc on Zinc Fortification of Rice"**, submitted in partial fulfillment of the requirements for the degree of **Master of Science** in **Agriculture (Soil Science and Agriculture Chemistry)** to the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, is original work and has similarities with published work not more than minor similarities as per UGC norms of 2018 adopted by the university. Further, the level of minor similarities has been declared after checking the manuscript with Urkund software provided by the University.

The work has been carried out by **Mr. Yahiya Akram Laskar**, Registration No. **J-20-M-767**, under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma. It is further certified that help and assistance received during the course of thesis investigation have been duly acknowledged.

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CERTIFICATE-II

We, the members of the advisory Committee of **Mr. Yahiya Akram Laskar,** Registration No. **J-20-M-767,** a candidate of the degree of **Master of Science in Agriculture (Soil Science and Agriculture Chemistry)** have gone through the manuscript of the thesis entitled **"Relative Performance of Zinc sulphate and Chelated Zinc on Zinc Fortification of Rice"** and recommend that it may be submitted by the student in partial fulfillment of the requirements for the degree.

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I own entire responsibility for all the errors and omissions.

Place: Jammu

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ABSTRACT

Title of thesis	:	'Relative Performance of Zinc sulphate and Chelated Zinc on Zinc Fortification of Rice'
Name of the student	:	Yahiya Akram Laskar
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Major Subject	:	Soil Science and Agriculture Chemistry
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Name of the University	:	Sher-e-Kashmir University of Agricultural Sciences & Technology, Jammu

An investigation entitled '**Relative Performance of Zinc sulphate and Chelated Zinc on Zinc Fortification of Rice'** was conducted at the Research Farm of Division of Soil Science and Agriculture Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu during the *kharif* 2021. The soil of the experimental field was clay loam in texture, near neutral to slightly alkaline in reaction, medium in organic carbon, available phosphorus and potassium, low in available nitrogen, medium in available sulphur and DTPA extractable Zn and sufficient in DTPA extractable iron. The experiment was laid under Randomized Block Design with three replications and nine treatments *viz.* T_1-recommended NPK, T_2-recommended NPK + 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application, T_3-recommended NPK + 2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal + 0.5% $ZnSO_4$ foliar spray at maximum tillering and panicle initiation stage, T_4-recommended NPK +2.5 kg Zn ha^{-1} through Zn-EDTA as basal application, T_5- recommended NPK + 2.5 kg Zn ha^{-1} through Zn EDTA as basal + 0.5% Zn-EDTA at maximum tillering and panicle initiation stage, T_6- recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal, T_7- recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA + 0.5% Zn-EDTA foliar spray at maximum tillering and panicle initiation stage, T_8- recommended NPK + 0.5% Zn EDTA foliar spray at maximum tillering, panicle initiation and grain filling stage, T_9-recommended NPK + 1.0 % foliar spray as Zn-EDTA at maximum tillering, panicle initiation and grain filling stage. The experimental results revealed that treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn EDTA as basal + 0.5% Zn-EDTA at maximum tillering and panicle initiation stage) recorded significantly higher values for various growth attributes viz. plant height at 60 DAT, 90 DAT, and at harvest (121.45 cm), number of tillers per hill at 30 DAT, 60 DAT, at harvest (16.09), significantly higher yield attributes and yield *viz.*panicle length (25.13 cm), grains per panicle (67.34), effective tillers per square metre (440.55), grain yield (39.13 q ha^{-1}), straw yield (102.81q ha^{-1}) and biological yield (141.95q ha^{-1}), significantly higher N,P,K-uptake in grain and straw over other treatments except treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at maximum tillering and panicle initiation stage) which was statistically at par to treatment T_5. Different zinc sources failed to produce any significant variations in uptake of N, P, K in root. Further, treatment T_9 (recommended NPK + 1.0% foliar spray as Zn-EDTA at maximum tillering, panicle initiation and grain filling stage) significantly recorded maximum zinc fortification of rice grain (144.2 g ha^{-1}).The results of the study indicated a non-significant response in soil parameters *viz.* pH, EC, OC, available S, Fe, Zn after harvest of rice crop whereas available N, P and K were significantly influenced through zinc ferti-fortification. Furthermore, recommended NPK + 0.5% Zn EDTA foliar spray at maximum tillering, panicle initiation and grain filling stage (T_8) significantly recorded higher zinc partial factor productivity (ZnPFP), agronomic efficiency (ZnAE) and crop recovery efficiency (ZnCRE).

Key words: Rice, Fortification, Zn-EDTA, $ZnSO_4$, Basal application, Foliar spray, Nutrient uptake.

Signature of the Major Advisor

Signature of the Student

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PLATES

LIST OF ABBREVIATIONS

%	=	Percentage
ºC	=	Degree centigrade
@	=	At the rate of
AE	=	Agronomic efficiency
ANOVA	=	Analysis of variance
CD (P=0.05)	=	Critical difference at 5% probability
cm	=	Centimetre
DAT	=	Days after transplanting
DTPA	=	Diethyl triamine penta acetic acid
dS m^{-1}	=	Deci siemen per meter
EDTA	=	Ethylene diamine tetra acetic acid
e.g.	=	For example (*exempli gratia*)
EC	=	Electrical conductivity
e*t al*.	=	And others (*et alibi*)
etc.	=	And so forth (*et cetera*)
Fe	=	Iron
g m^{-2}	=	gram per square metre
ha	=	Hectare
ha^{-1}	=	Per hectare
hrs	=	Hours
i.e.	=	That is
K	=	Potassium
kg	=	Kilogram
km	=	Kilometre
Max.	=	Maximum
Min.	=	Minimum

MT	=	Maximum tillering
N	=	Nitrogen
No.	=	Number
OC	=	Organic carbon
P	=	Phosphorus
PI	=	Panicle initiation
PE	=	Physiological efficiency
PFP	=	Partial factor productivity
pH	=	Potential of Hydrogen
ppm	=	Part per million
q ha^{-1}	=	Quintals per hectare
RH	=	Relative humidity
SEm	=	Standard Error of Mean
Viz.	=	Namely
ZHI	=	Zinc harvest index
Zn	=	Zinc
$ZnSO_4$	=	Zinc sulphate

CHAPTER-I

INTRODUCTION

CHAPTER-1

INTRODUCTION

Rice is the world's second most important staple food crop grown on 160 million hectares area and producing 740 million tonnes grain per year. Rice is grown on 43 million hectares in India with a total production of 165 million tonnes (Pathak *et al.* 2018) which accounts for 27 percent of the world's rice area and 22 percent of rice grain production. Rice provides 80 percent of the energy for about 3.3 billion people in Asia alone, as it comprises 80 percent carbohydrates, 7-8 percent protein, 3 percent fat and 3 percent fibre. Rice offers 21 percent of per capita energy and 15 percent of per capita proteins for humans on a worldwide basis. Basmati rice, also known as fine rice, is cultivated in India on an area of around 7.76 million hectares, with an annual production of roughly 6.5 million tonnes (FAO 2016). Basmati rice is a geographical indicator and a type of rice grown in South Asia for its high cooking quality parametres. Because of its good cooking qualities and uniqueness, such rice is becoming more popular in Western countries, Middle East and Asia. 'Basmati' rice is long grain aromatic rice with extra-long slender grains that lengthen at least twice their original size when cooked, as well as a soft and fluffy texture, delicious taste, superior scent and distinct flavour. Basmati rice is unlike any other aromatic long grain rice variety. India exports Basmati rice to a number of countries around the world. A total quantity of 7.09 lakh tonnes of basmati rice was exported to different countries from India during 2002-03. However, exports increased to 31.78 lakh tonnes in 2011-12, representing a 348 percent increase during the last ten years. The export increased from 2010-12 to 2012-13, with a total quantity increasing by 10.04 percent from 31.45 to 34.61 lakh tonnes (Anonymous 2013-2014).

Basmati rice has been grown for centuries in Jammu and Kashmir (UT), Himachal Pradesh, Punjab, Haryana, Delhi and Western Uttar Pradesh (Singh *et al.* 2018), with Jammu and Kashmir being the largest contributor to overall basmati rice production in India. The total area under Basmati cultivation in Jammu district (R.S Pura and Suchetgarh blocks) is 49080 hectares (Slathia *et al.* 2018). Traditional basmati rice varieties, on the other hand, are low yielders, with average productivity ranging from 1.5 to 2.0 tonnes ha^{-1} (Shivay *et al.* 2016). As a result, rice growers found that replacing low-yielding basmati cultivars is a viable option. Pusa basmati 1121 is one of those varieties that has high yield potential and is suitable for multiple cropping, as well as having excellent global acceptability. This variety, however, has a higher nutrient requirement than traditional basmati varieties. Furthermore, balanced crop fertilization necessitates the supply of both macro and micronutrients and among micronutrients; zinc (Zn) plays a critical role in increasing rice productivity.

Zinc is an essential micronutrient for normal plant growth and metabolism and it is involved in membrane integrity, carbohydrate synthesis, enzyme activation (dehydrogenase, alkaline phosphatase, etc.) (Singh *et al.* 2005). Zinc is also involved in cell division, genetic expression, physiological processes such as growth and development, genetic transcription, programmed cell death as well as the stabilization of bio-membranes and cellular components. Zinc is an immobile nutrient in plants, due to which the deficiency symptom appears first on younger leaves. Leaf wilting due to loss of turgidity, basal leaf chlorosis, delayed development, leaves bronzing and in some cases death of rice seedlings are the most visible signs in rice. Chlorosis in the midrib at the base of the youngest leaf (developed within 2-4 weeks after transplanting) and brown patches on older leaves have been observed in certain cases. Zinc deficiency causes stunted growth and reduced tillering in plants. Zinc deficiency symptoms were very similar to those of N, Mg, Mn or Fe, making it difficult to differentiate (Dobemann and Fairhurst, 2000).

Zinc deficiency is the most ubiquitous micronutrient problem throughout the world, affecting in any crops including the staples corn, rice and wheat (Alloway, 2008). About 49 percent of Indian soils are deficient in Zn and is expected to rise to 63 percent by 2025 (Arunachalam *et al.* 2013). Its deficiency is more prevalent particularly in the rice-wheat belt of northern India. Rice grown in flooded conditions has a higher Zn requirement because the availability of other nutrients increases in submerged conditions, reducing Zn availability to crop. According to recent estimates, roughly half of the world's population suffers from zinc shortage, which could be related to widespread Zn deficiency in global soils (Cakmak, 2008).

The importance of zinc in human nutrition has been reaffirmed by recent clinical and experimental studies. Results showed that zinc has an impact on immune function and cognitive development. Hypogonadism, oxidative damage, immune system changes, hypogeusia, neuropsychological impairment and dermatitis are all side effects of its deficiency (Mafra and Cozzolino, 2004). Zinc is such an important nutrient for human health that even a minor shortage can be fatal. In humans, lack of zinc causes anorexia, loss of appetite, loss of smell and taste (Chasapis *et al.* 2012). More than one-third of the world population suffers from zinc deficiency (Stein *et al*. 2007).

Cereals are the primary source of zinc for the world's population, particularly for the poor living in rural areas. However, the zinc content of cereal-based foods are insufficient to meet human needs. The problem is particularly acute for rice consumers because rice (*Oryza sativa* L.) has the lowest zinc content among the cereals. Considerable variation in brown rice zinc has been found among different rice genotypes. Ranges of 13.5 to 58.4 mg Zn per kg has been reported for a large rice germplasm at International Rice Research Institute (IRRI) which averaged only 25.4 mg zinc per kg compared with 35.0 mg Zn per kg in wheat (*Triticum aestivum L.*) (Welch and Graham, 2004).

Zinc fortification, which aims to increase Zn concentration as well as bioavailability of rice grain is viewed as a more sustainable and cost-effective solution to Zn deficiency. Among these methods, plant breeding strategy (e.g., genetic biofortification) appears to be the most effective and sustainable way of increasing Zn concentrations in grain. However, breeding method takes a long time and involves considerable effort and resources. Breeding for biofortified food crops with Zn depends heavily on soil Zn pools available to plants. However, soils in most parts of the cereal growing areas have a variety of chemical and physical problems that dramatically reduce Zn availability to plants. Due to this, the new (biofortified) cultivars might not have the genetic capability to absorb sufficient amounts of Zn from the soil and accumulate it in the grain. In order to improve Zn concentration in cereal grains, it is essential to have a short-term solution. Zinc fertilizers or zinc-enriched NPK fertilizers (e.g., agronomic biofortification) are an effective solution to this problem and represents useful complementary approach to ongoing breeding programs (Cakmak, 2008). Zinc deficiency is usually corrected through the application of inorganic salts, mainly zinc sulphate ($ZnSO_4$). However, due to its changes into other chemical forms, recovery of applied Zn is relatively limited. Other source of zinc, such as zinc ethylene diamine tetra-acetic acid (Zn-EDTA) is known to be more efficient as the central metal ion (Zn^{2+}) is surrounded by chelate ligands, which supplies a significant amount of Zn to the plant without interacting with soil components and thus improves use efficiency (Prasad *et al.* 2014). Therefore, increasing the use efficiency of zinc fertilizers is very important as it is very low and it ranges from only 2-5 percent of the applied dose (Singh *et al.* 2017).

There is growing evidence that foliar or combined soil + foliar application of Zn fertilizers in the field is highly effective. Zinc-enriched grains are also vital for crop productivity, resulting better seedling vigor, denser stands and higher stress tolerance on potentially Zn-deficient soils. During the reproductive growth stage, an agronomic biofortification strategy appears to be essential in maintaining a sufficient amount of accessible Zn in the soil solution and maintaining enough Zn transport to the seeds. Finally, agronomic biofortification is required for optimizing and ensuring the success of genetic biofortification of cereal grains with zinc. If foliar Zn has a higher bioavailability than soil zinc, agronomic biofortification would be a very appealing and useful strategy for solving Zn deficiency-related health problems globally and effectively (Cakmak, 2008). However the choice of proper fertilizer with respect to zinc use efficiency is also very important. Keeping the above facts in the forefront, a study entitled **"Relative Performance of Zinc sulphate and Chelated Zinc on Zinc Fortification of Rice"** was conducted with the following objectives:

1. To study the effect of chelated zinc on zinc fortification of rice.
2. To study the effect of zinc fertilization on soil properties.

CHAPTER-II

REVIEW OF LITERATURE

CHAPTER-2

REVIEW OF LITERATURE

Rice being a staple food of world population has been studied by researchers in different parts of India and worldwide. Here field trial is laid out to work **out "Relative Performance of Zinc sulphate and Chelated Zinc on Zinc Fortification of Rice".** This chapter elaborates the study which has been carried in different parts of country as well as world on the context stated above under following headings and subheadings:

2.1 Effect of different sources of zinc fertilization on

2.1.1 Growth attributes

2.1.2 Yield and yield attributes

2.2 Effect of different sources of zinc fertilization on zinc fortification of rice

2.3 Effect of different sources of zinc fertilization on soil properties

2.4 Effect of different sources of zinc fertilization on zinc use efficiency indices

2.1 Effect of different sources of zinc fertilization on

2.1.1 Growth attributes

Ravikiran and Reddy (2004) observed that there was an increase in tillers per hill of rice through 0.5 percent foliar spray along with soil application of zinc through zinc sulphate ($ZnSO_4$) over no zinc fertilization. However, Ahmad *et al*. (2012) studied the comparative effects of Zn-enriched farm yard manure (FYM), Zn-EDTA and $ZnSO_4$ on plant height and the number of tillers in rice. The results showed that $ZnSO_4$ enriched FYM was more effective than Zn-EDTA enriched FYM in enhancing plant growth attributes, but both Zn-EDTA and $ZnSO_4$ showed a significant superiority over control.

Keram *et al*. (2012) observed that NPK + 20 kg Zn per hectare recorded significantly higher growth characteristics like plant height and number of tillers in rice crop. However, 10 and 20 kg Zn per hectare were statistically at par in terms of growth attributes. Singh and Shivay (2013) carried out an experiment at IARI, New Delhi to investigate Zn uptake and economics of basmati rice-durum wheat cropping sequence with different sources of zinc. The researcher claimed that Zn-EDTA had considerably higher plant height and tiller numbers than other sources of zinc, the sequence being Zn-EDTA>$ZnSO_4.7H_2O$> $ZnSO_4.H_2O$>$ZnSO_4.7H_2O$+ZnO>ZnO in order.

Saha *et al*. (2013) conducted a study and reported that Zn application through both soil and soil plus foliar applications resulted a significant increase in plant height of rice crop over control. The results also revealed that there was an increase in height to the tune of 3.6 and 7.3% with soil and soil + foliar application of Zn respectively over control. In similarity to this study, Boonchuay *et al.* (2013) observed that the number of tillers in rice increased considerably over control by foliar application of 0.5 percent zinc sulphate during panicle initiation, booting and at flowering stages. The increase in number of tillers was to the extent of 170 percent over control.

Ram *et al.* (2013) revealed that the effects of micronutrients (Fe and Zn) on plant growth varied significantly depending on the mode of application. In both the years of experimentation, application of Zn and Fe, either separately or together, significantly improved the growth attributes at 90 DAT compared to control. The number of tillers per metre square and plant height of rice were considerably increased by the combined treatment of Zn as a soil application (1 kg ha^{-1}) through Zn-EDTA followed by Fe as a foliar application (0.5 kg ha^{-1}) through Fe-EDTA applied in two splits at 15 DAT and at 50 percent panicle initiation stage.

Gasal *et al.* (2015) conducted a field experiment on six basmati rice varieties at IARI, New Delhi. They found that the application of 1.25 kg Zn per hectare through Zn-EDTA + 0.5 percent foliar spray (FS) at maximum tillering and panicle initiation stage significantly recorded taller rice plants, closely followed by 2.5 kg Zn per hectare (ZnSHH) + 0.5 percent foliar spray at maximum tillering and panicle initiation stage, although the increase was non-significant. Among the varieties, Pusa basmati 1121 recorded significantly higher plant height (108.1 cm) at harvest which was at par with Pusa rice hybrid-10 (103.4 cm). However it was significantly higher to other varieties. In similarity to this study, Shivay *et al*. (2016) carried a study on sandy clay-loam soil at IARI, with different sources of zinc and reported that the significantly higher plant height of basmati rice variety Pusa Sugandh (118 cm) was achieved with three foliar sprays of 0.5 percent solution of Zn-EDTA at tillering, booting and grain filling stages.

They also reported that soil or foliar application of Zn improved plant height of basmati rice over NPK fertilization.

Arif *et al.* (2017) found that different zinc levels greatly influenced plant height of rice. The application of 15 kg Zn per hectare resulted in significantly higher plant height of 91.1 cm at harvest, while a minimum plant height of 64.6 cm was recorded under control.

