TRANSFORMATION OF ZINC IN SOIL AND ZINC NUTRITION IN LOWLAND RICE UNDER DIFFERENT LEVELS OF PHOSPHORUS

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(2019-11-013)

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KERALA, INDIA
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THESIS

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VELLANIKKARA, THRISSUR – 680656
KERALA, INDIA
2021

DECLARATION

I hereby declare that this thesis entitled **"Transformation of zinc in soil and zinc nutrition in lowland rice under different levels of phosphorus"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara
Date : 10-01-2022

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CERTIFICATE

Certified that this thesis entitled **"Transformation of zinc in soil and zinc nutrition in lowland rice under different levels of phosphorus"** is a bonafide record of research work done independently by **Ms. Najiya Rinthas K. (2019-11-013)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the advisory committee of **Ms. Najiya Rinthas K. (2019-11-013)**, a candidate for the degree of **Master of Science in Agriculture** with major field in Soil Science and Agricultural Chemistry, agree that this thesis entitled **"Transformation of zinc in soil and zinc nutrition in lowland rice under different levels of phosphorus"** may be submitted by **Ms. Najiya Rinthas K.** in partial fulfillment of the requirement for the degree.

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Najiya Rinthas K.

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Introduction

1. INTRODUCTION

Phosphorus is an essential nutrient required by the plants for metabolic activities, component of several major structural compounds and acts as a catalyst in many key biological reactions. Phosphorus is known for its ability to capture and convert solar energy into beneficial plant chemicals. Phosphorus is an essential component of energy unit of plant ATP, DNA, it is also a part of RNA, which reads the DNA genetic code and uses it to make proteins and other substances that are necessary for plant structure, seed yield and genetic transfer. Stimulated root development, increased stalk and stem strength, improved flower formation and seed production are some of the specific growth aspects that have been linked to phosphorus.

Zinc is a micronutrient that is required for various metabolic activities in plants, including cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll formation, enzyme activation and membrane integrity. Zinc has a big impact on basic plant life functions such as nitrogen metabolism and uptake, protein quality, photosynthesis and chlorophyll production, carbonic anhydrase activity, abiotic and biotic stress tolerance and oxidative damage prevention.

Rice (*Oryza sativa* L.) is a major staple crop that sustains more than half of the world's population and expanding rice production is very important because traditional rice producing countries populations will demand 70% more rice by 2025 (Swaminathan, 2007). Rice accounts for 35-60% of the nutritional calories consumed by three billion people, making it the most significant crop on the earth (Confalonieri and Bocchi, 2005).

In India, the use of modern agricultural techniques has resulted in micronutrient deficiency and a remarkable reaction of crops to their application. Nutrient interaction management is an important topic among the various ways to increase production. In order to provide enough micronutrient supply to plants, nutrient interactions must be recognized and taken into account.

Nutrient interactions can be positive or negative and they can even be absent. The interaction is positive when the combined effects of nutrients result in a growth response that is larger than the sum of their individual effects and in this case the nutrients are synergistic. The interaction is negative when the combined effect is low and the nutrients are antagonistic, phosphorus and zinc interaction is a good example. If there is no difference in the additive response of two nutrients when applied separately, then there is no interaction.

Phosphorus content in Kerala soils reported to be very high for variety of reasons (Srinivasan *et al*., 2014), including intensification of agriculture and the introduction of high-yielding varieties as well as concurrent use of high doses of chemical fertilisers and utilisation of low amounts of organic manures over time. Several micronutrients, particularly zinc, are also depleted due to continuous cultivation without zinc addition. Zinc deficiency has emerged as one of the greatest limitation to increasing crop production, apparently affecting 49% of India's farmland. Zn deficiency is the most common micronutrient deficiency in humans and it is the fifth most important risk factor for human disorders, affecting one-third of the world's population (roughly two billion people), especially in developing countries where cereal grains are the staple food (for calorie and protein intake) with low Zn concentrations. It is estimated that 30% of the world's population has insufficient Zn levels in their diet (Brown and Wuehler, 2000).

Increased phosphorus fertiliser use, as well as fertilisers with less zinc containing contaminants, can aggravate Zn shortage. A portion of the P given to soil through fertiliser and manure, smaller portion of P is used by plants, a large portion remains in the soil as residual P, contributing to high phosphorus in the soil solution. Continued use of greater fertiliser doses by farmers resulted in large build-up of accessible phosphorus. Excessive P fertiliser use cause $Zn_3(PO_4)_2.H_2O$ deposits resulting in diminished Zn availability in soil. High soil P levels can also prevent Zn from moving from the root to the straw and especially to the leaves, resulting in Zn deficiency in most crops. There's additional evidence that soil P affects grain Zn content and bioavailability in a negative way, but there are contradictions regarding the P-Zn interaction which is controlled by difference in native P and Zn status in soil.

In view of the above, the current study was programmed to examine P–Zn interaction in soil and plant at varied amounts of phosphorus and zinc application with the following objectives.

1) Assessment of the effects of different levels of P application on rice yield and Zn uptake in rice.
2) Study the efficiency of Zn fertilisation in neutralising the antagonistic effect of P fertilisation on Zn uptake.

Review of literature

2. REVIEW OF LITERATURE

In this chapter, an attempt has been made to review the published literature relevant to the topic, which is labelled as "Transformation of zinc in soil and zinc nutrition in lowland rice under different levels of phosphorus" with the following subheading.

2.1 Effect of long term application of fertilizers and manure on distribution of P forms in soil

2.2 Effect of long term application of fertilizers and manure on distribution of Zn forms in soil

2.3 Interactive effect of zinc and phosphorus

2.4 Phosphorus status in Kerala soils and response of crops to its application

2.5 Zinc status of Kerala soils and response of crops to applied zinc

2.6 Mechanism of phosphorus zinc interaction

2.1 EFFECT OF LONG TERM APPLICATION OF FERTILIZERS AND MANURE ON DISTRIBUTION OF P FORMS IN SOIL

A better understanding of the relationships between different forms of P in a variety of soils and available P as measured by plant growth and soil chemical testing is useful for a better understanding of the capacity of the amount of P in those particular forms to sustain an adequate supply of P availability during crop growth.

Agrawal and Singh (1987) used rice, wheat and cowpea rotation in long-term experiment on Mollisols. They observed that graded dose of NPK fertiliser increased Al-P, Fe-P and available-P status after 36 years of continuous fertiliser and manure application in an intensive cropping system. On the other hand, Ca-P did not change. Among the Al-P, Fe-P and Ca-P fractions, Fe-P showed the highest increase over the control (29 to 50 mg kg^{-1}), indicating a shift from Al-P and Ca-P to Fe-P, however Al-P was the most important percentage in defining available-P. As a result, maintaining a near-neutral soil pH will ensure optimal P availability.

Sood and Bhardwaj (1992) conducted a field experiment on acid Alfisols and observed that lime application increased available P by 87.2 and 125.8% before and after the crop. This also greatly increased Al-P (100.1%), Ca-P (68.5%), Fe-P (39.3%), Organic-P (36.2%) and Saloid-P (25.6%).

In a triple crop sequence experiment in TamilNadu, Singaram and Kothandaraman (1994) reported that using various sources of P supplying fertiliser significantly increased the Al-P, Ca-P and Fe-P fractions in soil. This influence was still noted throughout the growth of *Phaseolus mungo*. Diverse P sources had minimal impact on these P fractions, although the highest rates of application improved their status.