Several workers have studied the response of rice with both micronutrients *viz.* iron and zinc. Nisar *et al*., (2019) conducted an experiment with different zinc and iron fertilizers on basmati rice and reported that soil and foliar application of Zn and Fe increases the plant height. Soil application of zinc sulphate, iron sulphate and foliar application of zinc EDTA, iron EDTA at active tillering, panicle initiation and milking stages along with RDF significantly increased the plant height over control. Rao *et al*. (2019) also reported that combined soil application of $ZnSO_4$ @ 25 kg ha^{-1}, $FeSO_4$ @ 35 kg ha^{-1} along with foliar application of Zn-EDTA @ 1 %, Fe-EDTA @ 0.5%, significantly increased plant height (56.56 cm) and number of tillers (18.0) over other treatments and control at harvesting in rice crop.

Kumar *et al.* (2019) evaluated the influence of zinc fertilization through different sources at SVBPUAT, Meerut and reported that the significantly higher plant height (103.8 cm) was recorded under treatment 7.5 kg Zn per hectare through $ZnSO_4$ as soil application which was significantly superior to all treatments except 5 kg Zn per hectare (101.8 cm) through $ZnSO_4$ soil application and 1 kg Zn per hectare through Zn EDTA soil application (100.6 cm). Similar trend was observed for tillers per meter square. In similarity to these findings, Sardar *et al*. (2020) also studied the effect of different sources and modes of Zn (zinc sulphate heptahydrate, zinc sulphate monohydrate, chelated zinc and micronutrient mixture) and vermicompost with the combination of RDF (NPK @ 120:60:60) in different modes of application viz. soil application and foliar spray on Pusa basmati 1121 and found that growth attributes viz. plant height and number of tillers were found higher in soil and foliar application of Zn as compared to NPK alone. Among the different zinc sources, zinc sulphate is the best source and soil application of zinc was found best method for application than foliar.

2.1.2 Yield and yield attributes

Abid *et al.* (2002) observed that the use of Zn, either alone or in combination with Fe and Mn considerably improved growth and yield of rice. They also revealed that the basal dose of NPK fertilizers along with the application of 10 kg Zn per hectare as basal were found to be the most effective for increasing rice yield. Furthermore, it was observed that Zn + NPK + Mn treatment resulted in significantly increased numbers of grains panicle^{-1} (119), test weight (23.93 g) and grain yield (78.73 g plant^{-1}) as compared to control.

Nasir *et al.* (2006) noticed that application of 10 kg $ZnSO_4$ per hectare as basal application recorded significantly higher number of panicle bearing tillers (11.36), 1000 grain weight (22.17 g), grain yield (2.98 t ha^{-1}) and straw yield (7.09 t ha^{-1}) of rice as compared to control. On contrary to this Jena *et al*. (2006) performed an experiment at ANGRAU, Andhra Pradesh with both soil and foliar zinc application and reported that significantly higher number of productive tillers, filled grains per panicle and test weight of rice were recorded under treatment T_2 (soil application of 50 kg $ZnSO_4$ ha^{-1}) which was at par with treatment T_8 (Foliar application twice with Zn-EDTA equivalent to 0.2 percent $ZnSO_4$) and T_5 (Seedling dip in ZnO slurry equivalent to 10 kg $ZnSO_4$ ha^{-1}).

Chaudhary *et al*. (2007) reported that application of $ZnSO_4$ @ 50 kg per hectare significantly increased the number of grains per panicle of rice on silty-clay soil of Pusa, Bihar. In accordance to this Jana *et al.* (2009) carried out a field experiment in red and laterite soil and revealed that zinc application significantly increased yield attributes, grain and straw yield of rice. The number of effective tillers, panicle length, grains number per panicle, panicle weight, grain yield and straw yield were all significantly higher when 30 to 40 kg $ZnSO_4$ per hectare was applied.

Kumar and Kumar (2009) conducted an experiment and reported that yield attributes and grain yield of rice increased significantly with the basal application of 45 kg $ZnSO_4$ per hectare. Zinc added to the soil performed better than Zn given as a foliar spray.

Jatav and Singh (2018) assessed the effect of various zinc application methods on growth and yield of hybrid rice. They had taken different treatments of Zn *viz.* soil application, root dipping and foliar spray and observed that treatment T_9 (RDF + 5.0

kg Zn ha^{-1} soil application + 2% ZnO root dipping + (0.5% $ZnSO_4$ + 0.25% Lime) foliar spray at tillering and milking stage) showed maximum plant height, number of tillers, chlorophyll content, number of panicle, length of panicle, grains per panicle , straw yield, grain yield and 1000 grain weight in comparison to other treatments where only soil or foliar or root dipping was done.

Prasad *et al.* (2010) reported that under 100 percent crop residue level and 10 kg Zn per hectare in rice, significantly higher grain yield (4.35 t ha^{-1}) and straw yield (7.27 t ha^{-1}) were recorded as compared to no zinc application and other treatments.

Naik and Das (2010) revealed that split applications of 10 and 20 kg Zn per hectare as $ZnSO_4$ significantly increased grain yield by 7.3 percent and 6.0 percent, respectively over the corresponding basal application (10 and 20 kg Zn ha^{-1} at basal) in rice. However, Zn-EDTA @1.0 kg Zn ha^{-1} applied through basal application (resulted in a 2.8 percent increase in grain yield over the split application.

Mustafa *et al.* (2011) revealed that different zinc application techniques and timing significantly affected paddy production with basal application at the rate of 25 kg per hectare producing statistically higher yield and foliar application at 75 DAT with a 0.5 percent Zn solution producing the lowest yields. However, Ram *et al*. (2011) reported that with foliar applications of Zn through Zn-EDTA @ 1.0 kg per hectare and through Fe-EDTA 0.5 kg ha^{-1}, grain yield, straw yield and harvest index of rice significantly increased.

Shilpa (2011) reported significantly higher number of grains per panicle and 1000 grain weight with 100 percent NPK + FYM 10 t ha^{-1} + 1 percent FYM fortified $ZnSO_4$ + 1 percent FYM fortified $FeSO_4$ application under aerobic rice cultivation over other treatments and control.

Ahmad *et al*. (2012) conducted an experiment to test the effects of Zn-enriched farm yard manure (FYM) with chelated (Zn-EDTA) and non-chelated ($ZnSO_4$) Zn sources rice grains grown in salt-affected soil. Application of Zn has a significant impact on grain and straw yields. With a gradual increase in Zn application from either source, grain and straw yields increased. Zinc sulphate proved better than Zn-EDTA in terms of enhancing yield attributes and yield. The grain and straw yield was significantly increased by farm yard manure enriched with zinc sulphate in comparison to control and $ZnSO_4$ alone. In contrast to this study, Rehman *et al*. (2012) reported that foliar application of Zn as Zn-EDTA and $ZnSO_4$ increased grain yield and straw yield of rice but highest increase was significantly recorded in Zn-EDTA application.

Some workers have reported significant response of zinc through soil + foliar application. Zou *et al.* (2012) reported that applying soil and foliar Zn fertilizer together significantly enhanced rice grain production, whereas alone foliar Zn application had no negative effects and even slightly increase the yield.

Shaygany *et al. (*2012) reported that foliar application of iron (0.6%) and zinc (0.21%) at seedling, one spray at tillering and two sprays at panicle development stage as Fe-EDTA and Zn-EDTA, respectively in direct seeded rice had significant impact on 1000 grain weight (27.94 g), grain yield (5.74 Mg ha^{-1}) and biological yield (5.3Mg ha^{-1}) as compared to control. However, Boonchuay *et al.*(2013) observed that foliar application of 0.5 percent zinc sulphate spray at panicle initiation, booting stage and 1 or 2 weeks after flowering stage significantly increased grain weight (20.1 g $plant^{-1}$), straw weight (30.1 g $plant^{-1}$), and panicles $plant^{-1}$ (13) of rice with the lowest value observed in control.

Tabassum *et al*. (2013) reported that the yield of rice increased significantly with application of zinc @ 2.5, 5.0, 10 kg Zn per hectare by 17.5, 26.3 and 29.9 percent in grain and 21.0, 31.9 and 42.7 percent in straw, respectively over control.

Singh *et al*. (2014) conducted an experiment using various zinc fertilizers on basmati rice and recorded significantly higher effective tillers, panicle length, panicle weight, test weight, grains per panicle using Zn-EDTA. Zinc-EDTA recorded significantly higher grain yield (5.46 t ha^{-1}) than control.

Shivay *et al.* (2015) observed that the significantly higher grain yield (4.52 t ha^{-1}), straw yield (8.12 t ha^{-1}), grains $panicle^{-1}$ (94) and test weight (22.7 g) of rice were obtained by soil application of 5 kg Zn per hectare and foliar spray of 1 kg Zn per hectare as compared to soil application of ZnS or Zn-coated urea as well as no Zn treatment. Saha *et al.* (2015) conducted a study and reported that application of Zn as basal @ 20 kg per hectare with 2 foliar sprays @ 0.5 percent $ZnSO_4.7H_2O$ showed a significant increase in grain yield of rice as compared to only soil application as well as no Zn treatment. Application of Zn through soil increases the grain yield to the tune of 22 percent and soil + foliar significantly increased 29 percent over control.

Gasal *et al.* (2016) recorded significantly higher tillers per hill, panicle weight and length, grain weight and grains per panicle of rice under treatment 1.25 kg Zn per ha through Zn-EDTA + 0.5 percent foliar spray at maximum tillering and panicle initiation stages as compared to control, which was at par to 2.5 kg Zn (zinc sulphate heptahydrate) + 0.5 percent foliar spray at maximum tillering and panicle initiation stages but significantly higher than zinc sulphate treatments. Whereas, Kulhare *et al.* (2016) found that, applying 20 kg Zn per hectare as a basal + 0.5 percent foliar spray of $ZnSO_4$ showed a positive and significant increase in grain yield of rice crop and Zn uptake as compared to control.

Shivay *et al*. (2016) during a field experiment on a sandy clay-loam soil at IARI, observed that NPK + three foliar sprays of 0.5 percent solution of Zn-EDTA at tillering, booting and grain filling stages produced significantly higher panicles per hill, longer panicles, grain yield and straw yield of basmati rice although this treatment was at par with the treatment where NPK + two foliar sprays of Zn-EDTA @ 0.5 per at tillering and booting stages was applied but was significantly superior to other treatments where NPK + zinc sulphate heptahydrate foliar spray @ 0.2 or 0.5 per cent at two or three stages or basal was applied.

Ghoneim (2016) observed that amongst different Zn application methods *viz.*, basal application of 15 kg Zn ha^{-1} through $ZnSO_4$, root dipping @ 1.5 % Zn, foliar application @ 2.5 kg ha^{-1}, basal application of Zn @ 15 kg ha^{-1} significantly increased number of tillers, panicles, plant height, 1000-grain weight; filled grains percent and grains yield of rive variety Sakha 104.

Kumar *et al*. (2017) studied the effect of zinc application on hybrid rice under lowland conditions of Jharkhand and reported that different Zn levels of 2.5, 5.0, and 7.5 kg per hectare enhanced the grain and straw yield of rice but significantly higher grain yield (60.22 q ha^{-1}) was observed at 7.5 kg per hectare application which was statistically at par to 5.0 kg Zn per hectare.

Barua and Saikia (2018) reported significantly higher grain yield (21.46 q ha^{-1}) by the application of 25 kg $ZnSO_4$ per hectare along with foliar spray @ 0.5 percent at three stages than other treatments. However, Anusuya *et al*. (2019) conducted a study at TNAU, Coimbatore and reported that foliar application of 0.5 percent $ZnSO_4$ at grain filling stage recorded significantly higher grain yield (8870 kg ha^{-1}) and straw yield (24727 kg ha^{-1}) of rice and lowest value recorded under control.

Yadav *et al.* (2019) revealed that soil application of zinc @ 5 kg per hectare through Zn-EDTA recorded significantly higher grain yield (5.45 t ha^{-1}) of rice as compared to control (4.43 t ha^{-1}).In comparison to this Kumar *et al.* (2019) revealed that treatment of 7.5 kg Zn per hectare through $ZnSO_4$ as soil application recorded significantly higher panicle length, number of grains per panicle, grain yield, straw yield and biological yield of rice over control. Mondal *et al.* (2020) also reported that the combination of N, P, K (60, 30 and 30 kg ha^{-1}) along with Zn ($ZnSO_4$ @ 25 kg ha^{-1}) recorded significantly higher no of tillers and grain yield of rice as compared to control.

2.2 Effect of different sources of zinc fertilization on fortification of rice

Das *et al.* (2004) reported that the amount of Zn content in rice straw was significantly higher with the application of foliar spray of Zn- EDTA twice @ 0.05 percent at maximum tillering and panicle initiation stage over control on silty clay loam soils of Nadia. In similarity to this study, Karak *et al.* (2006) revealed that chelated Zn (Zn-EDTA) application in two splits increases Zn content in rice dry matter as compared to split application of zinc sulphate. Zinc concentration and uptake in grain and straw were significantly higher in the treatment that used chelated Zn (Zn-EDTA) as splits over control.

Cakmak (2008) reported that a 3.5-fold increase in grain Zn concentration was observed under soil + foliar Zn application, which was found to be the most effective method in increasing the Zn concentration in rice grain. Fang *et al.* (2008) also reported that foliar application of either $ZnSO_4$ or Zn-chelates (Zn-EDTA) can increase Zn concentration in rice grain and applying Zn fertilizer to the soil is effective in increasing grain Zn concentrations in cereals growing on most but not all soils.

Shivay and Prasad (2009) carried out an experiment and reported significantly higher zinc concentrations in grain and straw of rice with the foliar application of 0.2 percent $ZnSO_4$ at maximum tillering and panicle initiation stage, on sandy clay loam soils of New Delhi. On contrary to this study, Sridevi *et al.* (2010) revealed that application of recommended dose of NPK + 200 kg FYM enriched with 5.0 kg zinc per hectare enhanced the uptake of nitrogen, phosphorous, potassium and zinc in grain and straw of rice crop. However, Naik and Das (2010) reported that basal applications of Zn-EDTA (1.0 kg Zn ha^{-1}) significantly increased Zn content of rice grain by 2.7 percent over its split applications.

Cao *et al.* (2010) reported that soil application, foliar spray and soil + foliar application of Zn significantly increased grain Zn concentration in rice by 6.1 percent, 63.9 percent, and 82.6 percent, respectively over no Zn application. Similarly, Yadav *et al*. (2011) revealed that significantly higher zinc concentration in rice grain was recorded with foliar sprays of 0.2 percent zinc sulphate at maximum tillering and panicle initiation stages which was at par with soil applied zinc sulphate @ 25 kg per hectare and 2.0 percent zinc-enriched urea (zinc sulphate) and significantly better than prilled urea and the control on sandy loam soil of IARI, New Delhi.

Ram *et al.* (2011) performed an experiment at BHU with two rice varieties i.e. NDR-359 and HUBR 2-1 with 100 percent RDF along with two micronutrients *viz*. Zn and Fe in different combinations either as soil or as foliar application or both @ 0.5 and 1.0 kg per hectare. They recorded significantly higher N, P, K, Zn and Fe content through Zn-EDTA @ 0.5 kg per hectare and Fe-EDTA @ 1.0 kg per hectare as compared to other micronutrient treatments.

Ahmad *et al.* (2012) observed maximum Zn concentration in rice grains (13.9 mg kg^{-1}) and straw (19.1 mg kg^{-1}) with zinc-enriched FYM as compared to zinc sulphate or Zn-EDTA application. Narwal *et al.* (2012) reported that foliar and soil application of Zn significantly improved grain Zn concentration of rice over control, while foliar application increased Zn concentrations in straw and seed by 1.0 to 5.5 and 1.0 to 2.1-fold, respectively over control.

Zhang *et al*. (2012) reported that soil application of Zn, foliar application and foliar applied urea significantly affected the concentration of Zn in grain, but their interactions were not significant. Additionally, grain Zn concentration of rice was positively correlated with foliar Zn rates.

Wei *et al*. (2012) revealed that foliar fertilization of zinc significantly increased the Zn concentration in polished rice, which was recorded 22.92 mg kg^{-1} under control, 25.26 mg per kg under foliar Zn-EDTA application, 26.09 mg per kg in foliar Zn-Citrate application, 28.08 mg per kg in foliar $ZnSO_4$ application, and 28.67 mg per kg under foliar Zn-amino acid application. These values represented increase of 10.22 percent, 13.82 percent, 22.47 percent and 24.04 percent, respectively over control.

Muthukumararaja and Sriramachandrasekharan (2012) conducted a pot experiment and revealed that different concentrations of zinc supplied to soil had a significant influence on zinc content and uptake in rice crop. Because of the gradual rise in zinc addition to soil, Zn content in grain increases from 22.36 to 46.57 ppm and that in straw from 19.74 to 43.95 ppm. Statistically higher zinc concentration and uptake was reported under 7.5 mg Zn per kg soil application.

Phattarakul *et al.* (2012) reported that Zn fertilization, particularly foliar Zn treatment, significantly increased Zn concentrations in brown and white rice. Zinc content in brown rice improved by foliar and foliar + soil Zn applications by 25 percent and 32 percent, respectively but only 2.4 percent increase in soil Zn application was observed. Foliar Zn application increased Zn concentration by around 66 percent in unhusked rice but soil Zn application had only little effect.

Rana *et al.* (2013) observed that basal application of Zn-EDTA @ 10 kg per hectare recorded significantly higher N content in grain (5.02%) and straw (2.22%), P content in grain (2.11%) and straw (1.09%) and K content in grain (0.13%) and straw (0.42%) in rice crop as compared to all other treatments.

Singh and Shivay (2013) observed that zinc fertilizer application in rice significantly increased Zn concentrations in grain and straw but the rates of growth varied depending on the different sources. Basal application of Zn-EDTA significantly increased Zn concentration and uptake in grain and straw as compared to all other Zn sources. Furthermore, there was a significant correlation (0.994 and 0.996) between grain yield and Zn uptake in grain. On contrary to this Boonchuay *et al.* (2013) reported that in rice grain, application of zinc at different stages of growth had no effect on Zn concentration, regardless of whether it was applied before flowering, during panicle initiation or during booting stage. But one foliar Zn application one week after flowering increased Zn concentration by 76 percent, one week later by 164 percent, and combined by 264 percent.

Kabeya and Shankar (2013) revealed that soil application of 30 kg $ZnSO_4$ ha^{-1} significantly increased the concentration of Zn in straw, leaf and seed of rice over control. However, Guo *et al.* (2014) reported that Zn fertilizer applied as a foliar spray significantly increased the grain Zn content in rice as compared to soil application. In general, soil + foliar application produced higher Zn content and uptake than foliar spray or soil application.

Singh *et al*. (2014) compared all Zn sources and reported that Zn-EDTA showed statistically higher Zn content in grain and straw of rice crop. Among the two types of treatments tested, $ZnSO_4.7H_2O$ application was the second-best treatment with respect to Zn concentration in grain and straw. Zn-EDTA application increased the Zn concentration in rice grain and straw by 70.58 and 19.71 percent, respectively as compared to control.

Kumar *et al.* (2017) observed that N-uptake by rice grain was influenced by various treatment combinations. The maximum nitrogen uptake by grain (146.34 kg ha^{-1}) was recorded under the treatment soil application of the 50 kg $ZnSO_4$ ha^{-1} (T_2) which was statistically at par with Foliar application twice with Zn-EDTA equivalent to 0.2% $ZnSO_4$ (T_8) and were significantly superior over rest of the treatment combinations.

Barua and Saikia (2018) reported significantly higher Zn content in grain (32.03 mg kg^{-1}) and Zn content in brown rice (26.81 mg kg^{-1}) by the application of 25 kg $ZnSO_4$ per hectare along with foliar spray @ 0.5 percent at three stages than other treatments. However, Wang *et al.* (2020) reported that foliar Zn-EDTA application significantly improved the grain, straw and root Zn content of rice. The Zn content in grain, straw and root increased by 72.9 percent, 127.5 percent and 29.3 percent, respectively with the foliar spray of 0.3 percent Zn-EDTA and by 146.1 percent, 281.0 percent, and 20.8 percent, respectively under 0.5 percent Zn-EDTA treatment.

Phuphong *et al.* (2018) carried out an experiment in Thailand and reported that Zn concentration measured in brown rice was significantly affected by the foliar Zn treatment in three different field locations. They claimed that foliar application of 0.5 percent $ZnSO_4$ at booting, flowering and early milk stages of rice significantly improved the grain Zn concentration by 41 percent in one field and an average of 30 percent across the three fields as compared to other treatments.

Bana *et al.* (2020) carried out an experiment at Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu on Basmati rice and reported that application of 4 percent Zn through $ZnSO_4.7H_2O$ coated urea + 0.2 percent Zn foliar spray ($ZnSO_4.7H_2O$) + recommended NPK significantly recorded higher N-uptake in grain (40.09 kg ha^{-1}) and straw (34.20 kg ha^{-1}), P-uptake in grain (10.32 kg ha^{-1}) and straw (7.86 kg ha^{-1}), K-uptake in grain (10.89 kg ha^{-1}) and straw (114.04 kg ha^{-1}) and Zn-uptake in grain (128.99 g ha^{-1}) and straw (666.04 g ha^{-1}) over control but was at par with other treatments.

2.3 Effect of different sources of zinc fertilization on soil properties

Patil *et al.* (2003) reported that in rice soils, clay, organic carbon, and pH were positively correlated with DTPA-Zn. However, Cu and Mn were positively correlated with clay and CEC while Fe was negatively and significantly correlated with pH, $CaCO_3$ and clay.

Naik *et al.* (2008) conducted a field experiment and reported that application of chelated Zn enhanced rice yield while maintaining soil Zn concentrations for successive crops.

Prasad *et al.* (2010) observed that there was significant increase in soil available NPK after harvest of rice by the application of Zn @10.0 kg ha^{-1} along with 100 percent crop residue.

Naik and Das (2010) conducted a study to evaluate various zinc extractants in lowland rice soils of BCKV, West Bengal and reported that amount of zinc concentrations in post harvest soil was relatively greater with application of Zn-EDTA as compared to zinc sulphate due to which Zn-EDTA was superior in maintaining zinc in soil.

Kumar and Babel (2011) revealed lower levels of OC and CEC in post harvest soils which ranged from 0.06 percent to 0.43 percent and 2.40 to 10.40 cmol (p+) kg^{-1}, respectively. While $CaCO_3$ content ranged from 3.90 percent to 12 percent, pH ranged from 8.10 to 9.20 and EC (0.20 to 2.14 dSm^{-1}) was found to be non-saline. Zn availability, however, showed a positive and significantly correlation with soil organic carbon and CEC but a negative and significant correlation with soil calcium carbonate and pH.

Keram *et al.* (2012) observed that in combination with recommended dose of fertilizer (RDF), 20 kg of Zn ha^{-1} recorded significantly higher DTPA-Zn status (0.97 mg kg^{-1}) of soil after harvest of rice crop. However, Singh (2014) reported that when 20 kg Zn kg^{-1} was applied as basal, soil pH EC, OC, $CaCO_3$ and DTPA-Zn were recorded significantly higher as compared to control which showed minimum values for these parameters.

Ghoneim (2016) observed that there was a significant impact on nutrient status of soil through basal application of 15 kg Zn ha^{-1} through $ZnSO_4$ in comparison to root dipping @ 1.5 % Zn, foliar application @ 2.5 kg ha^{-1}. As a result of different Zn application methods, soil N and K contents tend to increase while P concentration decreased significantly. Zinc content in soil after harvesting was significantly affected by Zn application.

Barua and Saikia (2018) observed that the zinc content in soil after harvest of rice changed significantly with different rice varieties and Zn fertilization schedules. The rice variety Dishang shows higher soil zinc content after harvest as compared to other varieties, however amongst the various treatments highest available Zn in soil (6.98 mg kg^{-1}) was observed in treatment $ZnSO_4$ @ 25 kg ha^{-1} as basal + seed priming with 2% $ZnSO_4$ which was at par with other treatment of $ZnSO_4$ 25 kg ha^{-1} as basal + foliar spray @ 0.5 % at three stages *viz*., tillering, panicle initiation and milk stage.

Meena *et al*. (2018) conducted a study on mung bean and found that applying zinc-enriched FYM significantly increased the amount of available N and Zn when the level of nutrient was enhanced. However, phosphorus showed the opposite tendency, significantly decreases with increasing levels of zinc, whereas the effect on available K was non-significant.

Jatav and Singh (2018) assessed the effect of various zinc application methods on growth and yield of hybrid rice. They had taken different treatments of Zn *viz*. soil application, root dipping and foliar spray and observed that treatment T_9 (RDF + 5.0 kg Zn ha^{-1} soil application + 2% ZnO root dipping + (0.5% $ZnSO_4$ + 0.25% Lime) foliar spray at tillering and milking stage) showed highest DTPA-extractable Zn content (1.18 mg kg^{-1}) in post-harvest soil

Bana *et al.* (2020) carried out a field experiment at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu to study the post-harvest nutrient status and reported that zinc fortification treatments didn’t significantly influenced the available N, P, K and Zn content of soil after harvest of rice crop.

2.4 Effect of different sources of zinc fertilization on zinc use efficiency indices

Jain and Dhama (2007) reported that significantly higher physiological efficiency (6.84 kg g^{-1} Zn uptake) was recorded under the treatment 3 kg Zn ha^{-1} as basal application, whereas agronomic efficiency (115.3 kg ha^{-1} nutrient) and apparent Zn recovery (1.87%) were significantly higher at 6 kg Zn ha^{-1}.

Shivay *et al.* (2007b) reported that with successive increase in Zn-enriched urea (ZEU), partial factor productivity, agronomic efficiency, apparent recovery efficiency and physiological efficiency of applied Zn in a rice-wheat cropping system decreased significantly. In addition, they found that zinc sulphate offered superior nutrient use efficiency compared to zinc oxide when used as a coating urea. Again, Shivay *et al.* (2008) conducted an experiment to access the zinc efficiency of rice–wheat cropping system using partial factor productivity (PFP), agronomic efficiency (AE), recovery efficiency (RE) and physiological efficiency (PE) of zinc applied through zinc enriched urea (ZEUs) and prilled urea (PU). According to their findings, PFP, AE, AR and PE of Zn applied through ZEUs decreased as the level of Zn enrichment of PU increased. The difference in PFP, AE, RE and PE of applied Zn decreased with increasing ZEU levels.

Jat *et al.* (2011) reported that zinc fertilization had a significant effect on agronomic efficiency (AE) of applied zinc for aromatic hybrid rice and 2.0 percent $ZnSO_4 \cdot 7H_2O$ recorded significantly higher Agronomic Efficiency (AE) over all other zinc fertilization treatments in both the years of experimentation. The percentage increases in AE with 2.0 percent $ZnSO_4 7H_2O$ was 41.2, 80.1 and 161.5 percent over 2 percent ZnO, 5 kg Zn per hectare through $ZnSO_4 7H_2O$ and 5 kg Zn per hectare through ZnO, respectively.

Muthukumararaja and Sriramachandrasekharan (2012) reported that with increasing Zn levels, agronomic, physiological, agro-physiological efficiency, apparent Zn recovery and Zn utilization efficiency of rice crop decreased significantly.

Pooniya and Shivay (2013) reported that green manuring and various Zn fertilization treatments had significant effect on partial factor productivity (PFP) and agronomic efficiency (AE) of basmati rice. Significantly higher PEP (7040 and 7120 kg grain kg^{-1} zinc) and AE (360 and 360 kg grain increase kg^{-1} zinc applied) was obtained with ZnO slurry treatment in both the years of experiment, respectively as compared to other treatments.

Singh *et al*. (2014) observed that zinc fertilization had a significant impact on Zn use efficiencies. Basal application of Zn-EDTA application resulted in a higher partial factor productivity (781-1091 kg grain kg^{-1} Zn applied), agronomic efficiency (48-207 kg grain kg^{-1} Zn) and recovery efficiency (3.3-11.1%) of Zn in rice crop, which were significantly higher than all other treatments. Zn fertilization treatments also had a significant impact on the zinc harvest index (6.50-9.83%), physiological efficiency (1,339-2,091 kg grain kg^{-1} Zn uptake), and zinc mobilization efficiency index (0.138-0.198) by the application of Zn-EDTA as basal.

Shivay *et al*. (2015) reported that foliar application of 0.5 percent Zn-EDTA at tillering, booting and gain filling stage significantly recorded maximum agronomic efficiency, recovery efficiency and zinc harvest index of zinc in rice crop as compared to other treatments. They noticed that NPK + application of Zn-EDTA resulted in a higher partial factor productivity (781-1091 kg grain kg^{-1} Zn applied), agronomic efficiency (48-207 kg grain kg^{-1} Zn) and recovery efficiency (3.3-11.1%) of Zn in rice crop, which were significantly higher than all other treatments. Zn fertilization treatments also had a significant impact on the zinc harvest index (6.50-9.83%), physiological efficiency (1,339-2,091 kg grain kg^{-1} Zn uptake), and zinc mobilization efficiency index (0.138-0.198) by the application of Zn-EDTA as basal.

Kulhare *et al.* (2017) observed that application of Zn-EDTA and $ZnSO_4.7H_2O$ significantly increased the Zn use efficiency in rice over $ZnCl_2$, $Zn_3(PO_4)_2$ and ZnO. However, the Zn use efficiency with Zn-EDTA was also found significantly superior to $ZnSO_4.7H_2O$ but the zinc sources i.e. $ZnCl_2$, $Zn_3(PO_4)_2$ and ZnO were found at par. The zinc use efficiency with 0.5 percent foliar application of $ZnCl_2$ was found (82%) which significantly superior to 1.0 percent $ZnCl_2$ + 0.5 percent lime application.

CHAPTER-III

MATERIALS AND METHODS

CHAPTER-3

MATERIALS AND METHODS

The present investigation entitled '**Relative Performance of Zinc sulphate and Chelated Zinc on Zinc Fortification of Rice'** was conducted at the Research Farm of Division of Soil Science and Agriculture Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu during *kharif* 2021.

3.1 Experimental site and location

The field experiment was conducted during the *kharif* season of 2021 at the Research Farm of Division of Soil Science and Agriculture Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Main campus, Chatha. The experimental site is situated at 32^0-40′ N latitude and 74^0-58′ E longitude with an altitude of 332 m above mean sea level in the Shiwalik Foothills of N-W Himalayas.

3.2 Climate and weather during crop period

Jammu is situated in the northern part of India which comes under sub tropical climate. The climate is semi dry type with hot summer and cold winter. Temperature of this region starts to rise from mid of February and reaches to maximum by mid of June. Thus May and June are considered to be the hottest months of the year where maximum temperature ranges from 36.9°C to 39.6°C. The coldest month of the year is considered as January where minimum temperature ranges from 1.4°C to 9.8 °C. Mean annual rainfall of this region is about 1050-1115 mm during monsoon season, most of (75%) which is received between June to end of September. However, the total rainfall and its distribution were subjected to large variations. Data concerning weather conditions prevailing during the period of investigation (last week of July to first week of November) were obtained from the Agricultural meteorological observatory, SKUAST-J, Chatha. The weekly meteorological data concerning the details of the observation on maximum and minimum temperature, maximum and minimum relative humidity, total rainfall and normal rainfall are presented in table 3.1. and figure 3.1.

3.2.1 Temperature

The weakly mean temperature at the time of nursery was 31.6°C. The maximum temperature begins to rise up to 39.7°C in SMW 27^{tt} (July 5-11). After that it starts declining upto 44th SMW.

3.2.2 Relative Humidity (%)

The maximum relative humidity during most of the time of experiment was 75-90 percent. The highest maximum relative humidity recorded was 93 percent in 38th (September 20-26) SMW while the lowest of 55 percent in 26th SMW (June 28-July 4). The highest minimum relative humidity of 69 percent was recorded in 30th week (July 26-Augest 4) while the lowest was recorded in 25th SMW (June 21-27).

3.2.3 Rainfall (mm)

Total rainfall recorded during *kharif* season of 2021 was 956.6 mm. The highest maximum rainfall recorded was 167.4 mm in 28th SMW (July 12-18) while minimum of 0.2 mm in 32nd SMW (August 9-15). However in SMWs 25, 39, 41, 42 and 44, no rainfall was received.

3.3 Soil characteristics

Before the start of experiment, five soil samples were collected randomly from surface (0-15 cm) layer of the field. The soil samples collected were mixed together to form a composite sample, this composite soil sample so obtained was air dried, ground and passed through 2 mm sieve and was analyzed for different physico-chemical properties of the soil. Likewise, the treatment wise soil sampling was also done after harvest of the crop. The data recorded with respect to initial physico-chemical properties of the experimental site revealed that the soil was clay loam in texture, slightly alkaline in reaction, medium in organic carbon, available phosphorus and potassium, low in available nitrogen, sufficient in available S, DTPA-extractable Fe and insufficient in DTPA-extractable Zn (Table:3.2).

3.4 Experimental details

The experiment was laid out in randomized block design during *kharif* 2021 with three replications. Treatment details are presented in table 3.3 and layout plan in figure 3.2.

Table: 3.1. Weekly meteorological data during *kharif* 2021

Standard Mean Weeks	Date and Month	Rainfall (mm)	Temperature (°C)		Relative Humidity (%)		Normal Rainfall (mm)
			Max.	Min.	Max.	Min.	
25	June 21-27	0.0	38.3	24.9	56	27	18.1
26	June 28-July 4	1.0	39.4	25.5	55	30	42.6
27	July 5-11	23.0	39.7	25.4	56	32	57.6
28	July 12-18	167.4	33.0	24.8	85	68	63.4
29	July 19-25	140.8	33.5	26.3	89	69	78.0
30	July 26- Aug 1	154.0	32.8	26.4	89	71	74.2
31	Aug 2-8	25.2	34.4	25.9	79	66	111.6
32	Aug 9-15	0.2	35.3	26	77	56	79.8
33	Aug 16-22	26.8	35.7	25.9	79	54	62.1
34	Aug 23-29	79.6	34.4	26.2	84	67	73.2
35	Aug 30- Sept 5	58	34.3	25.1	80	61	34.1
36	Sept 6-12	122.2	32.8	24.8	86	72	49.7
37	Sept 13-19	3.0	32.3	24.4	86	67	34.7
38	Sept 20-26	48.2	32.0	22.6	93	68	16.7
39	Sept 27-Oct 3	0.0	34.1	24.6	86	58	18.0
40	Oct 4-10	5.2	32.7	22.4	86	54	4.6
41	Oct 11-17	0.0	33.9	20.1	77	44	7.3
42	Oct 18-27	0.0	32.6	18.0	80	46	6.3
43	Oct 25-31	102.0	26.4	14.3	79	54	1.8
44	Nov 1-7	0.0	27.8	12.1	78	37	1.3

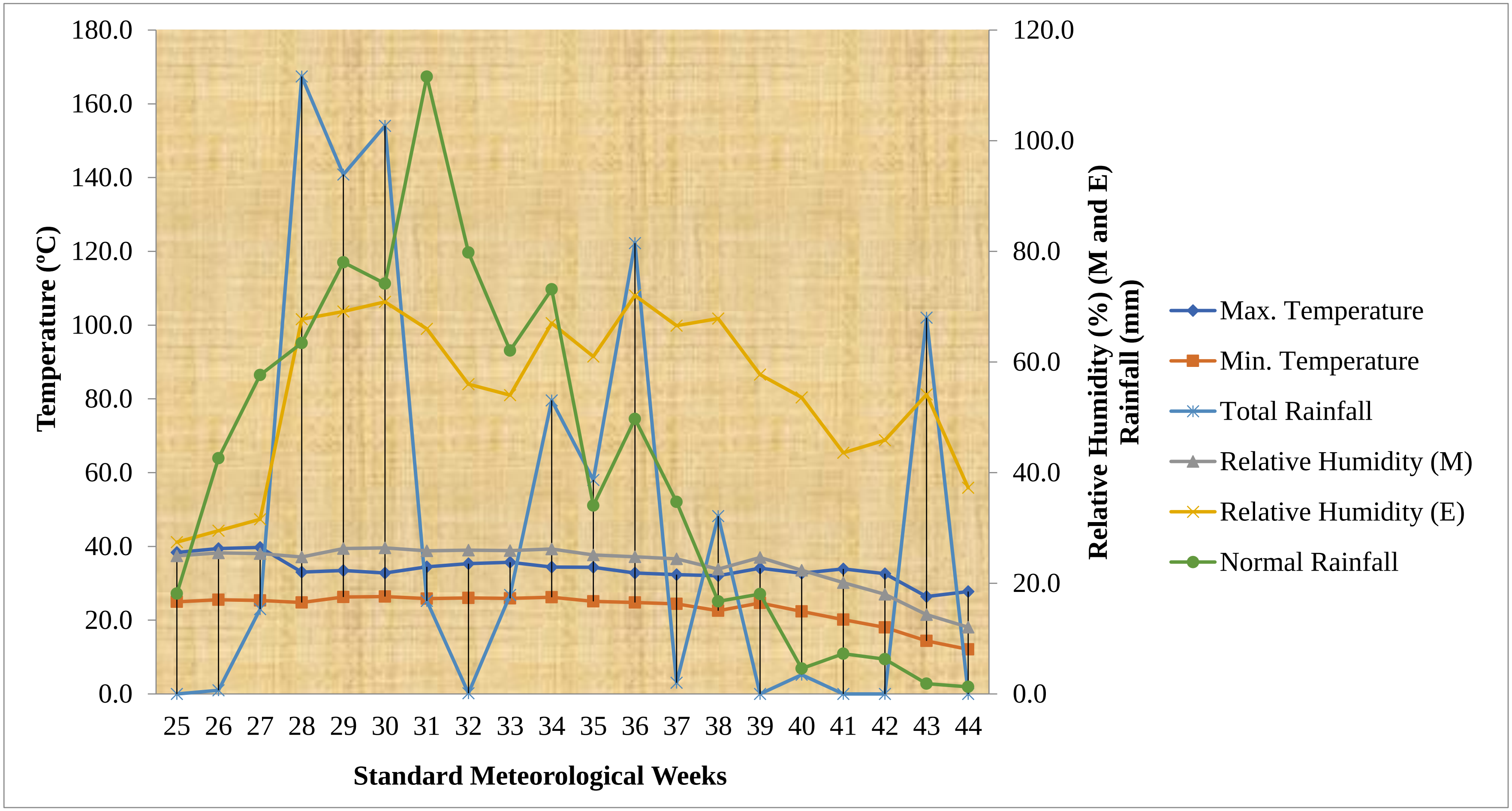


Figure: 3.1. Weekly meteorological data during *kharif* 2021

Table: 3.2 Physico-chemical characteristics of soil at the start of the experiment