Sugito *et al*. (2001) opined that incorporation of crop residues and organic matter increased organic P content, with the exception of rice straw alone and FYM. Organic matter and crop residues increased inorganic and available P. In this regard, Sen *et al*. (2002) conducted an experiment in Manipur on different forms of P and their distribution and found that total P content was relatively high, Fe-P occurred the most and Ca-P was the least abundant. On the soil surface, the organic P proportion of total P was noted to be larger compared to lower depth.

Sihag *et al*. (2005) reported that with the application of inorganic fertilizers and their combined use with organic material the amount of P recovered in Saloid-P, Al-P and Ca-P form increased significantly over control. Application of FYM followed by green manuring and press mud treatment had the highest concentration of all kinds of P.

Prasad and Mathur (1997) conducted a field experiment and investigated six soil samples from a long-term fertiliser experiment using the Langmuir adsorption equation. They observed that soils that received recommended NPK plus lime or FYM, the rate and extent of P adsorption were significantly reduced. Unfertilized soil recorded highest adsorption maximum, while NPK plus FYM had the lowest, followed by NPK plus lime. The trend in soil buffering capacity and P supply parameters was in the opposite direction. Unfertilized soil had the highest buffering capacity and the lowest P supply parameter. The soils treated with FYM had the highest phosphorus supply parameter, followed by limed soil at various levels of added P.

2.2 EFFECT OF LONG TERM APPLICATION OF FERTILIZERS AND MANURE ON DISTRIBUTION OF ZN FORMS IN SOIL

Various experimental evidences have shown that zinc deficiency occurs in crops, particularly during increased cultivation and that more acute deficiency develops when unbalanced fertiliser is used. In soils, zinc is found in five different pools. The strength (or reversibility) of these pools varies, as does their susceptibility to plant absorption, leaching, and extractability.

Plants can use water soluble, exchangeable and organically complexed forms, amorphous sesquioxide bound forms are partially available, but crystalline sesquioxide bound and residual zinc forms are not utilised by plants (Mandal *et al*., 1992). Water soluble, organic matter occluded, selectively adsorbed and acid soluble fractions all contributed directly to the zinc pool that was easily available. The exchangeable zinc fraction did not directly contribute to any of the zinc extractable forms. In many situations, residual fractions had a detrimental or adverse effect on the labile zinc pool (Kumar *et al*., 2004).

A variety of factors have been observed to influence zinc availability and distribution. Ghanem and Mikkelsen (1987) conducted a study to determine the effect of organic matter on changes in soil zinc fractions in five wetland soils under laboratory condition and the findings revealed that major portion of native or supplied Zn is bounded to the soil mineral component.

Mandal *et al*. (1988) observed that water soluble + exchangeable, organic complexed, amorphous sesquioxide and crystalline sesquioxide bound Zn fractions accounted for only 0.42, 0.85, 1.92, and 1.53% respectively of the total content, leaving the majority (95.3%) in residual forms which is associated with mineral fractions in soils.

The influence of water regimes and organic matter on the transformation of applied Zn in soils was investigated by Singh *et al*. (1993). Organic matter increased the transformation of applied Zn to Mn-oxide, organically and amorphously bound Fe-oxide forms, but it inhibited such conversions to water soluble + exchangeable and crystalline Fe-oxide fractions. Similarly, Phogat *et al*. (1994) found that organic matter increased Zn transformation to Mn-oxide Zn (manganese oxide bound), OM-Zn (organically bound), and AlFeOX-Zn (aluminium and iron oxide bound) fractions while decreasing Zn transformation to WE-Zn and CFeOX-Zn (crystalline iron oxide bound). They also noticed that by continuous submergence the organic matter had significant effect on all Zn fractions except for the OM-Zn.

Wijebandara *et al*. (2011) observed that the contents of various zinc fractions varied in paddy-growing soils in northern dry zone and hill zones of Karnataka. But the order of preponderance of different zinc fractions remained the same viz. water soluble plus exchangeable zinc < organically bound zinc < amorphous sesquioxide bound zinc < crystalline bound zinc < manganese oxide bound zinc < residual zinc.

2.3 INTERACTIVE EFFECT OF ZINC AND PHOSPHORUS

Phosphorus and zinc are two of the most important elements for plant growth and development. In some circumstances, both of these minerals are antagonistic to each other, resulting in a decrease in production and nutrient uptake in many crops, primarily owing to Phosphorus or Zinc shortages.

Growing hybrid rice with 120 kg ha^{-1} P + 15 kg ha^{-1} Zn not only improved total dry matter accumulation and partitioned greater amounts into panicles, but also resulted in a higher harvest index, according to Amanullah and Inamullah (2016).

In a field experiment, Shivay and Kumar (2004) investigated the effect of P and Zn fertilisation on aromatic rice productivity and P uptake under transplanted puddled condition. The interaction of P and Zn on rice development, yield characteristics, grain yield and P uptake was found to be non-significant.

Weldua *et al*. (2012) reported that individual effects of P at 60 kg ha^{-1} and Zn at 25 kg ha^{-1} had significant effects on plant height at 50% blooming, number of branches and grain production at maturity, however combined application had no significant effect.

Rupa *et al*. (2003) observed that phosphorus application up to 40 mg kg^{-1} improved the plant available Zn in soils, however greater P levels lowered plant available forms. The P effect was stronger in the shoot than in the root at 160 mg kg^{-1} of P, implying that a higher P level phosphorus limits Zn translocation from the root to the upper plant parts.

Perez-Novo *et al*. (2011) noticed that in acid soil, fractions of Zn desorbed after adsorption in the presence of P was much lower than in their absence, indicating that Zn binds to adsorbing surfaces more firmly in the presence of P. They also observed that in the presence of P particularly at higher concentrations, Zn adsorption increased which then attribute to the formation of P-Zn complex on colloid surfaces.

Rehim *et al*. (2014) observed that increasing rate of P fertiliser up to a specific optimum level enhanced dry matter output and Zn uptake by the plants, but at high P level thereafter lowered Zn availability thus resulting in Zn shortage that could be remedied by higher level of Zn application.

Amanullah *et al*. (2020) opined that rice and wheat production and profitability were higher when P and Zn were applied at higher rates 80 and 120 P kg ha^{-1} with 10 and 15 Zn kg ha^{-1} in the rice-wheat cropping system. They also reported that higher P and Zn rates was pooled to improve total biomass output, crop productivity and profitability in coarse rice cultivars.

Khan *et al*. (2012) reported that best number of grains per panicle, 1000-grain weight and prolific tillers plant^{-1} with the treatment of 90 kg ha^{-1} phosphorus mixed with 9 kg zinc ha^{-1}. These combination enhanced leaf index, harvest index and biomass production.

Mousavi (2011) stated that excessive phosphorus application reduced zinc absorption capacity and zinc in plants and soil had an antagonistic situation for phosphorus, resulting in negative interaction, concluding that zinc utilisation was necessary for higher yield and quality in crops. Shahane and Shivay (2018) carried out an interaction study of nitrogen, phosphorus and zinc fertilisation on growth, yield and nutrient content of aromatic rice varieties found that when P was applied with N and Zn or with N alone there was higher uptake of P in grain and straw, indicating that Zn had a positive effect on P uptake in rice.

Bukvic *et al*. (2003) studied the effects of phosphorus and zinc fertilisation on dry matter yield, plant height, stalk diameter, phosphorus and zinc concentrations in maize ear-leaves. The results showed that zinc fertilisation lowered total plant dry matter yield while phosphorus fertilisation enhanced it. Also P fertilisation enhanced the concentration of phosphorus in the ear leaves.

Hye *et al*. (2019) studied contribution of zinc and phosphorus on yield, phosphorus and zinc content in aman rice and distribution in post-harvest soil. They found that combining P and Zn increased grain, straw yield but decreased P, Zn content and availability from Al/Fe-P, Mg/Ca-P as a result of Zn-P interaction in soil solution.

Rahman *et al*. (2011) observed that by combining Zn_{10} in addition with P_{50} treatments had an important influence on the maximum yield output as well as a good influence on all yield contributing features.

Dash *et al*. (2015) found that macronutrients like N, P and K with micronutrients like S, B and Zn resulted in the largest grain yield response, which was reduced by 44-49% in lack of P or K and by 8% in the absence of B, Zn and S.

A field experiment was conducted by Amanullah *et al*. (2015) to assess the impact of phosphorus levels (0, 40, 80, 120 P kg ha^{-1}) and zinc levels (0, 5, 10, 15 Zn kg ha^{-1}) on the productivity of rice genotypes (fine and coarse) and their residual effects on tillers m^{-2}, straw and biomass yields and harvest index of the succeeding wheat under rice-wheat cropping system shown that tillers m^{-2}, straw, dry matter yield and harvest index of wheat were significantly greater in treatments receiving the higher P level ($120 > 80 > 40 > 0$ kg P ha^{-1}) and Zn level ($15 > 10 > 5 > 0$ Zn kg ha^{-1}) during the preceding rice season.

The application of phosphorus and zinc alone had no significant effect on the harvest index and test weight, but the greatest values of both parameters were recorded with 100 kg ha^{-1} phosphorus and 10 kg ha^{-1} zinc (Mishra *et al*., 2017).

Singh *et al*. (2017) noticed that grain yield of rice improved significantly from 40 to 80 kg ha^{-1} and phosphorus application at each level of zinc sulphate was under the interaction effect between phosphorus and zinc.

Bhardhwaj *et al*. (2020) reported that plant height, root length, ground above and below ground nutrient total uptake by plants all increased with increasing phosphorus from 0 to 75 kg ha^{-1} and Zinc doses from 5 to 10 kg ha^{-1}.

Phosphorus and zinc were antagonistic, resulting in lower output and nutrient uptake in variety of crops due to Phosphorus or Zinc deficiencies (Bhardwaj *et al*., 2019).

Debnath *et al*. (2015) conducted a field experiment to determine the influence of Zn fertilisation on yield, nutrient uptake, utilisation efficiency and grain output per unit of fertiliser use and found that effects of P and Zn interactions on basmati rice yield were not significant.

Sarkunan and Misra (2006) found that adding 10 mg kg^{-1} zinc per soil level increased grain and straw yields significantly. The interaction effect was also found to be significant. Zn did not increase grain or straw yield in the absence of additional P. Grain and straw yields, on the other hand increased significantly with each increment of P, regardless of Zn addition.

2.4 PHOSPHORUS STATUS IN KERALA SOILS AND RESPONSE OF CROPS TO ITS APPLICATION

2.4.1 Phosphorus status in the soils of Kerala

Information on the phosphorus fertility status of soils is critical for determining the amount of phosphorus fertiliser for use on crops. Suresh (1999) reported that only 5% of Indian soil had sufficient phosphorus availability, with the remainder 49.3% was in the low category, 48.8% in the medium and 1.9% fell in the high category.

Kavitha and Sujatha (2015) conducted a study in 8 Agro Ecology Unit (AEU) of Thrissur district in order to assess the soil fertility status. Soil samples from 0-15 cm depth per sample per hectare was collected together with details concerning names of the farmer, soil type, fertiliser information, irrigation etc. and found high P status in all agro ecological units.

Pathak (2010) reported that increasing trend of phosphorus in Kerala from 1967 to 1997. Soil fertility testing in the tropical wet area of Idukki district under the different land use scheme revealed that phosphate levels ranged from low to medium (Chandrakala *et al*., 2018).

The status of phosphorus fertility in Kerala soils and strategies to improve its efficiency remain unchanged in Kerala soils (Srinivasarao *et al*., 2015).

Rajasekharan *et al*. (2013) noticed that biggest soil related problems in Kerala are significant acidity of the soils and the accumulation of high amount of phosphorus in 62% of soil samples.

Aparna and Arya (2014) compared soil chemical and biological characteristics of red loam and laterite soils of Trivandrum district under the coconut plantation. Approximately 10 field visits were carried out in laterite and red loam soil pockets such as Neyyattinkara, Nedumangad, Trivandrum (Rural), Varkala and Kattakkada. They found that available phosphorus status was found to be high.

2.4.2 Response of phosphorus application to cereals

Phosphorus is the second most important nutrient for field crops. It is important for variety of plant physiological activities. Sainio *et al*. (2006) reported that because of promoting healthy growth, development of a robust root system, maximum tillering, increased blooming and seed generation, optimal P nutrition was crucial for maintaining optimal paddy yield.

With P treatment of 80 kg per ha, crop residue assimilation, maximum fertile tillers, spike length, grain per spike and grain production of paddy was achieved (Mahmood and Arshad, 2015).

Wei *et al.* (2018) observed that in rice, P application narrowed enzymatic activity of rhizosphere region. Amanullah and Inamullah (2016) reported that at heading and physiological maturity stages, P level of 120 kg ha^{-1} segregated more dry materials into panicles than leaves and culms.

Fageria (2007) found that using a greater P rate of 131 kg ha^{-1} increased biomass yield and grain production by 80% and 180% respectively, as compared to P-control plots. The biomass yield was highest in plots with the greatest rate of phosphorus application and lowest in plots with the lowest rate of P application (Amanullah *et al*., 2020).

The highest P content in paddy grain (0.305%) and straw (0.108%) was achieved from the P_{50} treatment, which has the highest rate of applied P (Hye *et al*., 2019). Rahman *et al*. (2011) reported that phosphorus had significant effect on the number of grain panicle^{-1}, tiller per hill, 1000-grain weight, grain yield and straw yield.

The influence of phosphorus on nutrient absorption properties of japonica and indica (IR-28) rice varieties were investigated at the screen house of Tsukuba International Centre (TBIC) in Japan. For both variety, the P content in rice plants grew progressively at different growth stages as P levels increased (Islam *et al*., 2008).

Mishra *et al*. (2017) inspected the response of late-sown wheat in eastern Uttar Pradesh to phosphorus and zinc addition. They noticed that treatment of 60 to 120 kg P_2O_5 per ha increased growth, yield characteristics, yield and nutrient uptake. According to Sharma *et al*. (2012) applying phosphorus beyond 60 kg ha^{-1} improved the uptake of N, P, K and Zn by wheat grain and straw up to 120 kg ha^{-1}.

Khan *et al*. (2016) investigated the effects of organic sources such as animal manures against plant residues at a rate of 10 t ha^{-1} each on hybrid rice production and productivity under varied phosphorus fertilisation levels (0, 30, 60, and 90 P kg ha^{-1}). Increasing P levels resulted in improved rice productivity in both tests ($90 > 60 > 30 > 0$ P kg ha^{-1}). They found that by combined application of 90 kg phosphorus with animal manures, particularly poultry manure improved rice productivity.