S. No.	Parametres	Value	Method employed
A.	**Physical properties**		
	Sand (%)	43.45	Bouyoucous Hydrometer method (Piper, 1966)
	Silt (%)	28.43	
	Clay (%)	28.12	
	Textural class	Clay Loam	Textural Diagram (Black, 1965)
B.	**Chemical properties**		
	pH	7.60	(Jackson, 1973)
	EC (dS m^{-1}) at 25° C	0.32	(Jackson, 1973)
	Organic carbon (g kg^{-1})	5.2	(Walkley and Black, 1934)
	Available nitrogen (kg ha^{-1})	246.4	(Subbiah and Asija, 1956)
	Available phosphorus (kg ha^{-1})	14.92	(Olsen *et al.*, 1954)
	Available potassium (kg ha^{-1})	144.3	(Jackson, 1973)
	Available sulphur (mg kg^{-1})	17.52	Chesnin and Yien (1950).
	Available iron (mg kg^{-1})	8.72	(Lindsay and Norwell,1978)
	Available zinc (mg kg^{-1})	0.58	(Lindsay and Norwell,1978)

Table: 3.3 Treatment details

T_1	Recommended dose of NPK
T_2	Recommended NPK + 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application.
T_3	Recommended NPK + 2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal + 0.5% $ZnSO_4$ foliar spray at maximum tillering and panicle initiation stage.
T_4	Recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal application.
T_5	Recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at maximum tillering and panicle initiation stage.
T_6	Recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal.
T_7	Recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at maximum tillering and panicle initiation stage.
T_8	Recommended NPK + 0.5% Zn EDTA foliar spray at maximum tillering, panicle initiation and grain filling stage.
T_9	Recommended NPK + 1.0 % foliar spray as Zn-EDTA at maximum tillering, panicle initiation and grain filling stage.

Table: 3.4 Cropping history

Year	**Season**	
	Kharif	***Rabi***
2018-2019	Rice	Wheat
2019-2020	Rice	Wheat
2020-2021	Rice	Wheat

3.5 Details of field cultural operations

The details of various cultural operations carried out during the crop growing period have been given in table 3.4.

3.5.1 Field preparation

Tractor drawn implement was used to prepare the field. The experimental field was cross harrowed and levelled properly after giving one deep ploughing. The puddling was done manually. The plots were prepared manually for transplanting the subsequent rice crop for the experimental study.

3.5.2 Fertilizer application

Fertilizer was applied as per the recommended dose of the cultivar. For Pusa Basmati-1121, fertilizer was applied at the rate of 40:25:15 kg N: P_2O_5: K_2O ha^{-1}, through urea, DAP and MOP, respectively. One third of nitrogen, full dose of phosphorus, and potassium were applied as per treatments. Remaining doses of nitrogen was applied at 30 and 60 days after transplanting. Selected doses of $ZnSO_4$ and Zn-EDTA were applied as basal application at the time of transplanting. Zinc was applied as foliar spray through $ZnSO_4$ and Zn-EDTA as per the treatments.

3.5.3 Transplanting

Twenty five days old seedlings were uprooted and transplanted manually with the help of rope at a specified row to row distance of 20 cm and plant to plant distance of 10 cm within in the row with two seedlings $hill^{-1}$.

3.5.4 Irrigation

A thin film of water was maintained at the time of transplanting for better establishment of the seedlings. Moist conditions were maintained at active tillering and reproductive phase and near about saturation at vegetative and maturity stages. Irrigation was given twice a week and 3-5 cm of standing water was maintained till 2 weeks before harvest.

3.5.5 Weeding

Weeds were removed from the plots by manual labour from four weeks after transplanting and the plots were kept weed free as and when necessary. Second weeding was done at panicle initiation (PI) stage (60 DAT).

3.5.6 Harvesting

The crop was harvested at physiological maturity stage. First of all, the border rows were dried. The harvested material from each net plot was sun dried and then carefully bundled, tagged and brought to the threshing floor separately.

3.5.7 Threshing

Threshing was done plot wise and grains were cleaned, dried and weighed separately for each net plot and computed to q ha^{-1} at 14% moisture level. The straw yield was also recorded plot wise after sun drying and computed to q ha^{-1}.

3.6 Growth and yield attributes

For the purpose of biometric observations during the crop growth period, 5 plants were randomly selected from each treatmental plot and were tagged. The following observations were recorded.

3.6.1 Plant height (cm)

Five rice plants selected from each plot were tagged. The height of rice plant was measured manually with the help of metre scale from the base of the plant to the tip of the last fully opened leaf at 30, 60 and 90 days after tansplanting and at harvest. Plant height at harvest was measured from the ground level to the upper most portion of the panicle and values were presented in centimetres (cm). Average of all the five plants was taken for statistical analysis.

3.6.2 Number of tillers $hill^{-1}$

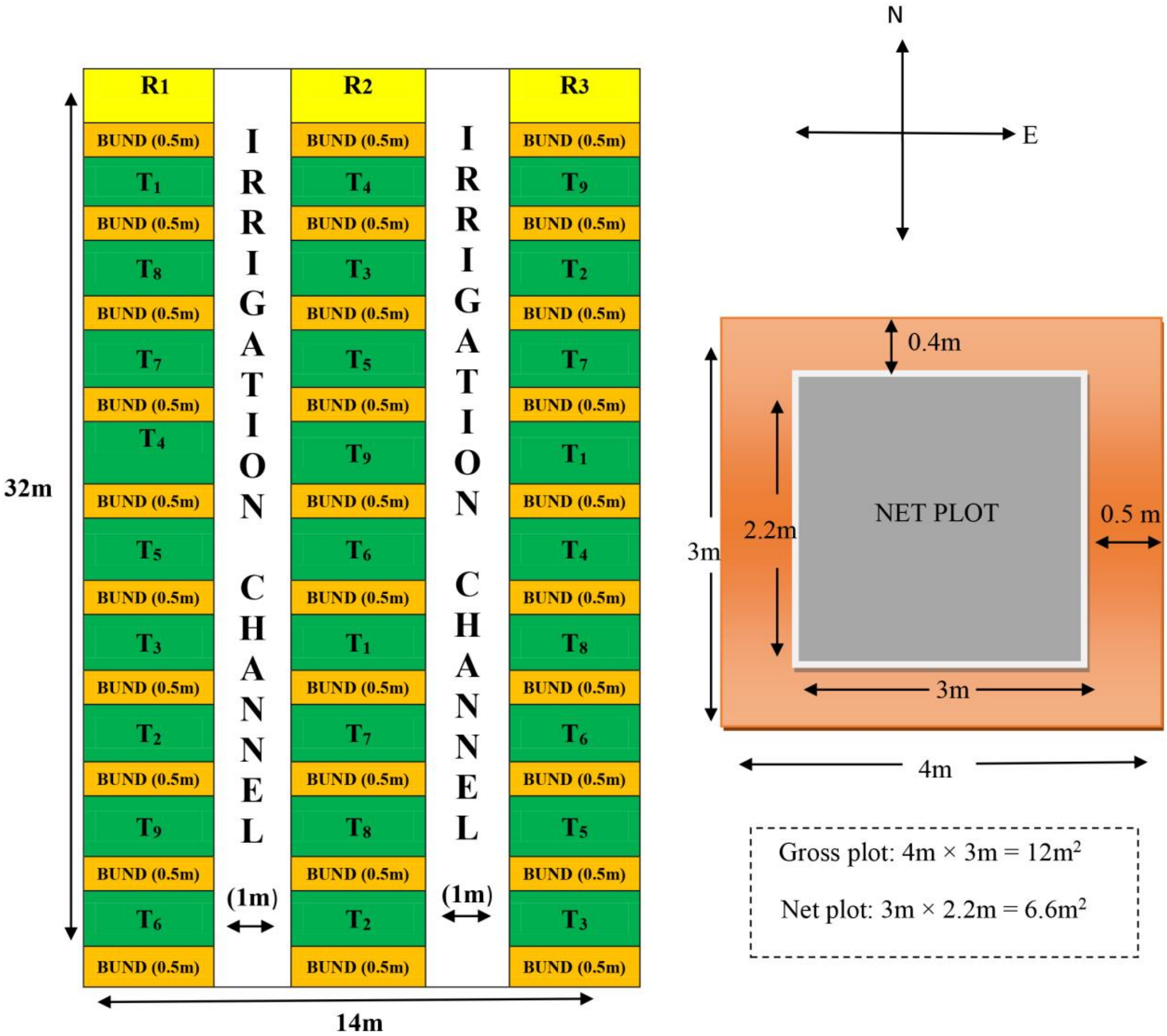
Tillers were counted from five tagged hills in each plot at 30, 60 and 90 days after transplanting and at harvest to compute number of tillers $hill^{-1}$.

3.6.3 Number of grains $panicle^{-1}$

The grains of ten panicles selected for panicle length from each plot were counted carefully and averaged to obtain the number of grains $panicle^{-1}$.

3.6.4 Panicle length (cm)

Ten panicles were sampled from the tagged plants in each plot. The length was measured from the base of the panicle to the tip of the top most spikelet. The mean panicle length was computed and expressed in cm.



- ✓ **Crop:** Rice
- ✓ **Variety:** Pusa Basmati-1121
- ✓ **Replications:** 03
- ✓ **Treatments:** 9
- ✓ **Treatment Combinations:** 3x9 = 27
- ✓ **Design: RBD**

Figure: 3.2 Layout plan of the experiment

Table: 3.5 Calendar of different operations carried out during experimentation

Operation	Date of Operation	Remarks
Field preparation and layout	16-07-2021	Field preparation and layout was done manually
Transplanting of rice	17-07-2021	Transplanting of rice was done Manually
Fertilizer application	17-07-2021	Application of full dose of phosphorus, potassium and 1/3 dose of nitrogen.
	16-08-2021	2nd dose of nitrogen.
	17-09-2021	3rd dose of nitrogen
Gap filling	24-07-2021	Gap filling was done where seedlings failed to establish and died.
Herbicide application	17-07-2021	Pre-emergence application of (Pendimethalin @ 1 lt a.i ha^{-1})
	12-08-2021	Application of herbicide (Butachlor @ 2kg a.i/ha)
Basal application	20-07-2021	Basal application of $ZnSO_4$ and Zn-EDTA was done manually
Irrigation	28-07-2021 14-08-2021 15-09-2021 28-09-2021 07-10-2021	Irrigation was given to maintain moist condition in soil
Manual weeding	4-09-2021	Intercultural operations were done manually to keep experimental field weed free
Foliar Application	22-08-2021 24-09-2021 12-10-2021	Foliar application of $ZnSO_4$ and Zn-EDTA was done manually
Harvesting of crop	08-11-2021	Harvesting was done manually
Threshing of crop	10-11-2021	Threshing was also done manually

Plate: 3.1. Initial soil sampling

Plate: 3.2. Transplanting of rice seedlings

Plate: 3.3. Field visual at tillering stage

Plate: 3.4. Measuring height at 30 DAT

Plate: 3.5. Maximum tillering stage

Plate: 3.6. Physiological maturity stage

Plate: 3.7. Spraying of pesticide

Plate: 3.8. Harvesting

Plate: 3.9. Threshing

3.6.5 Effective tillers m^{-2}

Number of ear bearing tillers from the labeled plants at physiological maturity stage were counted and expressed as productive tillers m^{-2}.

3.6.6 1000 grain weight (g)

Grain samples from each plot collected separately at threshing and dried properly. 1000-grains from each of these samples were taken and their weight recorded and expressed in grams.

3.6.7 Grain yield (q ha^{-1})

Produce of net plots was threshed and grain thus obtained was winnowed, clean and weighted. The yield recorded in kg per plot was standardized to 14 percent moisture and expressed in q ha^{-1}.

3.6.8 Straw yield (q ha^{-1})

Dry weight of straw collected from net plot was recorded after sun drying for 5-6 days and expressed in q ha^{-1}

3.6.9 Biological yield (q ha^{-1})

Dry weight of tagged bundled collected from net plot was recorded after sun drying for 5-6 days and expressed in q ha^{-1}.

3.6.10 Harvest index (%)

Harvest index was calculated by following formula:

$$\text{Harvest index (\%)} = \frac{Grain\ yield}{Biological\ yield} \times 100$$

3.7 Plant analysis

Five randomly selected plants from each net plot were oven dried and used for chemical analysis after grinding. For chemical analysis of plant samples the plant material were taken at harvest. Samples were cleaned properly by repeated washing followed by 0.1 N HCl solutions. Finally all the samples were subjected to washing by double distilled water. Samples were then dried under shade followed by hot air oven at 60 $\pm 1^0$ C for 48 hours. After drying samples were weighed and grounded in Willey's Mill as per treatment separately and stored in butters paper covers. Samples were then subjected to chemical analysis for nitrogen, phosphorous, potassium, sulphur, iron and zinc content.

3.7.1 Nitrogen uptake

Nitrogen content in grain, straw and root were determined by digesting the plant samples with concentrated sulphuric acid and digestion mixture. The digested samples were distilled by Micro kjeldhal method in an alkaline condition and titrated against standard acid (Piper, 1966). N uptake was calculated by multiplying grain, straw yields and root dry weight with corresponding values of N concentration and expressed in as kg ha^{-1}.

3.7.2 Phosphorus uptake

Phosphorus content in grain, straw and root at harvest were determined by "Vanado-Molybdo-phosphoric acid yellow colour method" using systronics spectrophotometer after digestion in tri acid mixture (HNO_3: $HClO_4$: H_2SO_4 at the rate of 10:4:1). Subsequently phosphorus uptake was calculated by multiplying grain, straw yields and root dry weight with corresponding values P concentration and expressed in as kg ha^{-1}.

3.7.3 Potassium uptake

K content in the plant samples was determined by flame photometer (Jackson, 1973). K uptake in grain, straw and root was calculated by multiplying grain, straw yields and root dry weight with corresponding values of K concentration and expressed in as kg ha^{-1}.

3.7.4 Sulphur uptake

Sulphur content in grain, straw and root samples of rice at harvest were estimated using the method given by Chesnin and Yien (1950) respectively. S uptake was calculated by multiplying grain, straw yields and root dry weight with corresponding values of S concentration and expressed in as kg ha^{-1}.

3.7.5 Iron and zinc uptake

The Fe and Zn content in rice grains, straw and root were determined as per the procedure described by Prasad (2006) using Atomic Absorption Spectrophotometer (AAS). The Fe and Zn content was expressed as mg kg^{-1} and uptake was calculated by grain, straw yields and root dry weight with their respective Fe and Zn concentration and expressed in g ha^{-1}.

3.8 Chemical properties of soil

Before the start of experiment, composite soil samples from 0-15 cm depth were collected from the experimental site processed to pass through 2 mm sieve and preserved for further analysis. Similarly, representative soil samples from each plot were collected after harvest of rice crop. The soil samples were dried in shade, processed to pass through 2 mm sieve and used for further analysis. The soil samples were analyzed for pH, electrical conductivity, organic carbon, available nitrogen, phosphorus, potassium, sulphur, DTPA-extractable iron and zinc content of the soil.

3.8.1 pH and electrical conductivity

The soil pH was measured in 1:2.5 soil: water suspension by potentiometry (Piper, 1966). The clear supernatant solution of above soil water suspension was taken and electrical conductivity was measured using conductivity bridge (Jackson, 1973).

3.8.2 Organic carbon (g kg^{-1})

The organic carbon was determined by Walkley and Black's wet oxidation method by oxidizing organic matter as described by Jackson (1973) and it was expressed in g kg^{-1}.

3.8.3 Available nitrogen (kg ha^{-1})

The available nitrogen was estimated by alkaline permanganate oxidation method as outlined by Subbaiah and Asija (1956) and expressed in kg ha^{-1}.

3.8.4 Available phosphorus (kg ha^{-1})

The available phosphorus was determined by Olsen's method using spectrophotometer (660 nm wave length) as outlined by Jackson (1973). It was expressed in kg ha^{-1}.

3.8.5 Available potassium (kg ha^{-1})

The available potassium was extracted with neutral ammonium acetate (1N NH_4OAC) and the content of K in the solution was estimated by Flame photometer (Jackson, 1973). It was expressed in kg ha^{-1}.

3.8.6 Available sulphur (mg kg^{-1})

The available sulphur content of soil was determined using the method given by Chesnin and Yien (1950) where calcium chloride (0.15% $CaCl_2 . 2H_2O$) was used as an extractant. 5 g of air-dried soil was taken, and 25 ml of calcium chloride solution (0.15%) was added to it and was shaken for 30 minutes. Whatman No. 42 filter paper was used to filter the suspension. 10 ml of the filtrate was taken in a volumetric flask and 1 g $BaCl_2$ was added and was swirled for 1 minute. After that 1 ml of gum acacia was added and volume makeup was done using distilled water. The readings were taken using spectrophotometer at wavelength of 420 nm.

3.8.7 DTPA extractable iron and zinc (mg kg $^{-1}$)

10 g of air dried soil was shaken with 20 ml of DTPA extracting solution for two hours. The soil suspension was filtered and the content of iron and zinc were estimated by using Atomic Absorption Spectrophotometer (AAS) (Lindsay and Norvell, 1978).

3.9 Estimation of zinc use efficiency indices

3.9.1 Partial factor productivity (PFP)

Partial factor productivity defined as grain production per unit zinc applied. It is calculated by formula given by Fageria and Baligar, (2003).

$$\text{Partial factor productivity (kg kg}^{-1}\text{)} = \frac{Yzn}{Zna}$$

Yzn = Grain yield (kg ha^{-1}) in Zn applied plots

Zna = Zinc applied (kg ha^{-1})

3.9.2 Agronomic efficiency (AE)

Agronomy efficiency is the ratio of yield to zinc supply, commonly referred to as agronomy efficiency. It is calculated by using the formula (Fageria and Baligar, 2003; Ladha *et al*., 2005).

$$\text{Agronomy efficiency (kg kg}^{-1}\text{)} = \frac{Yzn - Ypu}{Zna}$$

Yzn = Grain yield (kg ha^{-1}) in Zn applied plots

Ypu = Grain yield (kg ha^{-1}) in PU (no Zn) applied plots

Zna = Zinc applied (kg ha^{-1})

3.9.3 Recovery efficiency (RE)

Recovery efficiency is the ratio of plant zinc to kg^{-1} Zn applied and calculated by following formula (Doberman, 2005; Ladha *et al*., 2005)

$$\text{Recovery efficiency (kg kg}^{-1}\text{)} = \left[\frac{Uzn-Upu}{Zna}\right] \times 100$$

Uzn = Total Zn uptake (kg ha^{-1}) in Zn applied plots

Upu = Total Zn uptake (kg ha^{-1}) in PU (no Zn) applied plots

Zna = Zinc applied (kg ha^{-1})

3.9.4 Physiological efficiency (PE)

Physiological efficiency is represented as the ability of a plant to transport zinc acquired from fertilizer into economic yield. It is calculated by formula (Fageria and Baligar, 2003; Doberman, 2005).

$$\text{Physiological efficiency (kg kg}^{-1}\text{)} = \frac{Yzn-Ypu}{Uzn-Upu}$$

Yzn = Grain yield (kg ha^{-1}) in Zn applied plots

Ypu = Grain yield (kg ha^{-1}) in PU (no Zn) applied plots

Uzn = Total Zn uptake (kg ha^{-1}) in Zn applied plots

Upu = Total Zn uptake (kg ha^{-1}) in PU (no Zn) applied plots

3.9.5 Zinc harvest index (ZHI)

Zinc harvest index is the ratio of Zn uptake in grain to total Zn uptake or defined as portioning of total plant Zn into grain. Normally, ZHI is expressed in percentage and calculated by formula (Fageria and Baligar, 2003).

$$\text{Zinc harvest index (\%)} = \frac{GUzn}{Uzn}$$

GUz = Zn uptake (kg ha^{-1}) in grain

Uzn = Total Zn uptake (kg ha^{-1}) in Zn applied plots

3.10 Statistical analysis

Statistical analysis of all the data collected are carried out following the analysis of variance technique for randomized block design (RBD) as outlined by Panse and Sakhtme (1954). Statistical significance was tested by applying F-test at 0.05 level of probability and critical differences were calculated for those parameters, which turned to be significant (P = 0.05) in order to compare the effects of different treatments. The results were presented in tables and depicted graphically wherever necessary.

Table: 3.6 Analysis of Variance (ANOVA)

Source of variation	Degree of freedom
Replication (r-1)	3-1= 2
Treatment combinations (t-1)	9-1= 8
Error (r-1) (t-1)	(3-1) (9-1) = 16
Total (rt-1)	27-1= 26

CHAPTER-IV

RESULTS

CHAPTER-4

RESULTS

The present investigation was undertaken to study the **'Relative Performance of Zinc sulphate and Chelated Zinc on Zinc Fortification of Rice'** during the *kharif* 2021. The results obtained during the course of investigation was subjected to statistical analysis. The interferences drawn along with suitable interpretations have been presented and elucidated through tables and graphs wherever required under following headings.

4.1 Effect of different sources of zinc fertilization on

4.1.1 Growth attributes

4.1.1.1 Plant height

4.1.1.2 Number of tillers hill^{-1}

4.2 Effect of different sources of zinc fertilization on

4.2.1 Yield attributes

4.2.1.1 Panicle length

4.2.1.2 Grain panicle^{-1}

4.2.1.3 Effective tillers m^{-2}

4.2.1.4 1000-grain weight

4.2.2 Yield

4.2.2.1 Grain yield

4.2.2.2 Straw yield

4.2.2.3 Biological yield

4.2.2.4 Harvest index

4.3 Effect of different sources of zinc fertilization on macronutrient uptake

4.3.1 N and P-uptake in grain, straw and root after harvest of rice crop

4.3.2 K and S-uptake in grain, straw and root after harvest of the rice crop

4.3.3 Fe and Zn-uptake in grain, straw and root after harvest of the rice crop

4.1 Effect of different sources of zinc fertilization on

4.1.1 Growth attributes

4.1.1.1 Plant height

The data on mean plant height pertaining to different treatments recorded chronologically at various growth stages have been presented in table 4.1 and figure 4.1. Upon analysis of the data, it was found that shoot elongation increased with plant age, however rapid growth rate was recorded up to 90 DAT and increase was slow thereafter.

The various zinc fertilization practices recorded significant variation on plant height of rice crop at different growth stages except 30 DAT. However, at 30 DAT maximum plant height (66.58 cm) was recorded under treatment T_7 (recommended NPK+ 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5 % Zn-EDTA foliar spray at MT and PI stage) and minimum plant height (56.12 cm) was recorded under control. Moreover, various treatments showed non-significant effect.

At 60 DAT, significant variations on plant height were noticed due to application of different zinc fertilization practices. Significantly higher plant height (110.53 cm) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment

Table 4.1 Effect of zinc ferti-fortification on periodic plant height of Pusa basmati-1121

S. No	Treatments	Plant height (cm)			
		30 DAT	60 DAT	90 DAT	At harvest
T_1	Recommended dose of NPK (control)	56.12	89.43	106.30	110.38
T_2	Recommended NPK+ 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application	59.39	100.46	110.33	115.54
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage	65.34	102.34	112.53	117.61
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application	66.46	105.21	113.13	118.33
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage	66.33	110.53	117.06	121.45
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	64.42	104.59	111.30	116.74
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage	66.58	108.41	116.33	120.70
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage	63.43	105.67	113.13	118.36
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage	65.52	107.32	114.50	118.65
	SEm (±)	2.73	0.74	0.81	0.93
	CD (p= 0.05)	NS	2.20	2.45	2.78

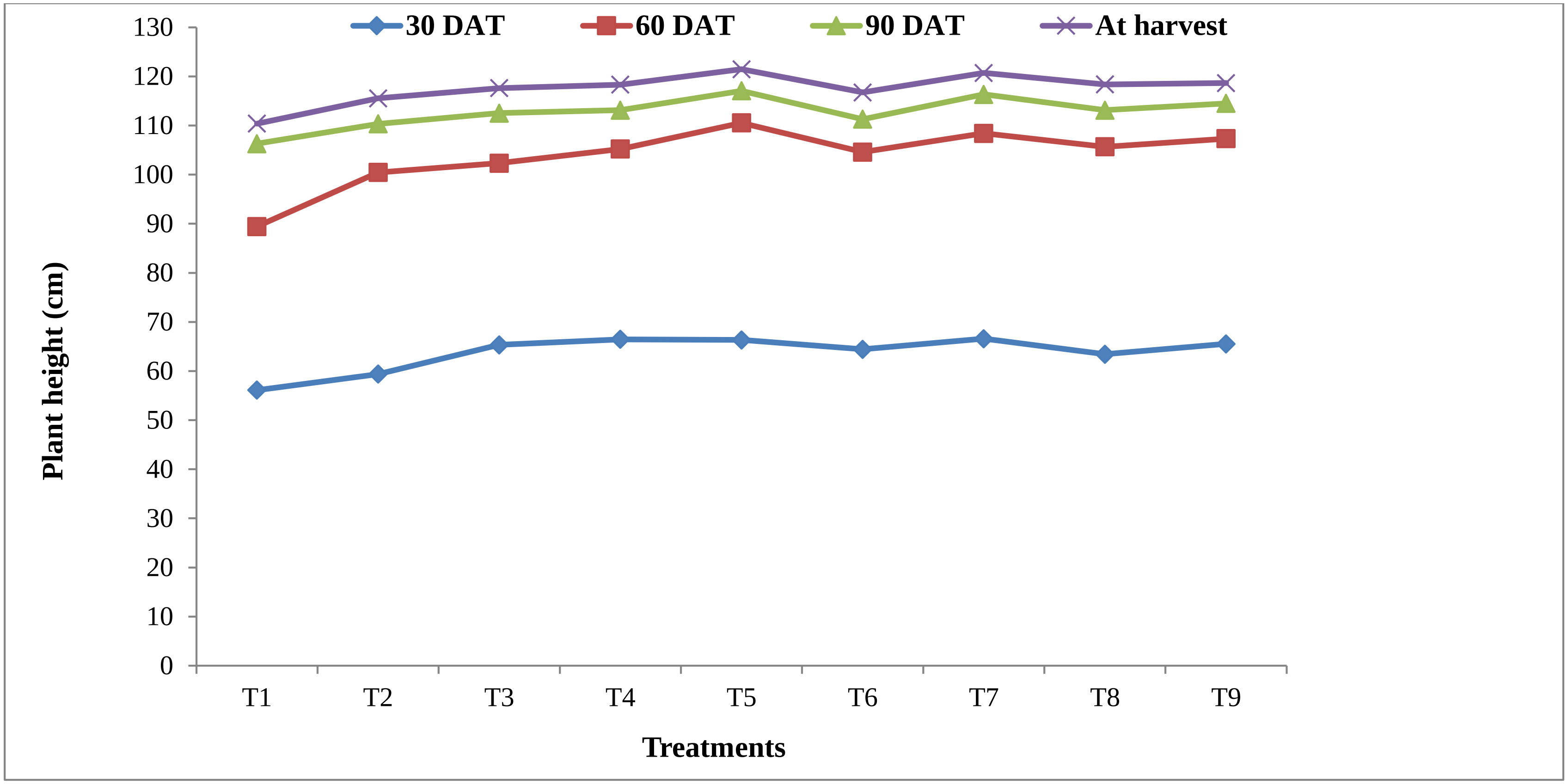


Figure 4.1 Effect of zinc ferti-fortification on periodic plant height of Pusa basmati-1121

T_7 (RDF NPK+ 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage) and minimum under control (89.43 cm)

Similar trend was noticed at 90 DAT and different zinc treatments recorded significant variations on plant height of rice cultivar Pusa basmati-1121. Data revealed that the statistically higher plant height (117.06 cm) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was at par with treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage) and minimum under control (106.30 cm). All the zinc treatments showed significant superiority over control.

At harvest, different zinc fertilization practices recorded significant influence on plant height of rice cultivar Pusa basmati-1121. Results revealed that significantly higher plant height (121.45 cm) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage) and minimum under control (110.38 cm). Treatment T_5 was recorded superiority of 10.02 percent over control.

4.1.1.2 Number of tillers hill^{-1}

The data pertaining to number of tillers per hill at different growth stages have been presented in table 4.2 and figure 4.2. Perusal of the data revealed significant variations on the production of tillers with different zinc fertilization practices. Production of tillers consistently increased upto 60 DAT and thereafter declined up to harvest.

The results revealed that at 30 DAT, different zinc fertilization practices recorded non-significant influence on number of tillers per hill. However, maximum value (17.50) was recorded under treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage) and lowest under control (11.93). However various treatments also showed non-significant effect.

At 60 DAT, different zinc treatments recorded significant influence on number of tillers per hill of rice. Significantly higher value (23.07) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage) and lowest under control (12.46).

Similar pattern was recorded at 90 DAT and different zinc fertilization practices recorded significant variations on number of tillers per hill of rice crop. Significantly higher value (16.38) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage) and minimum under control (12.33).

At harvest, different zinc treatments recorded significant influence on number of tillers per hill of basmati rice. Results revealed that significantly higher value (16.09) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage) with value being 15.76 and lowest under control (12.10). Treatment T_5 was recorded superiority of 33 percent over control.

4.2 Effect of different sources of zinc fertilization on

4.2.1 Yield attributes

The data pertaining to yield attributes *viz*. panicle length (cm), grains per panicle, effective tillers per square metre and 1000-grains weight (g) influenced by different zinc sources have been presented in table 4.3. and figure 4.3.

4.2.1.1 Panicle length (cm)

The various zinc fertilization sources recorded significant influence on panicle length (cm) of rice cultivar Pusa Basmati 1121. Data clearly indicated that significantly

Table 4.2 Effect of zinc ferti-fortification periodically on number of tillers of Pusa basmati-1121

S. No	Treatments	Number of tillers hill^{-1}			
		30 DAT	60 DAT	90 DAT	At harvest
T_1	Recommended dose of NPK (control)	11.93	12.46	12.33	12.10
T_2	Recommended NPK+5 kg Zn ha^{-1} through $ZnSO_4$ as basal application	13.78	17.24	14.47	13.25
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage	13.38	17.35	15.46	14.03
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application	17.44	19.42	15.43	14.47
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage	17.45	23.07	16.38	16.09
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	16.94	18.44	14.68	13.80
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage	17.50	22.62	15.98	15.76
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage	16.57	20.40	15.37	14.63
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage	14.81	21.36	15.35	14.92
	SEm (±)	3.49	0.52	0.42	0.36
	CD (p= 0.05)	NS	1.55	1.26	1.10

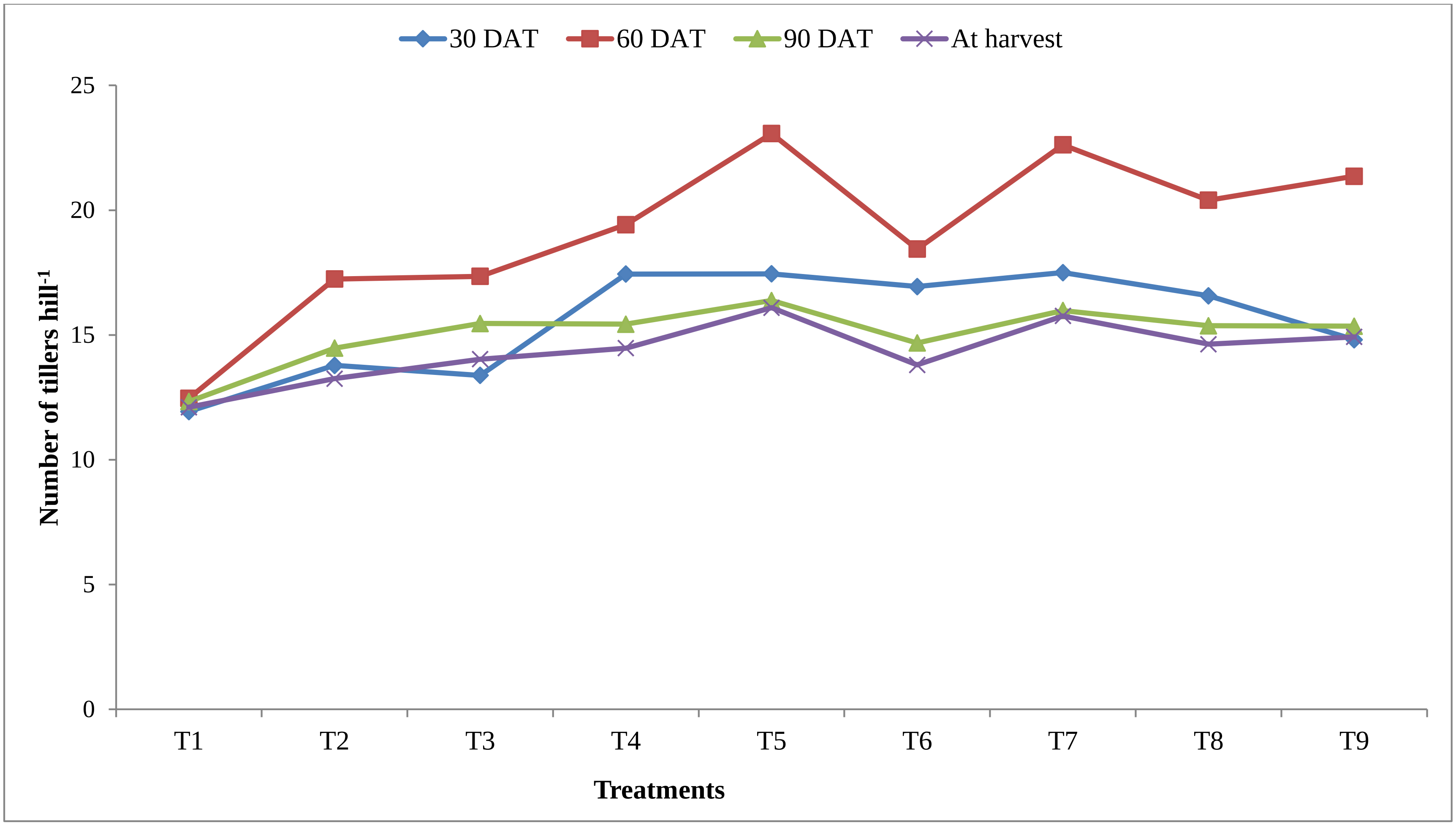


Figure 4.2 Effect of zinc ferti-fortification periodically on number of tillers of Pusa basmati-1121

higher value (25.13 cm) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage), value being 24.90 and lowest under control (21.80 cm). Treatment T_5 was recorded superiority of 15.27 percent over control.

4.2.1.2 Grain panicle^{-1}

The sources, levels and methods of applications of zinc recorded significant influence on grains per panicle of rice. The results revealed that significantly higher value (67.34) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was at par with treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage), with value being 66.71 and lowest under control (54.23). Treatment T_5 was recorded superiority of 24.17 percent over control.

4.2.1.3 Effective tillers m^{-2}

The various zinc fertilization practices recorded significant influence on effective tillers per square metre of rice. Results revealed that significantly higher value (440.55) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was at par with treatment T_7 (RDF NPK+ 1.25 kg Zn ha^{-1} through Zn-EDTA + 0.5% Zn-EDTA foliar spray at MT and PI stage) and lowest under control (332.94). Treatment T_5 was recorded superiority of 32.32% over control.