Higher phosphorus levels improved P availability, which had a positive impact on growth, yield and yield contributing characters (Hao *et al*., 2009). The findings are in consistent with those of Begum *et al*. (2002), who found that seedlings treated with optimum phosphorus had the greatest bearings of tillers $hill^{-1}$.

Rasavel and Ravichandran (2013) reported that maximum grain and straw yield by the application of 50 kg ha^{-1} phosphorus. With 90 kg ha^{-1} P, Yoseftabar (2013) noticed utmost grain and biological yield of paddy. According to Mafi *et al*. (2013), increasing P levels increased rice yield and harvest index.

Phosphorus application at 80 kg ha^{-1} improved rice grain yield by 19.12 and 29.02% in the first and second year, respectively as compared to 40 kg ha^{-1} dose of phosphorus (Singh and Sharma, 2014).

Increasing the phosphorus rate from 0 to 36 kg ha^{-1} enhanced the leaf area index, number of tillers m^{-2}, number of panicles m^{-2}, panicle length, panicle weight, number of filled grains per panicle, grain yield and harvest index. However, the application of 54 kg ha^{-1} phosphorus resulted in the maximum dry weight m^{-2}, 1000-grain weight, straw yield and N, P and crude protein content of grains (Gharib *et al*., 2011).

According to Alam *et al*. (2009), phosphorous application up to 72 kg ha^{-1} greatly improved rice growth parameters, grain yield, straw yield, harvest index and yield attributing features. Zayed *et al.* (2010) opined that increasing the phosphorus rate increased the crude protein content of rice grains grown on saline soil.

2.5 ZINC STATUS OF KERALA SOILS AND RESPONSE OF CROPS TO APPLIED ZINC

2.5.1 Zinc status of Kerala soils

Zinc is one of the necessary micronutrient that plays a key function in plant growth but plant available Zn levels are low in more than 30% of soils around the world.

Rajasekharan *et al*. (2014) observed that Kerala soils had adequate levels of Fe and Mn, however there is 12 and 15% deficiency for Zn and Cu, respectively. Aiyer *et al*. (1975) studied the micronutrient status of three primary soil types in the regions of kari, kayal and karapadam in acid red soils of Kuttanad and found that all three soil types are low in available copper (90%) and 50% zinc deficiency in kayal soil.

Geetha and Balagopalan (2010) compared micronutrient status of natural forest with plantation and reported that among the four micronutrients studied (exchangeable iron, copper, manganese and zinc) there was significant increase in iron, but a drop in copper content and found no significant variation in zinc and manganese levels.

Sheeba *et al*. (2019) investigated the available nutrient status of rice soil in southern laterites. Samples were collected from (AEU 8) wetlands of selected farmer's field in Chenkal panchayath of Parassala block, Thiruvananthapuram, Kerala and discovered wide range of micronutrient deficiencies, with zinc deficiency being found in 92% of soil samples in the region.

A survey was conducted to assess the micronutrient status in rice ecosystems of Kasaragode district. 3500 surface soil (0-15 cm) samples were collected to assess the soil acidity and available micro nutrient status. The available zinc (0.1N HCl extractable) was found to be sufficient in 98% of the samples and inadequate in 2% (Gladis *et al*., 2016).

Susan and Venugopal (2005) assessed major nutrient status in Typic Kandiustult of Kerala and found that P, K, S and B were limiting, whereas other micronutrients like Cu, Zn and Mn were sufficient.

A study of the fertility on surface soils of Kerala revealed that deficiencies in primary nutrient potassium, secondary nutrients calcium and magnesium and micronutrients zinc and boron (Rajasekharan *et al*., 2013). Significant Zn deficiency was noted in AEU 8 soils, as well as widespread B deficiency (KSPB, 2013).

In the weighted average of key macro and micronutrients, Zn concentration of 3.94 and 5.68 mg kg^{-1} was identified in soils collected from 43 and 161 panchayats and their related regions under AEU 3 and AEU 9, respectively (Anju *et al*., 2020).

John *et al*. (2012) collected 10348 soil samples from 51 panchayats of pathanamthitta district. From the collected soil samples chemical analysis was done and found that all micronutrients, including Fe, Cu, Mn, Zn and B were sufficient.

Survey conducted in different locations of the Onattukara sandy plain, fluvial and marine sand area in the Alappuzha and Kollam districts of Kerala state had reported problems related to micronutrient shortages Zn, Cu and B (KSPB, 2013).

Mini and Usha (2015) conducted a study in Onattukara sandy plains (AEU 3) to analyse the available nutritional quality. Two hundred georeferenced soil samples were randomly selected from twenty Onattukara soil series and tested for 13 soil fertility indicators. The soils was highly acidic, with high phosphorus levels, poor oxidisable organic carbon, available potassium and widespread calcium, magnesium, boron and zinc deficiency.

2.5.2 Response of crops to applied zinc

Safak *et al.* (2009) reported that zinc fertilisation had significant influence on yield, crude protein and zinc content. Rice grain productivity augmented by applying 13.5 kg ha^{-1} Zn due to this an increase was recorded in dry matter accumulation, tissue Zn concentration and above ground Zn uptake (Nathan *et al*., 2005).

Ali *et al*. (2009) observed that supplying 5 kg ha^{-1} Zn increased wheat grain production by 31.6% over control. A greenhouse experiment was undertaken with the goal of assessing the Zn requirements of lowland rice. Zinc application had significant effect on shoot dry weight and yield, as well as soil and plant Zn concentration and uptake (Fageria *et al.*, 2011).

The improvement in milling recovery of rice due to Zn treatment was highlighted by Shivay and Prasad (2012). Khan *et al.* (2012) piloted a field experiment to investigate the influence of various quantities of zinc including 0, 3, 6, 9, 12, and 15 kg ha^{-1} Zn on the rice genotype. Plant height, productive tillers per hill, number of grains per panicle, 1000 grain weight, paddy straw and grain yield all showed an increasing tendency up to 9 kg ha^{-1} zinc.

Beneficial effect of zinc was observed by applying zinc at 10 kg ha^{-1}, thus enhanced the plant growth, yield characteristics, yield and nutrient uptake. The percent increase in rice grain yield was greater due to 10 kg ha^{-1} zinc as compared to 5 kg zinc (Mishra *et al.*, 2017). Zinc application resulted in greater uptake of N, P, K and Zn in wheat (Mauriya *et al.*, 2015).

The effects of various Zn fertiliser sources on grain Zn concentration in rice and wheat had been well established. Zn treatment increased chlorophyll content, tiller m^{-2}, total biomass and paddy yield, as well as Zn concentration in grain and straw, with the exception of P content in paddy and straw (Wei *et al.*, 2012).

Increasing zinc concentration in grain and straw could be attributable to presence of more Zn in soil solution caused by zinc application, which promoted better absorption (Mollah *et al.*, 2009).

In both unpolished and polished rice zinc addition increased grain Zn content and decreased the phytate: Zn molar ratio however the ratios may vary depending up on the cropping year and cultivar (Khampuang *et al.*, 2020).

Increased Zn uptake by Zn fertilisation resulted in better biomass production and photosynthate translocation to reproductive regions, resulting in higher basmati rice yields (Ozkutlu *et al.*, 2006).

Asadi *et al.* (2012) opined that when the plant was grown at a Zn level of 5 mg kg^{-1}, it flourished optimally. Distributions of zinc in different plant parts dropped in the following order: shoot > root.

2.6 MECHANISM OF PHOSPHORUS ZINC INTERACTION

Several investigators have reported the depressing action of applied phosphorus on zinc content and uptake in several crops. But the exact mechanism and the conditions under which the interaction takes place were not fully established. The phenomenon has been attributed by some to be primarily the result of chemical reaction in soil system like formation of zinc hydroxide and zinc phosphate. Others viewed that the antagonism between the two elements occurred within the plant. It was suggested that zinc and phosphorus interaction might be physiological due to either root-surface adsorption or to a translocation phenomenon within plant. The calcium from superphosphate might interfere with zinc absorption, to the extent of causing zinc deficiency.

While Burleson *et al.* (1961) visualised a possibility of phosphorus and zinc antagonism within the plant roots as the principal cause of phosphorus induced zinc deficiency. Bingham (1963) considered that the plant was not exclusively involved with regards to the mechanism of phosphorus induced zinc deficiency.

Langin *et al.* (1962) reported that the adverse effect of phosphorus on zinc fertilisation was considered to be largely physiological in nature. Stukenholtz (1966) suggested that phosphorus and zinc interaction was physiological within the plant and in root cells but not a chemical precipitation, external to roots.

Burleson and Page (1967) observed from their studies with flax that phosphorus and zinc reacted together within roots in a manner that reduced either their mobility or solubility. Pauli *et al.* (1968) while determining the water extractable zinc and phosphorus, found that high phosphorus increased the zinc content, evidently showing that phosphorus and zinc interaction problem did not reside in the soil, external to the plant.

Islam *et al*. (2005) reported that increasing individual doses of P and Zn raised the concentrations of both P and Zn in wheat, rice and mungbean. Both P and Zn interactions were additive and favorable to P and Zn concentrations in wheat and rice plants.

Materials and methods

3. MATERIALS AND METHODS

The present investigation entitled "Transformation of zinc in soil and zinc nutrition in lowland rice under different levels of phosphorus" was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Kerala Agricultural University during 2020-2021. Two separate experiments were conducted to achieve the objective of the study. The details of the experiment no. 1 are presented under section 3.1 and the details of experiment no. 2 are presented under section 3.2. This section contains a description of the experiment, the materials used and the procedures used in the investigation.

3.1 FRACTIONS OF ZN UNDER DIFFERENT P LEVELS IN LONG TERM FERTILIZER EXPERIMENT (LTFE)

3.1.1 Field Experimentation

3.1.2 Experimental details

In this experiment fractions of Zn under different P levels were studied during the year 2020. Field experiments under All India coordinated Research Project on Long Term Fertiliser Experiment with 12 treatments was commenced in 1997 at Regional Agricultural Research Station (RARS), Pattambi. Among the 12 treatments, 6 treatments having different P levels was taken for the study and treatments selected for the study are presented below.

T1	Control
T2	50% NPK
T3	100% NPK
T4	150% NPK
T5	100% NPK + FYM @ 5 t ha^{-1}
T6	100% NPK + lime @ 600 kg ha^{-1}

NPK 90:45:45 as per package of practices recommendations of Kerala Agricultural University

Number of Treatments: 6

Replications: 4

Design: RBD

Test crop: Paddy (var. Aiswarya)

Plot size: 125 m^2

The crop was sown on July 20, 2020 with a seed rate of 60 kg ha^{-1} and transplanted after specific days with a spacing of 20 X 10 cm. At the time of transplanting, half of the nitrogen and the whole amount of P_2O_5 and half dose of K_2O were applied according to the treatments and at the tillering and flowering stage remaining half of nitrogen and potash were applied in two equal splits. During the later stages of crop development, the necessary cultural practices were carried out and the crop was harvested on November 6, 2019 after which samples of grain and straw were collected.

3.1.3 Processing of soil samples and analysis

Following the harvest of paddy crop, soil samples from 0-15 cm depth were taken from the required plots of experimental fields. The samples were dried in the shade, ground with wooden pestle and mortar, sieved through 2 mm sieve and kept in polythene bags. Major macro and micro nutrients like N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, total P and total Zn, were analysed with the processed soil samples as per the methodology given in the table 3.1. Additionally various fractions of Zn like water soluble + extractable, Organically bound Zn, amorphous sesquioxide Zn and crystalline sesquioxide Zn and P fractions like saloid-P, Al-P, Fe-P, sesquioxide occluded phosphate and Ca-P also determined by sequential extraction.

Plate I. Field view after harvest of paddy in LTFE

Table 3.1. Methodology for analysis of soil sample

Sl. No.	Soil parameter	Method	Reference
1	Available Nitrogen	Distillation using permanganate in alkaline medium followed by titration	Subbiah and Asijah (1956)
2	Available Phosphorus	Extraction with Bray No. 1/ Olsen reagent and measurement with a spectrophotometer using the reduced molybdate ascorbic acid blue colour method	Bray and Kurtz (1945)

3	Available Pottasium	Extraction using neutral normal ammonium acetate and then estimated with flame photometer	Jackson (1973)
4	Exchangeable Calcium and Magenesium	Extraction with neutral normal ammonium acetate followed by estimation using atomic absorption spectrophotometer	Jackson (1973)
5	Available Sulphur	Extraction with 0.15% $CaCl_2$, followed by turbidometric estimation with $BaCl_2$ using a spectrophotometer	Williams and Steinberg (1959)
6	Available Iron, Manganese and Zinc	Extraction with 0.1M HCl and estimation using atomic absorption spectrophotometer	Sims and Johnson (1991)
7	Total Phosphorus	Pre digestion of soil using nitric: perchloric acid (9:4), followed by filtration to known volume. Estimate using the vanadomolybdophosphoric yellow colour method in spectrophotometer	Olsen and Sommers (1982)
8	Total Zinc	Digestion of nitric: perchloric acid (9:4), followed by filtration. Determination by ICP-OES	Piper (1966)

3.1.4 Phosphorus fractionation

The inorganic phosphorus fractions were extracted using the procedure described by Peterson and Corey (1966), which involved sequential extraction of soluble and loosely bound phosphorus, aluminium phosphate, iron phosphate, sesquioxide occluded phosphate and calcium phosphate (Fig. 1). Whatmann No. 42 filter paper was employed for filtration and respective P fractions were estimated using ICP-OES (Model: Perkin Elmer-Optima 8000).

Saloid bound P

Weigh 1g of soil samples in 100 mL centrifuge tube and add 50 mL of 1 N NH_4Cl. It was agitated for 30 minutes then centrifuged at 2000 rpm for 10 minutes to extract the soluble and loosely bound phosphorous.

Aluminium phosphate

To the soil residue, 50 mL of 0.5 N NH_4F (pH 8.2) was added and stirred for 1 hour. Following shaking, it was centrifuged for 10 minutes at 2000 rpm to remove aluminium phosphate.

Iron phosphate

The soil residue was washed twice with 25 mL of saturated NaCl after centrifugation at 2000 rpm for 5 minutes. It was shaken for 17 hours after adding 50 mL of 0.1 N NaOH. The material was centrifuged for 15 minutes at 2400 rpm to extract iron phosphate.