4.2.1.4 1000-grain weight

Zinc fertilization practices failed to produce significant variations on the 1000-grain weight of rice. However highest value (25.91g) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) followed by T_7 (23.95g) and lowest under control (21.51g)

4.2.2 Yield

The data pertaining to grain yield, straw yield and biological yield of rice cultivar Pusa basmati 1121 was influenced by different zinc fertilization practices and is presented in table 4.4 and illustrated in figure 4.4. Scrutiny of the data exhibited significant variation on grain yield, straw yield and biological yield except harvest index due to all experimental variables

4.2.2.1 Grain yield

The various zinc treatments recorded significant influence on grain yield of rice. Results revealed that significantly higher grain yield (39.13 q ha^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (38.91 q ha^{-1}), the value being 38.91 quintal per hectare and lowest under control (33.25 q ha^{-1}). Treatment T_5 was recorded superiority of 17.68% over control.

4.2.2.2 Straw yield

Similar pattern was observed for straw yield and significantly higher straw yield (102.81 q ha^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (102.14 q ha^{-1}) and lowest under control (91.74 q ha^{-1}). Treatment T_5 was recorded superiority of 12.06% over control. All the zinc sources showed significant superiority over control.

4.2.2.3 Biological yield

The various zinc treatments recorded significant influence on the biological yield of rice. Results revealed that significantly higher biological yield (141.95 q ha^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was at par with treatment T_7 (141.05 q ha^{-1}) and lowest under control (125.75 q ha^{-1}).

4.2.2.4 Harvest index (%)

The Various zinc sources and levels failed to produce significant variation on the harvest index of rice. However, highest value (27.85%) was recorded under treatment T_5

Table 4.3 Effect of zinc ferti-fortification on yield attributes of Pusa basmati-1121

S. No	Treatments	Yield attributes			
		Panicle length (cm)	Grain panicle^{-1}	Effective tillers m^{-2}	1000 grain weight (g)
T_1	Recommended dose of NPK (control)	21.80	54.23	332.94	21.51
T_2	Recommended NPK+5 kg Zn ha^{-1} through $ZnSO_4$ as basal application	22.37	57.95	345.76	23.13
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage	22.47	59.63	377.51	23.39
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application	22.70	60.84	385.50	23.09
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage	25.13	67.34	440.55	25.91
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	22.30	60.29	374.84	23.57
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage	24.90	66.71	430.48	23.95
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage	23.23	61.02	399.81	23.38
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage	23.93	61.94	407.20	23.86
	SEm (±)	0.39	0.80	10.85	0.74
	CD (p= 0.05)	1.13	2.40	32.54	NS

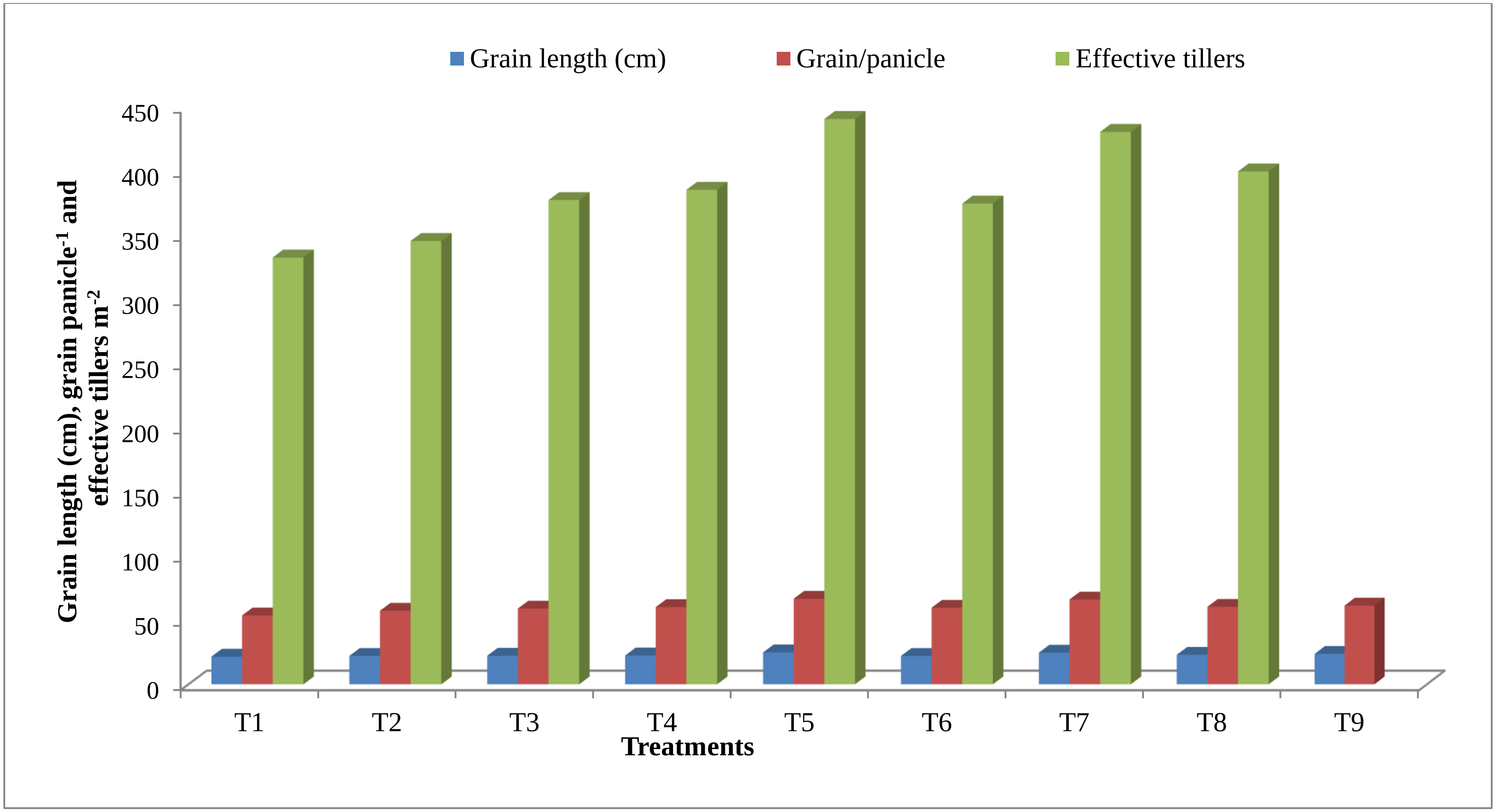


Figure 4.3. Effect of zinc ferti-fortification on yield attributes of Pusa basmati-1121

Table 4.4 Effect of zinc ferti-fortification on grain yield, straw yield, biological yield and harvest index of Pusa basmati-1121

S. No	Treatments	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Biological yield (q ha^{-1})	Harvest index (%)
T_1	Recommended dose of NPK (control)	33.25	91.74	125.75	25.23
T_2	Recommended NPK+5 kg Zn ha^{-1} through $ZnSO_4$ as basal application	35.36	92.93	128.29	25.97
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage	35.80	94.84	130.64	26.61
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application	36.85	92.42	129.27	26.66
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage	39.13	102.81	141.95	27.85
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	36.36	92.69	129.05	26.22
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage	38.91	102.14	141.05	27.18
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage	37.34	95.57	132.91	26.73
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage	37.39	97.51	134.90	27.26
	SEm (±)	0.47	1.20	1.04	0.63
	CD (p= 0.05)	1.42	3.58	3.12	NS

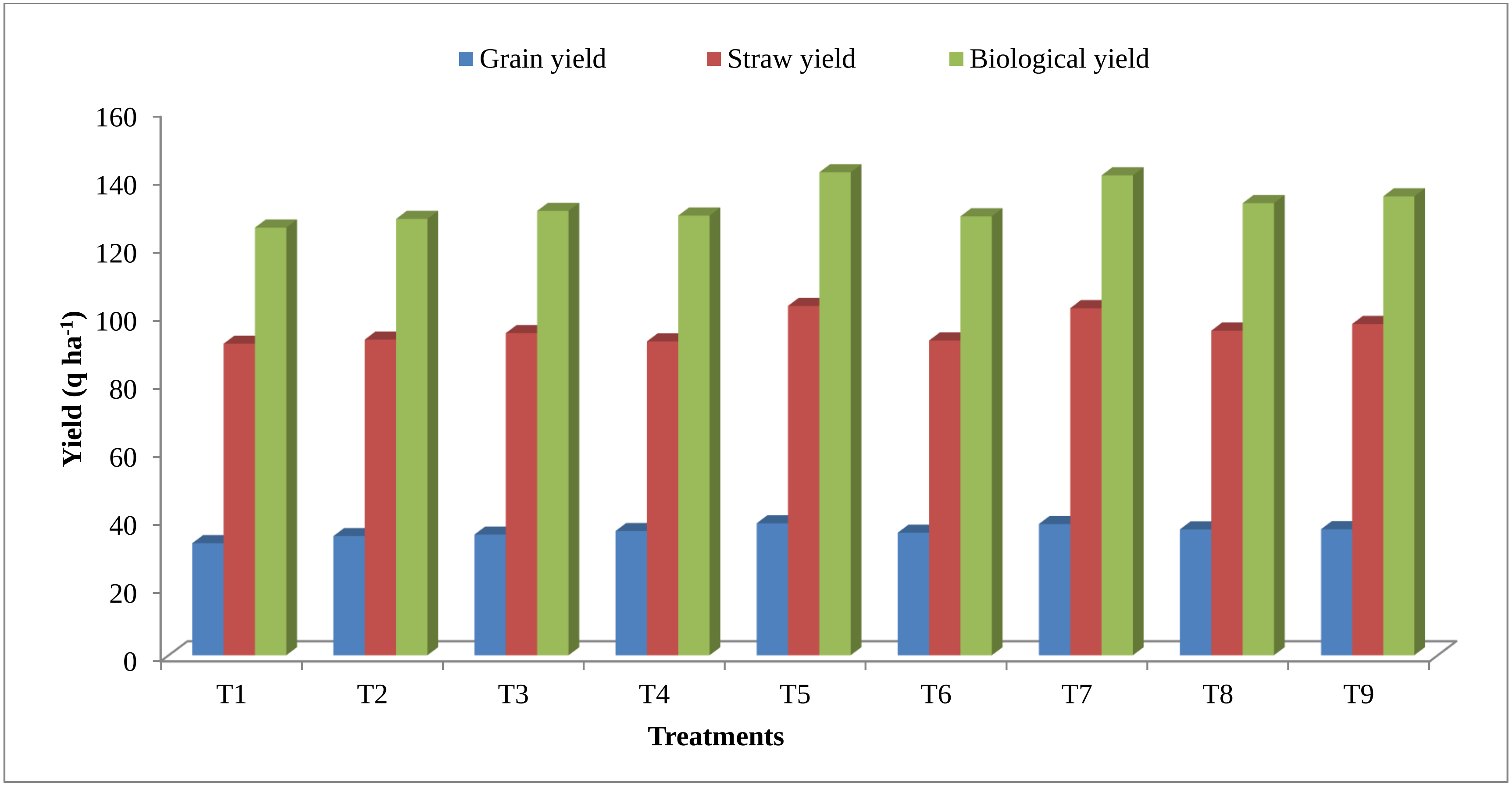


Figure 4.4. Effect of zinc ferti-fortification on grain yield, straw yield and biological yield of Pusa basmati-1121

(recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) and lowest under control (25.23%).

4.3 Effect of different sources of zinc fertilization on nutrient uptake

4.3.1 N and P-uptake in grain, straw and root after harvest of rice crop

The results on N and P-uptake in grain, straw and root are summarized in table 4.5. Different zinc sources produced noticeable variation in grain and straw but failed to record any significant variations in root.

The various zinc fertilization practices recorded significant influence on N-uptake in grain and straw after harvest of rice crop. Significantly higher N-uptake in grain (56.35 kg ha^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (54.35 kg ha^{-1}) and lowest under control (30.69 kg ha^{-1}). In case of N-uptake in straw significantly higher N-uptake (73.0 kg ha^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (71.2 kg ha^{-1}) and lowest under control (41.38 kg ha^{-1}). N-uptake in root failed to produce any significant variations. However, highest N-uptake (23.38 kg ha^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) and lowest under control (14.94 kg ha^{-1}).

The various zinc fertilization practices recorded significant influence on P-uptake in grain and straw after harvest of rice crop. Significantly higher P-uptake in grain (10.08 kg ha^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (9.86 kg ha^{-1}) and lowest under control (5.86 kg ha^{-1}). In case of P-uptake in straw significantly higher N-uptake (9.49 kg ha^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (9.28 kg ha^{-1}) and lowest under control (4.78 kg ha^{-1}). P-uptake in root failed to produce any significant variations. However, highest P-uptake (3.23 kg ha^{-1}) was recorded under treatment T_5

(recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) and lowest under control (1.22 kg ha^{-1}).

4.3.2 K and S-uptake in grain, straw and root after harvest of the rice crop

The results related to K and S-uptake in grain, straw and root are summarized in table 4.6. Different zinc sources produced noticeable variation in grain and straw in case of K-uptake but failed to record any significant variations on S-uptake in grain, straw and root.

The various zinc fertilization practices recorded significant influence on K-uptake in grain and straw after harvest of rice crop. Significantly higher K-uptake in grain (8.35 kg ha^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (8.26 kg ha^{-1}) and lowest under control (4.54 kg ha^{-1}). In case of P-uptake in straw significantly higher P-uptake (107.27 kg ha^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (100.79 kg ha^{-1}) and lowest under control (77.25 kg ha^{-1}). K-uptake in root failed to produce any significant variations. However, highest K-uptake (9.22 kg ha^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) and lowest under control (6.80 kg ha^{-1}).

The Results clearly revealed that different zinc fertilization practices failed to produce any significant variations on S-uptake in grain, straw and root. However, highest S-uptake in grain (5.85 kg ha^{-1}), straw (15.03 kg ha^{-1}) and root (2.57 kg ha^{-1}) were was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) and lowest under control, i.e. grain (3.10 kg ha^{-1}), straw (6.71 kg ha^{-1}) and root (1.22 kg ha^{-1}).

4.3.3 Fe and Zn-uptake in grain, straw and root after harvest of the rice crop

The Data on Fe and Zn-uptake in grain, straw and root are summarized in table 4.7 and Zn-uptake presented in figure 4.5. Different zinc sources produced noticeable

Table 4.5 Effect of zinc ferti-fortification on N and P uptake in grain, straw and root of Pusa basmati-1121

S. No	Treatments	N-uptake (kg ha^{-1})			P-uptake (kg ha^{-1})		
		Grain	Straw	Root	Grain	Straw	Root
T_1	Recommended dose of NPK (control)	30.69	41.38	14.94	5.86	4.78	1.22
T_2	Recommended NPK+5 kg Zn ha^{-1} through $ZnSO_4$ as basal application	45.26	57.95	17.34	7.85	6.85	2.50
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage	47.49	59.92	20.75	7.88	7.94	2.49
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application	44.71	59.02	21.79	8.92	7.96	2.63
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage	56.35	73.00	23.38	10.08	9.49	3.23
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	41.09	56.34	17.60	8.90	7.75	2.92
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage	54.35	71.20	23.22	9.86	9.28	2.72
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage	47.72	62.55	20.18	8.98	8.50	2.73
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage	47.77	65.98	22.87	9.02	8.56	2.87
	SEm (±)	2.22	2.49	1.97	0.29	0.28	0.34
	CD (p= 0.05)	6.67	7.47	NS	0.87	0.83	NS

Table 4.6 Effect of zinc ferti-fortification on K and S uptake in grain, straw and root of Pusa basmati-1121

S. No	Treatments	K-uptake (kg ha^{-1})			S-uptake (kg ha^{-1})		
		Grain	Straw	Root	Grain	Straw	Root
T_1	Recommended dose of NPK (control)	4.54	77.25	6.80	3.10	6.71	1.22
T_2	Recommended NPK+5 kg Zn ha^{-1} through $ZnSO_4$ as basal application	6.84	90.24	7.77	4.24	11.76	1.99
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage	7.57	87.04	8.75	4.70	11.52	2.17
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application	7.62	88.42	9.24	4.85	12.78	2.07
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage	8.35	107.27	9.95	5.85	15.03	2.57
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	7.27	87.54	9.22	4.79	10.77	2.15
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage	8.26	100.79	9.94	5.11	13.04	2.57
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage	7.75	97.40	9.40	4.89	12.91	2.31
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage	7.88	99.65	9.82	5.11	13.04	2.37
	SEm (±)	0.15	2.29	0.94	0.59	1.72	0.31
	CD (p= 0.05)	0.44	6.88	NS	NS	NS	NS

variations in grain and straw in case of Zn-uptake but failed to record any significant variations on Fe-uptake in grain, straw and root.

The Data clearly revealed that different zinc fertilization practices failed to produce any significant variations on Fe-uptake in grain, straw and root. However, highest Fe-uptake in grain (230.73 g kg^{-1}), straw (4893.33 g kg^{-1}) and root (301.23 g kg^{-1}) were recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) and lowest under control, i.e. grain (172.19 g kg^{-1}), straw (1538.90 g kg^{-1}) and root (94.0 g kg^{-1}).

The various zinc fertilization practices recorded significant difference in zinc uptake both in grain and straw due to various treatments. However no significant difference was observed for root zinc uptake. The uptake of zinc in grain (14.2 g kg^{-1}) was significantly higher under treatment T_9 (recommended NPK + 1.0% foliar spray as Zn-EDTA at MT, PI and GF stage) which was superior to all other treatments. However in case of straw Zn uptake, treatment T_9 showed highest zinc uptake (599.7 g kg^{-1}) and significantly superior to all other treatment.

4.4 Effect of different sources of zinc fertilization on soil properties

4.4.1 pH, EC and organic carbon

The Data on pH, EC and organic carbon of soil after harvest of rice pertaining to different zinc fertilization has been presented in table 4.8. Perusal of data didn’t show any marked variations. Different zinc sources failed to produce significant variation on pH, EC and organic carbon after harvest of the rice crop. pH ranged between 7.41 to 7.59, EC varied from 0.32 dSm^{-1} to 0.29 dSm^{-1}. In case of organic carbon it ranged from 4.78 to 5.61 g kg^{-1}. However, highest value (5.61 g kg^{-1}) was recorded under the treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) and lowest under control (4.78 g kg^{-1}).

4.4.2 Available nitrogen, phosphorus, potassium and sulphur

The Results on available nitrogen, phosphorus, potassium and sulphur status of soil after harvest of rice pertaining to different zinc fertilization practices has been presented in table 4.9. Perusal of data clearly showed marked variation on available nutrients status of soil after harvest of the crop except available sulphur.

The results clearly revealed that zinc sources recorded significant influence on soil available nitrogen after harvest of rice cultivar Pusa basmati 1121. Results revealed that significantly higher available nitrogen (248.5 kg ha^{-1}) was recorded under control and lowest value (222.8 kg ha^{-1}) under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage).