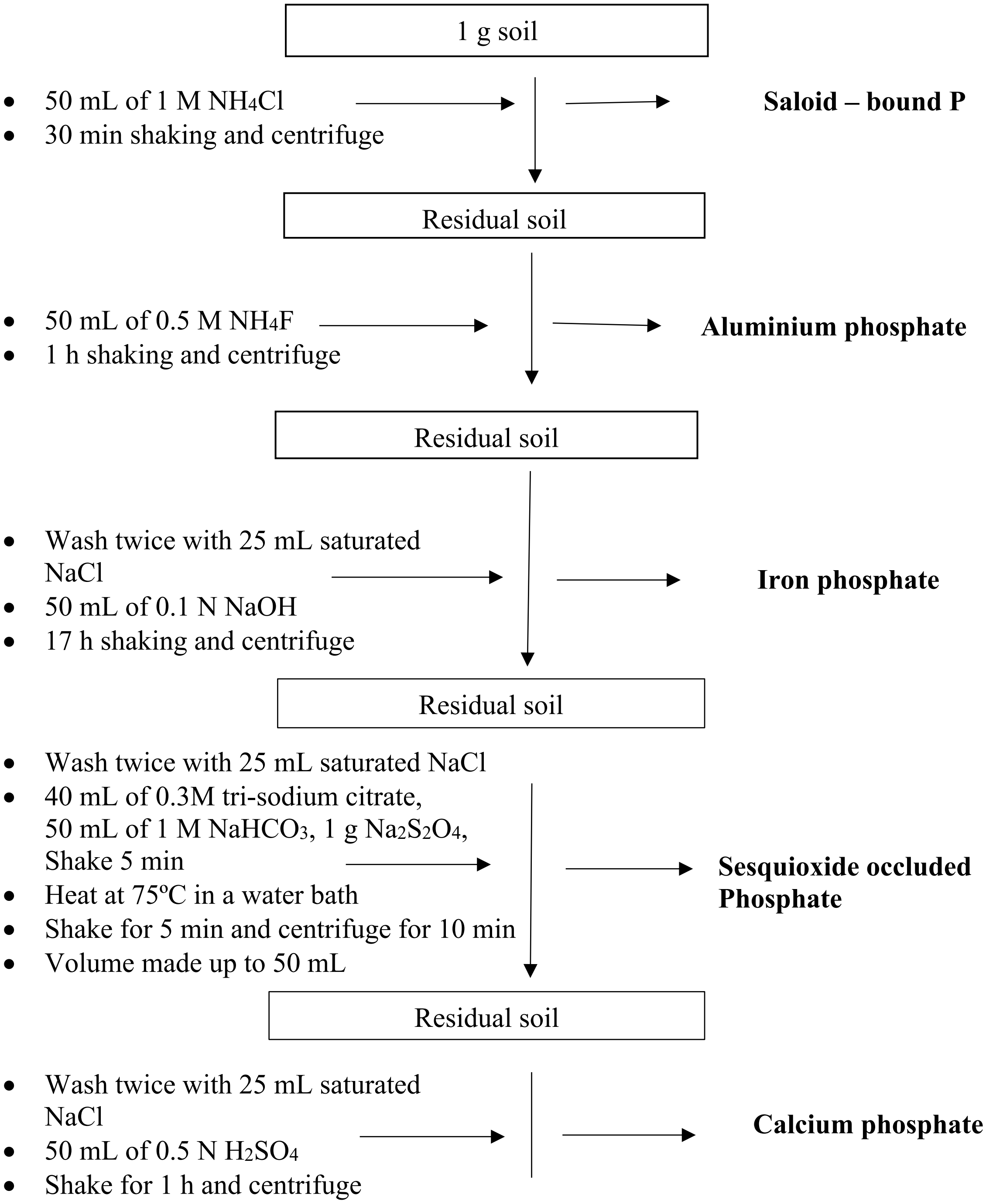
Sesquioxide occluded phosphate

The soil residue was washed twice with sequential centrifuge washings with 25 mL of saturated NaCl, then suspended in 40 mL of 0.3 M tri-sodium citrate with 5 mL of 1 M $NaHCO_3$, 1g of solid $Na_2S_2O_4$ and shaken for 5 minutes. The suspension was heated to 75°C to 80°C in a water bath. These suspension was agitated for 5 minutes and centrifuged at 2000 rpm for 10 minutes to remove the sesquioxide occluded phosphate. The volume was made up to 50 mL.

Calcium phosphate

In a centrifuge, the remaining soil residue was washed twice with saturated NaCl (25 mL), then 50 mL of 0.5 N H_2SO_4 was added. Following a one-hour shaking interval, the suspension was centrifuged for 10 minutes at 2000 rpm to remove calcium phosphate.

Fig. 3.1. Flow diagram of fractionation of inorganic P in soil



1 g soil

- 50 mL of 1 M NH_4Cl
- 30 min shaking and centrifuge

Saloid – bound P

Residual soil

- 50 mL of 0.5 M NH_4F
- 1 h shaking and centrifuge

Aluminium phosphate

Residual soil

- Wash twice with 25 mL saturated NaCl
- 50 mL of 0.1 N NaOH
- 17 h shaking and centrifuge

Iron phosphate

Residual soil

- Wash twice with 25 mL saturated NaCl
- 40 mL of 0.3M tri-sodium citrate, 50 mL of 1 M $NaHCO_3$, 1 g $Na_2S_2O_4$, Shake 5 min
- Heat at 75ºC in a water bath
- Shake for 5 min and centrifuge for 10 min
- Volume made up to 50 mL

Sesquioxide occluded Phosphate

Residual soil

- Wash twice with 25 mL saturated NaCl
- 50 mL of 0.5 N H_2SO_4
- Shake for 1 h and centrifuge

Calcium phosphate

3.1.5 Zinc Fractionation

To explore the distribution of Zn between the various binding forms, Iwasaki and Yoshikawa (1990) employed the sequential fraction approach, which is a modified method of Miller *et al*., (1986) fractionation methodology. For the various fractions, the following extractants and procedures were used. The soil sample used in each phase is 1.5 g.

Water soluble zinc fraction: Soil sample with 25 mL H_2O was shaken for 16 hours.

Organically bound zinc fraction: Add 50 mL of 0.1 M potassium pyrophosphate solution at pH 10 was shaken for two hours with required amount of soil sample.

Amorphous iron oxide occluded fraction: Soil sample with 50 mL of 0.1 M oxalic acid solution and 0.175 M ammonium oxalate [$(NH_4)_2C_2O_4$] solution at pH 3.25 were stored in the dark for 4 hours.

Crystalline iron oxide occluded fraction: 50 mL of 0.1 M oxalic acid solution, 0.175 M $(NH_4)_2C_2O_4$ solution (ammonium oxalate) and 0.1 M ascorbic acid was added to soil and kept in a boiling water bath for 30 minutes.

Table 3.2. Methodology followed for plant analysis

Sl. No.	Parameter	Method
1	Phosphorus	The digestion of nitric: perchloric acid (9:4) is followed by filtration. In a nitric acid system, vanadomolybdate has a phosphoric yellow tint (Piper, 1966)
2	Zinc	Digestion of nitric: perchloric acid (9:4), filtering, and ICP-OES determination (Piper, 1966)

3.1.6 Collection and analysis of plant samples

Representative grain and straw samples were collected after paddy (*kharif*, 2020) harvest. The samples were dried in an oven at 60°C. The dried samples were then ground and kept in paper bags for subsequent analysis. The analytical methods employed for plant analysis are given in table 3.2.