The various zinc sources recorded significant influence on soil available phosphorus after harvest of rice cultivar Pusa basmati 1121. Results revealed that significantly higher available phosphorus (16.0 kg ha^{-1}) was recorded under control and lowest value (11.50 kg ha^{-1}) under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage).

The results clearly revealed that zinc sources recorded significant influence on soil available potassium after harvest of rice cultivar Pusa basmati 1121. Results revealed that significantly higher available potassium (152.77 kg ha^{-1}) was recorded under control and lowest value (138.85 kg ha^{-1}) under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage).

The various zinc sources failed to produce significant variations on soil available sulphur content after harvest of rice crop. However, highest available sulphur content (18.02 mg kg^{-1}) was recorded under the treatment T_2 (recommended NPK + 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application and lowest under control (14.44 mg kg^{-1}).

4.4.3 DTPA extractable Fe and Zn

Results pertaining to DTPA extractable iron and zinc status of soil after harvest of rice crop didn’t show any marked variation and presented in table 4.10.

The results clearly revealed that zinc sources failed to produce significant variation on DTPA extractable iron after harvest of rice crop. However, maximum DTPA extractable iron content (9.07 mg kg^{-1}) was recorded under control and minimum under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5%

Table 4.7 Effect of zinc ferti-fortification on Fe and Zn uptake in grain, straw and root of Pusa basmati-1121

S. No	Treatments	Fe-uptake (g ha^{-1})			Zn-uptake (g ha^{-1})		
		Grain	Straw	Root	Grain	Straw	Root
T_1	Recommended dose of NPK (control)	172.19	1538.90	94.00	69.7	229.9	59.4
T_2	Recommended NPK+5 kg Zn ha^{-1} through $ZnSO_4$ as basal application	186.59	2386.43	195.36	83.9	267.6	74.6
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage	197.44	2583.50	111.80	101.5	307.0	99.5
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application	201.00	3671.03	192.54	130.9	499.6	102.5
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage	230.73	4893.33	301.23	132.3	508.1	104.4
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	203.06	3819.43	166.62	110.0	387.3	107.7
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage	227.97	4603.73	240.93	119.5	379.3	105.0
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage	213.54	2923.13	233.50	138.7	515.1	114.4
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage	223.09	3628.83	237.89	144.2	599.7	121.7
	SEm (±)	22.84	790.9	41	1.74	27.79	12.59
	CD (p= 0.05)	NS	NS	NS	5.21	83.3	NS

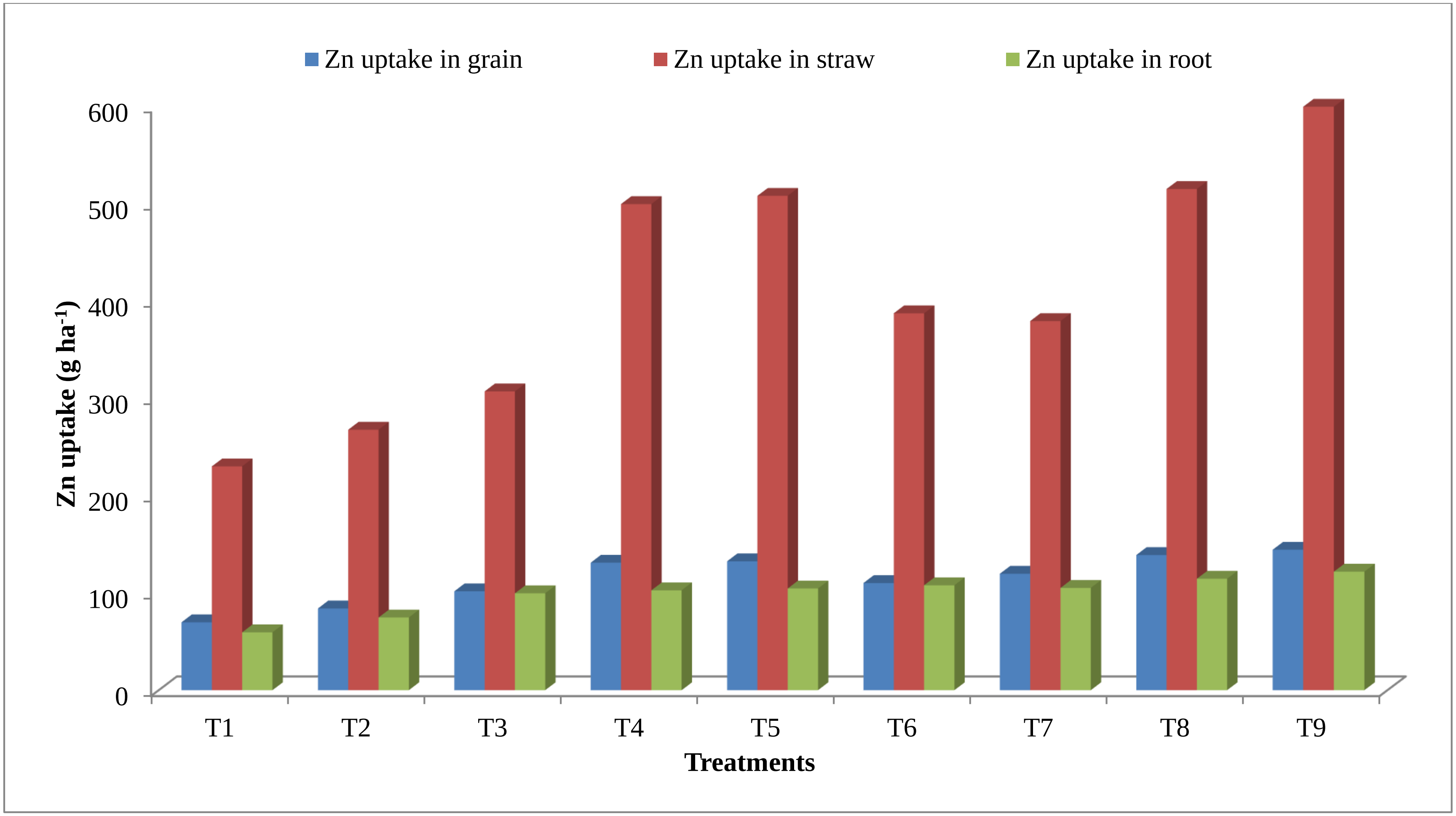


Figure 4.5 Effect of zinc ferti-fortification on Zn uptake in grain, straw and root of Pusa basmati-1121

Table 4.8 Effect of zinc ferti-fortification on pH, EC and organic carbon after harvest of Pusa basmati-1121

S. No	Treatments	pH	EC (dS m^{-1})	OC (g kg^{-1})
T_1	Recommended dose of NPK (control)	7.59	0.29	4.78
T_2	Recommended NPK+5 kg Zn ha^{-1} through $ZnSO_4$ as basal application	7.57	0.30	4.84
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage	7.56	0.31	4.97
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application	7.56	0.33	5.19
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage	7.41	0.34	5.61
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	7.46	0.30	5.08
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage	7.57	0.32	5.56
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage	7.49	0.31	5.27
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage	7.44	0.30	5.50
	SEm (±)	0.09	0.02	0.33
	CD (p= 0.05)	NS	NS	NS

Table 4.9 Effect of zinc ferti-fortification on available N, P, K and S after harvest of Pusa basmati-1121

S. No	Treatments	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	S (mg kg^{-1})
T_1	Recommended dose of NPK (control)	248.6	16.00	152.77	14.44
T_2	Recommended NPK+5 kg Zn ha^{-1} through $ZnSO_4$ as basal application	243.2	14.81	146.27	18.02
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage	238.3	13.22	143.64	17.59
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application	238.0	12.58	143.29	17.55
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage	222.8	11.50	138.85	17.32
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	233.2	12.23	141.54	17.32
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage	234.2	12.44	143.43	16.72
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage	235.3	12.43	143.15	16.99
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage	234.2	12.23	141.57	15.68
	SEm (±)	1.79	0.29	1.91	0.74
	CD (p= 0.05)	5.35	0.86	5.74	NS

Table 4.10 Effect of zinc ferti-fortification on available Fe and Zn after harvest of Pusa basmati-1121

S. No	Treatments	Fe (mg kg^{-1})	Zn (mg kg^{-1})
T_1	Recommended dose of NPK (control)	9.07	0.54
T_2	Recommended NPK+5 kg Zn ha^{-1} through $ZnSO_4$ as basal application	8.84	0.56
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage	7.97	0.56
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application	8.20	0.58
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage	7.51	0.60
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	8.26	0.56
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage	7.63	0.57
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage	8.12	0.57
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage	7.92	0.58
	SEm (±)	0.47	0.01
	CD (p= 0.05)	NS	NS

Zn-EDTA at MT and PI stage) (7.51 mg kg^{-1}). Also various treatments showed non-significant effect.

The various zinc sources failed to produce significant variations on DTPA extractable zinc after harvest of rice crop. However, maximum value (0.60 mg kg^{-1}) was recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) and minimum under control (0.54 mg kg^{-1}). Various treatments also showed non-significant effect.

4.5 Effect of different sources of zinc fertilization on zinc use efficiency indices

Results revealed that Partial factor productivity (PEP), Agronomic efficiency (AE), Recovery efficiency (RE), Physiological efficiency (PE) and Zinc harvest index (ZHI) are summarized in table 4.11. Different zinc sources produced noticeable variations in ZnPEP, ZnAE, ZnCRE, ZnPE and ZnHI.

4.5.1 Partial factor productivity (PFP)

Results clearly revealed that different zinc fertilization practices recorded significant influence on partial factor productivity (PFP). Significantly higher value (4148.5 kg grain kg^{-1} Zn applied) was recorded under treatment T_8 (recommended NPK + 0.5% Zn EDTA foliar spray at MT, PI and GF stage) which was followed by treatment T_6 and lowest value (707.2 kg grain kg^{-1} Zn applied) under treatment T_2 (recommended NPK + 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application).

4.5.2 Agronomic efficiency (AE)

Results clearly revealed that different zinc fertilization practices recorded significant influence on agronomic efficiency (AE). Significantly higher value (454.4 kg grain increase kg^{-1} Zn applied) was recorded under foliar treatment T_8 (recommended NPK + 0.5% Zn EDTA foliar spray at MT, PI and GF stage) which was followed by treatment T_6 and lowest value (42.3 kg grain increase kg^{-1} Zn applied) under treatment T_2 (recommended NPK + 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application).

4.5.3 Recovery efficiency (RE)

Results clearly revealed that different zinc fertilization practices recorded significant influence on recovery efficiency (RE). Significantly higher value (52.4%) was recorded under foliar treatment T_8 (recommended NPK + 0.5% Zn EDTA foliar spray at MT, PI and GF stage) which was followed by another foliar treatment T_9 (recommended NPK + 1.0% foliar spray as Zn-EDTA at MT, PI and GF stage) and lowest value (2.4%) was recorded under treatment T_2 (recommended NPK + 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application).

4.5.4 Physiological efficiency (PE)

Results clearly revealed that the different zinc fertilization practices was recorded significant influence on physiological efficiency (PE). Significantly higher value (1850.1 kg grain kg^{-1} Zn uptake) was recorded under treatment (T_2 (recommended NPK + 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application) which was followed by treatment T_4 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal application) and lowest value (830.9 kg grain kg^{-1} Zn uptake) was recorded under treatment T_9 (recommended NPK + 1.0% foliar spray as Zn-EDTA at maximum tillering, panicle initiation and grain filling stage).

4.5.5 Zinc harvest index (ZHI)

Results clearly revealed that the different zinc fertilization practices was recorded significant influence on zinc harvest index (ZHI). Significantly higher value (13.59%) was recorded under treatment T_4 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal application) which was followed by treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) and lowest value (11.30%) under control.

Table 4.11 Effect of zinc ferti-fortification on zinc use efficiency indices of Pusa basmati-1121

S. No	Treatments	ZnPFP (kg grain kg^{-1} Zn applied)	ZnAE (kg grain increase kg^{-1} Zn)	ZnCRE (%)	ZnPE (kg grain kg^{-1} Zn uptake)	ZnHI (%)
T_1	Recommended dose of NPK (control)	-	-	-	-	11.30
T_2	Recommended NPK+5 kg Zn ha^{-1} through $ZnSO_4$ as basal application	707.2	42.3	2.4	1850.1	11.42
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage	862.7	61.5	4.2	1453.7	12.84
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application	1474.0	144.1	10.6	1534.1	13.59
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage	1262.4	189.9	13.1	1448.5	12.91
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	2909.1	249.3	21.1	1342.1	12.51
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage	2062.0	264.9	21.5	1260.8	12.90
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage	4148.5	454.4	52.4	871.3	12.73
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage	2077.4	230.4	28.1	830.9	12.44
	SEm (±)	21.5	21.6	1.79	253.5	0.45
	CD (p= 0.05)	74.6	64.8	5.39	760.2	1.36

CHAPTER-V

DISCUSSION

CHAPTER-5

DISCUSSION

The investigation entitled **'Relative Performance of Zinc sulphate and Chelated Zinc on Zinc Fortification of Rice'** was undertaken during *kharif* 2021. The data obtained were evaluated and results were reported in previous chapter. In this chapter, the findings of the study are discussed under the following headings:

5.1 Effect of different sources of zinc fertilization on

5.1.1 Growth attributes

5.1.2 Yield attributes

5.1.3 Yield (Grain, straw and biological)

5.2 Effect of different sources of zinc fertilization on

5.2.1 Nitrogen, phosphorus and potassium uptake

5.2.2 Iron and Zinc uptake

5.3 Effect of different sources of zinc fertilization on physico-chemical properties after harvesting

5.3.1 Soil pH, EC and organic carbon

5.3.2 Available macronutrients

5.3.3 Available micronutrients

5.4 Effect of different sources of zinc fertilization on

5.4.1 Zinc use efficiency indices

5.1 Effect of different sources of zinc fertilization on

5.1.1 Growth attributes

It is clear from the results presented in previous chapter that zinc fertilization practices evinced favorable effect on growth parametres *viz.* plant height and number of tillers (Table 4.1) during the year of experimentation. Zinc might be responsible for the improvement in growth characters, as it is an important component of many enzyme systems. The metabolism of amino acids, proteins and carbohydrates is also regulated by zinc. In meristematic regions of plants, these three compounds result in rapid cell division and elongation, resulting better crop growth. (Mandal *et al.* 2009). Khan *et al.* (2005a) also reported that zinc application might increase plant height because it influences auxin production, which regulates stem elongation and cell expansion.

An inspection of the data revealed that shoot elongation continued to increase with advancement in age but rapid increase in height was recorded upto 90 DAT, thereafter it increased but with slower rate. Possibly, slow growth of the plant after 90 DAT is due to the reason of photosynthates being diverted to grain and reproductive parts of the plant. Application of RDF (NPK) + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage (T_5) recorded significantly taller plants at 60 and 90 DAT over rest of treatments except (T_7) RDF (NPK) + 1.25 kg Zn ha^{-1} through Zn-EDTA + 0.5% Zn-EDTA foliar spray at MT and PI stage. The reason might be due to the availability of zinc via two routes, namely soil through xylem, and foliar application through phloem. In addition, chelated zinc (Zn-EDTA) has a greater capacity to transport zinc to the roots of plants. This result corroborates the findings of Ram *et al.* (2011) and Boonchuay *et al*. (2013).

Production of tillers concomitantly increased upto 60 DAT and after that it declined till the harvest (Table 4.2). This might be due to the reason that newly formed tillers may not get sufficient food because of diversion of photosynthates to the grain and reproductive parts during this elongation and reproductive phase. In addition, reduction in tillers might also be due to the death of some late-born tillers as a result of competition for light and nutrients (Mandal *et al.* 2009). It is also possible that, during the growth phase between developing panicles and young tillers (late emerging tillers), there is a competition for assimilates. When young tillers are suppressed, they may eventually senesce without producing seeds (Shivay *et al*. 2010). It is believed that zinc is an important component of several matalloenzymes that contribute to the senescence of leaves and stimulates the production of tillers (Nawaz *et al*. 2015). Application of RDF (NPK) + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage (T_5) significantly recorded higher tillers $hill^{-1}$ than all other treatments except (T_7) RDF (NPK) + 1.25 kg Zn ha^{-1} through Zn-EDTA + 0.5% Zn-EDTA foliar spray at MT and PI stage. This might be due to reason that the combination of soil and foliar applications facilitated a more favourable environment for root and shoot development and increased zinc availability. Similar results were reported by Rehman *et al*. (2012) and Naik and Das (2008).

5.1.2 Yield attributes

The yield attributing characters *viz*. panicle length, number of grains per panicle, effective tillers per square metre were positively influenced by different zinc fertilization treatments (Table 4.3). Significant increase in the length of panicle, number of grains per panicle, effective tillers per square metre were recorded due to the application of RDF (NPK) + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage (T_5) and it showed significant superiority over rest of the treatments except treatment T_7 (RDF NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA + 0.5% Zn-EDTA foliar spray at MT and PI stage) during the year of experiment. It might be due to higher response of rice to Zn applied to the soil, which is absorbed by xylem, and foliar Zn absorbed and transported through the phloem, resulting higher dry matter accumulation, higher plant height and more photosynthetic activity. Similar results were obtained by Cakmak, (2008); Ram *et al*. (2013) and Naik and Das (2008). Zinc fertilizer applied together to both soil and foliar surfaces appears to have higher potential to increase plant growth and grain yield (Cakmak *et al*. 2010). These results are also in accordance to those of Ghasal *et al.* (2015). Higher zinc absorption by the plants from tillering to panicle initiation stage helped to produce more panicle length, number of grains per panicle and effective tillers per square metre. The increase in the number of panicles per metre might be attributed to adequate Zn supply which might have increased the supply of other nutrients and stimulated the overall plant growth. Increase in number of grains per panicle has also been reported by many earlier workers (Veeranagappa, 2010; Khan *et al*. 2012; Naik and Das, 2008). Non-significant results were recorded for the 1000-grain weight, possibly due to the dominant genetic influence on the crop, without much influence from environmental or managerial factors (Naik and Das, 2008).

5.1.3 Yield (Grain, straw and biological)

Yield is a function of complex inter-relationships of various yield components, which are determined from the growth rhythms in vegetative phase and its subsequent reflection in reproduction phase of the plant. Vigorously growing plants are able to absorb larger quantity of mineral nutrients through well-developed root system.