3.1.7 Statistical analysis

The data were statistically tested using analysis of variance (ANOVA) and multiple comparison procedures. The significant difference between treatments were compared by critical difference (C.D) and correlations using various parameters were computed.

3.2 INTERACTION OF PHOSPHORUS & ZINC UNDER DIFFERENT LEVELS OF NATIVE P & ZN SOILS WITH RESPECT TO NUTRIENT UPTAKE AND YIELD OF RICE

3.2.1 Basic characterisation of six types of soil with different gradient of P and Zn

Interaction of Phosphorus and Zinc under different levels of native P & Zn soils with respect to nutrient uptake and yield of rice was studied. Six different type soil samples of different categories having gradient P and Zn, (Soil P > 24 kg ha^{-1}, 12-24 kg ha^{-1}, <12 kg ha^{-1}, soil Zn <1 mg kg^{-1}, 1-3 mg kg^{-1}, >3 mg kg^{-1}) were drawn from different locations of Palakkad district.

3.2.1.1 Soil sampling and soil studies

Soil samples were collected from rice fields of different farmers and from different blocks of the research station with varying phosphorus and zinc gradients. The first sample was taken from Vavannur region of Palakkad district and this soil had low phosphorus (P < 12 kg ha^{-1}) and medium zinc (1-3 mg kg^{-1}) represented as S_1. The second soil was collected from A block of RARS Pattambi with high phosphorus content (>24 kg ha^{-1}) and designated as S_2. The third soil type farm soil, was drawn from Research farm area with a high zinc level (> 3 mg kg^{-1}) and designated as S_3. Low zinc gradient soil (<1 mg kg^{-1}) was taken from farmer's paddy field in Chalissery region and represented it as S_4. The last soil type with medium P (12-24 kg ha^{-1}) was obtained from G block of research farm represented as S_5. These soil samples were taken from paddy fields up to a depth of 0-15 cm.

Bulk soil samples were air dried in the shade, then gently crushed using a wooden roller before being used to fill the pots. After drying and crushing, another composite sample were drawn from the bulk surface sample for laboratory examination of the experimental soils chemical parameters. The characteristics of soil types selected are given in the table 3.3.

Table 3.3. Chemical composition of experimental soils

Characteristics	**Vavannur soil (S_1)**	**A block soil (S_2)**	**Farm soil (S_3)**	**Chalissery soil (S_4)**	**G block soil (S_5)**
Organic carbon (%)	0.82	1.64	0.58	0.95	1.40
Available nitrogen (kg ha^{-1})	218.14	332.30	91.70	201.67	298.56
Available phosphorus (kg ha^{-1})	9.59	37.41	12.04	6.05	15.57
Available potassium (kg ha^{-1})	55.78	109.20	146.27	43.90	43.23
Exchangeable calcium (cmol (P+) kg^{-1})	0.24	0.46	0.42	0.27	0.35
Exchangeable magnesium (cmol (P+) kg^{-1})	0.14	0.10	0.21	0.12	0.18
Available sulphur (mg kg^{-1})	1.79	1.74	1.26	1.05	5.73
Fe (mg kg^{-1})	100.90	65.67	240.60	23.87	109.20
Mn (mg kg^{-1})	1.46	2.48	1.83	0.82	1.16
Cu (mg kg^{-1})	0.76	0.78	0.45	0.411	0.67
Zn (mg kg^{-1})	1.69	2.44	3.58	0.71	0.69
Total P (mg kg^{-1})	572.00	1349	544	336.00	658.00
Total Zn (mg kg^{-1})	15.80	17.40	22.4	13.4	11.90

3.2.2 Treatment details

Four levels of phosphorus (0, 25, 50, 100 mg kg^{-1}) as KH_2PO_4 and four levels of zinc (0, 5, 10, 15 mg kg^{-1}) as $ZnSO_4.7H_2O$ are used in the treatments. The following was the treatment combination in detail:

P_0Zn_0	$P_{50}Zn_0$
P_0Zn_5	$P_{50}Zn_5$
P_0Zn_{10}	$P_{50}Zn_{10}$
P_0Zn_{15}	$P_{50}Zn_{15}$
$P_{25}Zn_0$	$P_{100}Zn_0$
$P_{25}Zn_5$	$P_{100}Zn_5$
$P_{25}Zn_{10}$	$P_{100}Zn_{10}$
$P_{25}Zn_{15}$	$P_{100}Zn_{15}$

3.2.3 Filling of Pots

For filling the soil plastic pot was used and each pot was labelled to identify the treatments. There were 240 (5× 4 × 4) pots in all and 4 kg of gently crushed soil were transferred into each pot. These pots were then arranged accordingly in factorial completely randomised design (CRD) with three replications.

3.2.4 Sowing and transplanting rice

Rice variety Jyothi was selected and sown in a tray on March 6, 2021. On March 21, 2021, two healthy rice seedling was transplanted into each pot under submerged conditions. Treatments were applied after establishment of the seedling through solution.

3.2.5 Irrigation scheduling and weed management

Irrigation was done on a regular basis to keep 5 cm of standing water in each pot and weeding was done whenever necessary. To reduce environmental effects caused by pot placement, pots were rotated on a regular basis. Throughout the growth period the incidences of disease and pests as well as nutrient deficiency were monitored.

Plate II. General view of pot culture experiment

Plate III. Crops at harvesting stage

3.2.6 Fertilisation

Calculated quantity of air dried cow dung was applied at the time of pot filling by mixing with soil. To achieve a homogeneous soil condition, a basal application of nitrogen and potash were applied as per soil test-based recommendation. Urea and murate of potash were used in accordance with package of practices recommendations of Kerala Agricultural University (KAU, 2016). At planting time, half dose of potassium and urea was applied and remaining half of the dose was applied at panicle initiation stage.

3.2.7 Harvesting

Plants were harvested at its maturity and roots were also taken to determine dry weight. Plant samples were then dried in an oven at a consistent temperature (60°C) and then weighed. Dry samples were ground with a mechanical grinder and kept for further examination.

3.2.8 Observation of crop growth and yield attributes

The following crop growth and yield parameters were determined during rice growth period.

3.2.8.1 Plant height **-** At maturity or harvesting stage, the plant height of each plant in each pot was measured using a meter scale from the soil surface to the extreme top of the plant. For each treatment, the average height per plant was calculated.

3.2.8.2 Number of productive tillers - After the initial parent shoot grows from a seed, the number of productive shoots that emerge was determined.

3.2.8.3 1000 grain weight - A thousand seeds were randomly selected from threshed plant ears and weighed on an electronic balance to ascertain their weight.

3.2.8.4 Grain yield **-** The grains from pods were manually threshed after that dry weight of plants were estimated. The grain yield per pot was calculated using the weight of the grains obtained from each pot and g pot^{-1} is the unit of measurement.

3.2.8.5 Straw yield - By deducting grain yield from the dry weight of plant from each pot during harvest, straw yield was estimated. The straw yield of each pot was measured in g pot^{-1}.

3.2.8.6 Total nutrient uptake **-** Total nutrient uptake was estimated by multiplying the dry matter yield of whole paddy sections by the nutrient content of the grains, straw, leaves, and root.

3.2.9 Plant sampling

Grain and straw samples were taken during harvest and stored for analysis.

3.2.10 Statistical analysis

The significance of the experiment was examined using analysis of variance (ANOVA) for a 5 X 4 X 4 factorial CRD experiment. Multiple comparison procedure using critical difference (C.D) were performed for significant results obtained.