The significant improvement in growth characteristics and yield components led to higher grain and straw yields (Table 4.4). Application of RDF (NPK) + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage (T_5) recorded significantly superior grain and straw yield over rest of the treatments except T_7 (RDF NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA + 0.5% Zn-EDTA foliar spray at MT and PI stage). Because of favourable influence of Zn on yield attributes, positive effect reflected in the final grain yield. It therefore appears that the contribution of Zn applications to increase rice grain yield might have been related to the onset of early panicle emergence, which might have allowed for greater storage of assimilates in rice grains. Zn treatment increased plant height, leaf area index, tillering capacity, and thus overall vegetative growth in rice. This could be attributed to increased enzymatic and hormonal activity, which stimulated the rapid buildup of photosynthates. Straw makes up a large portion of overall biomass, hence Zn application increased its production. These findings are in agreement to those reported by Veeranagappa *et al.* (2010), Khan *et al*. (2012), Naik and Das (2008) and Karak *et al.* (2005). The use of Zn-EDTA reduces zinc leaching and fixation in the soil as well as increased Zn availability to the crop. Increased yield is due to participation of Zn in the biosynthesis of indole acetic acid (IAA) as well as its role in the initiation of primordial reproductive parts and the partitioning of photosynthates towards them. Chelated zinc exhibited greater Zn solubility and stability, thus enhanced the movement of Zn ions into plants to increase grain yield. These results are in agreement with finding of Karak *et al.* (2005); Cakmak, (2008) and Naik and Das, (2008). The catalytic or stimulatory effect of applied Zn on most of plant physiological and metabolic process might also contribute to its favourable influence on yield (Mandal *et al.* 2009) and Dhaliwal *et al*. (2009).

5.2 Effect of different sources of zinc fertilization on

5.2.1 Nitrogen, phosphorus potassium and sulphur uptake

The various sources, levels and methods of application of zinc failed to produce significant effect on the N, P, K and S uptake in root but showed significant difference in grain and straw of rice. But sulphur uptake was non-significant in case of grain and straw (Table 4.5 and 4.6). Application of RDF (NPK) + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage (T_5) showed significant superiority over rest of the treatments except T_7 (RDF NPK + 1.25 kg Zn

ha^{-1} through Zn-EDTA + 0.5% Zn-EDTA foliar spray at MT and PI stage). Nitrogen has been found to interact positively with Zn. Correction of Zn deficiency in soil might have resulted in increased enzymatic activity, which led to greater nitrogen accumulation. Zinc application accelerated the uptake of nutrients, especially N and K by stimulating root and shoot growth. Diffusion plays a significant role in the transport of Zn and other nutrients, such as P and K to the root surface when the Zn concentration is low, especially in soils with low plant-available Zn. This is because mass flow can only carry a tiny portion of the minerals needed by the plants. These findings corroborate the findings of Khan *et al.* (2005);Yadi *et al*. (2012); Ghatak *et al.* (2005) and Pooniya and Shivay (2011). Different zinc sources considerably boosted nitrogen uptake in grain and straw over control, which is a product of yield (grain and straw) and N, P, and K concentration. Since Zn application stimulated the vegetative growth which in turn increased the grain and straw yield. The total N, P, and K uptake was obvious as a result of the increased N, P and K content combined with the grain and straw yield. Increase in N, P and K uptake due to Zn application has been widely reported by a number of workers (Swami and Shekhawat, 2009; Darade and Bankar, 2009).

5.2.2 Zinc and Iron uptake

The various fertilization levels of zinc failed to produce significant effect on the Fe and Zn uptake in root but showed significant difference in case of Zn for grain and straw. The treatment T_9 (RDF NPK + 1.0% foliar spray as Zn-EDTA at MT, PI and GF stage) showed maximum Zn uptake in grain and straw (Table 4.7) followed by T_8 (RDF NPK + 0.5 % foliar spray as Zn-EDTA at MT, PI and GF stages) and was significantly superior to control and other treatments. The higher Zn uptake by the crop through three foliar applications might be due to greater availability and rapid rate of absorption brought on by enhanced mobility of zinc when applied as a foliar spray because uptake is a product of content and dry matter production. The findings are inconformity those of Das *et al*. (2004); Yadav *et al.* (2011). Zinc has close relationship with plant metabolism and physiology which might have improved the uptake in grain. These results are in agreement with the findings of Karak *et al*. (2006); Cakmak *et al*. (2010) and Keram *et al*. (2012). The presence of an increased amount of zinc in soil solution from the foliar application of zinc fertilizers might have made it much easier for zinc to get absorbed through phloem and eventually increases zinc uptake in grain and straw at harvest. The higher concentration of zinc in straw as compared to grain was reported by Naik and Das (2007). The increase in zinc uptake due to foliar application might be due to zinc remobilization into the rice grain through phloem and absorption by the leaf epidermis, as well as several membranes of zinc-regulated transporters that might have governed this process. This result is in agreement with the findings of Phuphong *et al.* (2018); Wu *et al.* (2010); Li *et al.* (2013); (Bashir *et al.* 2012). Zinc uptake in root was found to be non-significant but increased with zinc fertilization as compared to no zinc fertilization treatment. This might be due to increase in availability of Zn from rhizosphere by mechanisms such as decrease in pH, release of organic acids due to decomposition of FYM, chelating and other compounds resulting an increase in root growth that promoted the increased nutrient uptake per unit root volume. These results are in agreement with the findings of Ahmed *et al.* (2012); Aziz *et al.* (2010).

5.3 Effect of different sources of zinc fertilization on physico-chemical properties

5.3.1 Soil pH, EC and organic carbon

Data on pH, EC and organic carbon of soil after harvest of rice pertaining to different zinc fertilization has been presented in (Table 4.8). There was no marked variations in these basic properties of soil after harvest of rice. Different zinc sources failed to produce significant variation on pH, EC and organic carbon after harvest of the rice crop. Although the pH values decreased slightly from initial soil pH, EC value increased slightly in treatment T_5 and organic carbon increased numerically from initial soil status. This might be due to application of different zinc sources which increased microbial activity, improving bacterial community which ultimately helped in the decomposition of organic matter and eventually increased the organic carbon content in the soil. These findings are in accordance to those reported by Gu *et al.* (2019).

5.3.2 Available macronutrients

It is clearly evident from the results that different zinc fertilization practices directly influenced the available N, P and K contents of soil after harvest of rice crop (Table 4.9). Results further showed a significantly higher content of available N, P and K in soil under treatment T_1 (Recommended dose of NPK) as compared to other treatments. It could be because of sub-optimal zinc supplies at T_1, which led to decrease in uptake of N, P and K from the soil and thus poor growth and yield under control. These findings are in good agreement to those reported by Khan *et al.* (2005), Prasad *et al.* (2010) and Kulhare *et al.* (2017).

5.3.3 Available micronutrients

Both Fe and Zn content in soil showed non-significant effect by the application of different levels of zinc (Table 4.10). However, available Fe content in soil after harvest of rice crop slightly decreased from initial Fe status of soil except treatment T_1. This might be due to uptake by the plant from the soil which decreased the soil available content (Marquez-Quiroz *et al.* 2015). Zn content in soil showed non-significant effect among treatments which might be due to higher growth and development of rice plants with all zinc application treatments resulting into higher root biomass production, which recycle zinc into the soil. These results are in agreement with the finding of Bana *et al.* (2020)

5.4 Effect of different sources of zinc fertilization on

5.4.1 Zinc use efficiency indices

Various indices are commonly used in research to assess the efficiency of applied nutrients. Data clearly revealed that different zinc fertilization practices significantly improved different zinc use efficiency indices. Among the different zinc sources, application of RDF (NPK) + 0.5% Zn EDTA foliar spray at MT, PI and GF stage (T_8) registered significantly higher partial factor productivity, agronomic efficiency and recovery efficiency which was significantly superior over other treatments (Table 4.11). This could be as a result of greater grain yield and comparative improvement in uptake of fertilizers (Jayadeva *et al.* 2008). Physiological efficiency recorded significantly higher with the application of RDF (NPK) + 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application (T_2) which might be due to the application of higher amount of zinc fertilizer as compared to other treatments and thus increased the physiological efficiency (Dobermann, 2005). Agronomic efficiency, physiological efficiencies and recovery efficiency decreased significantly with increased fertilizers doses (Limon *et al*. 2000b). This might be due to inverse relationship often observed between utilization and rate of application. The progressive decline in grain yield or dry matter production was another factor contributing to the decrease in zinc use efficiency at higher levels of Zn applied. (Muthukumararaja and Sriramachandrasekharan, 2012). The results were in agreement with the findings of Fageria and Baligar (2003), Dobermann (2005), Shivay *et al*. (2008), Singh *et al*. (2014).

CHAPTER-VI

SUMMARY AND CONCLUSIONS

CHAPTER-6

SUMMARY AND CONCLUSIONS

An investigation entitled '**Relative Performance of Zinc sulphate and Chelated Zinc on Zinc Fortification of Rice'** was conducted at the Research Farm of Division of Soil Science and Agriculture Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu during the *kharif* 2021. The soil of the experimental field was clay loam in texture, near neutral in reaction, medium in organic carbon, available phosphorus and potassium, low in available nitrogen and medium in DTPA extractable Zn and available sulphur whereas sufficient in DTPA extractable iron. The experiment was laid under Randomized Block Design with three replications and nine treatments *viz.* T_1-recommended NPK, T_2-recommended NPK+ 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application, T_3-recommended NPK+ 2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+ 0.5% $ZnSO_4$ foliar spray at MT and PI stage, T_4-recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application, T_5- recommended NPK+ 2.5 kg Zn ha^{-1} through Zn EDTA as basal+ 0.5% Zn-EDTA at MT and PI stage, T_6- recommended NPK+ 1.25 kg Zn ha^{-1} through Zn-EDTA as basal, T_7- recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA+ 0.5% Zn-EDTA foliar spray at MT and PI stage, T_8-recommended NPK+ 0.5% Zn EDTA foliar spray at MT, PI and GF stage, T_9-recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage. All the nine treatments received uniform application of 40 kg N, 25 kg P_2O_5 and 15 kg K_2O ha^{-1}. One third of the total quantity of nitrogen along with the full dose of phosphorus and potassium was applied through urea, diammonium phosphate (DAP) and muriate of potash (MOP) respectively, just before transplanting on puddled soil surface. The remaining urea fertilizer was top dressed in two equal splits at active tillering and panicle initiation stage. Zinc fertilizer was applied according to the treatments through Zn-EDTA and $ZnSO_4$.Three seedlings were transplanted by using index finger and thumb and gently planting them at the intersection of marking 20 cm $\times$10 cm in puddled soil on 17th July, 2021.The salient features of the experimental findings presented and discussed in the preceding chapters are briefly summarized here under the following headings:

6.1 Effect of different sources of zinc fertilization on

6.1.1 Growth attributes

The experimental results revealed that a significant increase in plant height and number of tillers per hill at all growth stages (60, 90 DAT and at harvest) except 30 DAT. Significantly higher plant height and number of tillers per hill were recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA + 0.5% Zn-EDTA foliar spray at MT and PI stage) and minimum under control. At 30 DAT, the experimental findings also revealed that there is no significant effect of application of different sources and levels of zinc on the plant height and number of tillers $hill^{-1}$. However maximum value recorded under treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA + 0.5% Zn-EDTA foliar spray at MT and PI stage) and minimum under control.

6.1.2 Yield and yield attributes

The experimental results revealed that there is a significant increase in yield attributes *viz.* panicle length, number of grains per panicle and effective tillers per square metre except 1000-grain weight and yield *viz.* grain yield, straw yield and biological yield except harvest index by the application of treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was statistically at par with treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA + 0.5% Zn-EDTA foliar spray at MT and PI stage) and minimum under control.

6.1.3 Nutrient uptake

Experimental findings revealed that different zinc fertilization practices failed to produce any significant variations on S and Fe uptake in grain, straw and root. However, application of different zinc sources significantly increases the uptake of N, P, K and Zn in grain and straw except root. Significantly higher values recorded under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) which was at par with treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage) and minimum under control. In case of Zn uptake in grain and straw, significantly higher value recorded under treatment T_9 (recommended NPK+1.0 % foliar spray as Zn-EDTA at maximum MT and PI and GF stage) which was followed by treatment T_8 (recommended NPK + 0.5% Zn EDTA foliar spray at MT and PI and GF stage) and lowest under control.

6.1.4 Soil fertility status

Different zinc sources and levels failed to produce significant variations on pH, EC, organic carbon, available S, DTPA extractable Fe and Zn after harvest of rice crop. However, different zinc fertilization practices produced significant influence on soil available N, P and K. The results revealed that significantly higher values were recorded under control and lowest under treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage).

6.1.5 Zinc use efficiency indices

The experimental results revealed that different zinc fertilization practices significantly improve different zinc use efficiency indices. Among the different zinc sources and methods of application, treatment T_8 (recommended NPK + 0.5% Zn EDTA foliar spray at MT and PI and GF stage) registered significantly higher partial factor productivity, agronomic efficiency and recovery efficiency and lowest under control. In case of physiological efficiency, treatment T_2 (recommended NPK+ 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application) significantly recorded higher value which was followed by treatment T_4 (recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application) and lowest under treatment T_9 (recommended NPK +1.0 % foliar spray as Zn-EDTA at MT and PI and GF stage). Moreover, significantly higher value of zinc harvest index was recorded under treatment T_4 (recommended NPK+ 2.5 kg

Zn ha^{-1} through Zn-EDTA as basal application) followed by treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA at MT and PI stage) and lowest value under control.

6.2 Conclusions

Based on above summarization, following conclusions may be drawn:

- The treatment T_5 (recommended NPK + 2.5 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage) showed significantly higher growth attributes (plant height and number of tillers hill^{-1}), yield attributes (panicle length, number of grains panicle^{-1} and effective tillers m^{-2}) and yield (grain, straw and biological) of rice variety Pusa basmati 1121. However it was statistically at par with treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage).
- So treatment T_7 (recommended NPK + 1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage) was equally potent to enhance all growth and yield parametres and yield of Pusa basmati 1121.
- However, treatment T_9 (recommended NPK + 1.0 % Zn-EDTA foliar spray at at MT, PI and GF stages) was better and showed higher zinc uptake in grain and straw.
- Thus it is concluded that overall growth, yield attributes and yield were better under treatment T_7 whereas treatment T_9 showed better response from zinc fortification point of view.
- However, in case of zinc use efficiency, treatment T_8 (Recommended NPK + 0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage) significantly showed higher zinc partial factor productivity (PFP), agronomic efficiency (AE) and crop recovery efficiency (CRE).

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APPENDICES

APPENDIX-I

Effect of zinc ferti-fortification on N and P concentration in grain, straw and root of Pusa basmati-1121

S. No	Treatments	N concentration (%)			P concentration (%)		
		Grain	Straw	Root	Grain	Straw	Root
T_1	Recommended dose of NPK (control)	0.92	0.45	0.52	0.18	0.84	0.05
T_2	Recommended NPK+ 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application.	1.28	0.62	0.60	0.22	0.97	0.10
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage.	1.33	0.63	0.72	0.22	0.92	0.10
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application.	1.21	0.63	0.75	0.24	0.96	0.11
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage.	1.44	0.71	0.81	0.26	1.04	0.13
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	1.13	0.61	0.61	0.24	0.94	0.12
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage.	1.40	0.70	0.80	0.25	0.99	0.11
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage.	1.28	0.65	0.70	0.24	0.99	0.11
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage.	1.28	0.68	0.79	0.24	1.01	0.11
	SEm (±)	0.03	0.02	0.07	0.006	0.008	0.01
	CD (p= 0.05)	0.09	0.06	NS	0.018	0.025	NS

APPENDIX-II

Effect of zinc ferti-fortification on K and S concentration in grain, straw and root of Pusa basmati-1121

S. No	Treatments	K concentration (%)			S concentration (%)		
		Grain	Straw	Root	Grain	Straw	Root
T_1	Recommended dose of NPK (control)	0.13	0.84	0.27	0.09	0.07	0.05
T_2	Recommended NPK+5 kg Zn ha^{-1} through $ZnSO_4$ as basal application.	0.19	0.97	0.31	0.12	0.13	0.08
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage.	0.21	0.92	0.35	0.13	0.12	0.09
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application.	0.21	0.96	0.37	0.13	0.14	0.09
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage.	0.21	1.04	0.40	0.15	0.15	0.11
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	0.20	0.94	0.37	0.13	0.12	0.11
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage.	0.21	0.99	0.40	0.13	0.13	0.11
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage.	0.21	0.99	0.38	0.13	0.14	0.10
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage.	0.21	1.01	0.39	0.14	0.13	0.10
	SEm (±)	0.01	0.008	0.05	0.04	0.02	0.01
	CD (p= 0.05)	0.03	0.02	NS	NS	NS	NS

APPENDIX-III

Effect of zinc ferti-fortification on Fe and Zn concentration in grain, straw and root of Pusa basmati-1121

S. No	Treatments	Fe concentration (mg kg^{-1})			Zn concentration (mg kg^{-1})		
		Grain	Straw	Root	Grain	Straw	Root
T_1	Recommended dose of NPK (control)	51.8	167.7	34.8	21.0	25.1	27.0
T_2	Recommended NPK+ 5 kg Zn ha^{-1} through $ZnSO_4$ as basal application.	52.8	256.8	72.4	23.7	28.8	26.9
T_3	Recommended NPK+2.5 kg Zn ha^{-1} through $ZnSO_4$ as basal+0.5% $ZnSO_4$ foliar spray at MT and PI stage.	55.2	272.7	41.4	28.4	32.4	29.9
T_4	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal application.	54.5	397.2	71.3	35.5	54.1	31.3
T_5	Recommended NPK+2.5 kg Zn ha^{-1} through Zn-EDTA as basal+0.5% Zn-EDTA at MT and PI stage.	59.0	476.0	111.6	33.8	49.4	31.8
T_6	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal	55.8	413.1	61.7	30.3	41.8	32.9
T_7	Recommended NPK+1.25 kg Zn ha^{-1} through Zn-EDTA as basal + 0.5% Zn-EDTA foliar spray at MT and PI stage.	58.6	451.7	89.2	30.7	37.1	31.9
T_8	Recommended NPK+0.5% Zn EDTA foliar spray at maximum MT, PI and GF stage.	57.2	305.9	60.2	37.1	53.9	35.9
T_9	Recommended NPK+1.0 % foliar spray as Zn-EDTA at MT, PI and GF stage.	59.7	372.1	88.1	38.6	61.5	38.4
	SEm (±)	4.09	71.4	20	0.44	0.41	2.51
	CD (p= 0.05)	NS	NS	NS	1.31	1.22	NS

CERTIFICATE-IV

Certified that all necessary corrections as suggested by the external examiner and advisory committee have been duly incorporated in the thesis entitled **"Relative Performance of Zinc sulphate and Chelated Zinc on Zinc Fortification of Rice"**, submitted by **Mr. Yahiya Akram Laskar**, Registration No. **J-20-M-767**.

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