Results

4. RESULTS

This chapter presents the results of two experiments undertaken to investigate the "Transformation of zinc in soil and zinc nutrition in lowland rice under different levels of phosphorus" with the aim of achieving the goal.

The findings of impact of long-term application of organic and inorganic sources of nutrients on changes in phosphorus and zinc fractions is given under section 4.1 and the interaction of Phosphorus & Zinc under different levels of native P & Zn soils with respect to nutrient uptake and yield of rice is given under section 4.2.

4.1 FRACTIONS OF ZN UNDER DIFFERENT P LEVELS IN LONG TERM FERTILIZER EXPERIMENT (LTFE)

4.1.1 Effect of long term application of organic and inorganic sources of nutrients on nutrient status of soil after harvest of paddy

The data regarding major soil nutrient status as a result of various long-term fertiliser treatments are presented in table 4.1, 4.2 and 4.3.

4.1.1.1 Available nitrogen

The data on available nitrogen is presented in table 4.1. The amount of available nitrogen increased as the dose of fertilisers increased and significantly higher content was noted in treatment T5 (245 kg ha^{-1}) where FYM was used in conjunction with 100% NPK over T4. In the control plot (T1) available nitrogen content decreased significantly.

4.1.1.2 Available phosphorus

The data on the available phosphorus content is presented in table 4.1. The table revealed that there was significant difference between each treatments and the highest available phosphorus content of 19.35 kg ha^{-1} was noted in treatment T4 (150% NPK) followed by 18.85 kg ha^{-1} in treatment T5 (100% NPK + FYM) and lowest value was observed in control.

4.1.1.3 Available potassium

The data on available potassium content is furnished in table 4.1. The amount of available potassium in the soil was shown to rise with increasing doses of fertiliser and treatment T4 (150% NPK) had significantly higher available potassium (85.99 kg ha^{-1}) over T5 and lowest content was noted in control plot where no fertiliser was applied.

Table 4.1. Effect of long term fertilizer application on major nutrients in soil

Treatment	**Available nitrogen (kg ha^{-1})**	**Available phosphorus (kg ha^{-1})**	**Available potassium (kg ha^{-1})**
T1: Control	181.00^{f}	12.06^{f}	49.61^{f}
T2: 50% NPK	204.00^{e}	17.05^{e}	61.94^{e}
T3: 100% NPK	212.50^{de}	17.52^{d}	67.08^{d}
T4: 150% NPK	222.00^{c}	19.35^{a}	85.99^{a}
T5: 100% NPK+ 5 t ha^{-1} FYM	245.00^{a}	18.85^{b}	78.01^{bc}
T6: 100% NPK+ Lime @ 600 kg ha^{-1}	233.25^{b}	18.35^{c}	74.27^{c}
C.D.	8.590	0.429	6.453
SE(m)	2.824	0.141	2.121

4.1.1.4 Exchangeable calcium

The status of exchangeable calcium content is given in table 4.2. The plot treated with lime namely T6 had significantly more exchangeable calcium (171.7 mg kg^{-1}) in the soil than the other treatments. The table also showed lower exchangeable calcium (102.2 mg kg^{-1}) was recorded in control plot which was on par with T2 and T3.

4.1.1.5 Exchangeable magnesium

The exchangeable magnesium differed significantly among different treatments (Table 4.2). Highest magnesium content of 30.64 mg kg^{-1} was recorded in treatment T5 where 100% NPK + FYM was applied followed by T6 (100% NPK + lime) while the control plot had lowest value of 18.17 mg kg^{-1} exchangeable magnesium.

4.1.1.6 Available sulphur

The data revealed that sulphur content increased in all treatments as compared to the control group (Table 4.2). Integrated nutrient management in treatment T5 had significantly high available sulphur content (6.57 mg kg^{-1}) over T6 (100% NPK + lime). Significant lower value of sulphur (4.46 mg kg^{-1}) was noted in T1.

Table 4.2. Effect of long term fertilizer application on secondary nutrients in soil

Treatment	Exchangeable calcium (mg kg^{-1})	Exchangeable magnesium (mg kg^{-1})	Available sulphur (mg kg^{-1})
T1: Control	102.20^{f}	18.17^{f}	4.46^{f}
T2: 50% NPK	107.57^{ef}	19.63^{e}	5.16^{e}
T3: 100% NPK	109.00^{def}	20.91^{d}	5.44^{de}
T4: 150% NPK	123.00^{c}	22.27^{c}	5.79^{c}
T5: 100% NPK+ 5 t ha^{-1} FYM	157.58^{b}	30.64^{a}	6.57^{a}
T6: 100% NPK+ Lime @ 600 kg ha^{-1}	171.70^{a}	25.08^{b}	5.80^{bc}
C.D.	7.835	1.126	0.339
SE(m)	2.576	0.370	0.111

4.1.1.7 Available iron

Each treatment showed significant variation on available iron content (Table 4.3) except treatment T3 which was on par with treatment T2. Integrated application of fertilisers with FYM in T5 registered significantly higher available iron content (254.74 mg kg^{-1}) over T4 while control had the lowest value (120.93 mg kg^{-1}).

4.1.1.8 Available copper

The status of available copper presented in the table 4.3 showed that increasing fertiliser dose increased available copper and higher copper content (8.78 mg kg^{-1}) was recorded in treatment T5. The plot with no fertiliser input namely T1 had significantly lower available copper content.

4.1.1.9 Available zinc

The data pertaining to available zinc is presented in table 4.3. With the addition of higher fertiliser doses, available Zn content in soil increased and each treatment remained on par. Highest zinc content (1.32 mg kg^{-1}) was noted for treatment T5 which was on par with T6 and lowest in control plot.

Table 4.3. Effect of long term fertilizer application on micronutrient in soil

Treatment	Iron (mg kg ^{1})	Copper (mg kg ^{1})	Zinc (mg kg ^{1})
T1: Control	120.93^{f}	7.07^{f}	1.17^{f}
T2: 50% NPK	162.89^{d}	7.79^{e}	1.19^{ef}
T3: 100% NPK	169.54^{cd}	7.85^{de}	1.22^{def}
T4: 150% NPK	190.53^{b}	8.21^{cde}	1.23^{cdef}
T5: 100% NPK+ 5 t ha ^{1} FYM	254.74^{a}	8.78^{abc}	1.32^{ab}
T6: 100% NPK+ Lime @ 600 kg ha ^{1}	135.36^{e}	8.43^{bcd}	1.26^{bcd}
C.D.	12.245	0.629	0.066
SE(m)	4.026	0.207	0.022

4.1.2 Influence of long term fertilizer application on total nutrient content in soil after harvest of paddy

4.1.2.1 Total phosphorus

Total phosphorus content showed significant difference between treatments (Table 4.4). By increasing the fertiliser dose, each treatment had significant variation on total phosphorus content. Highest total-P content of 1134.57 mg kg^{-1} was registered in the plot where 100% NPK+ FYM treatment was applied and lowest value (599.69 mg kg^{-1}) was noted for control plot.

4.1.2.2 Total zinc

Data from the table 4.4 revealed that total zinc content (21 mg kg^{-1}) recorded highest in treatment T5 and lowest content in control plot. Each treatment had significant difference on total zinc content.

Table 4.4. Effect of long term fertilizer application on total phosphorus and zinc in soil

Treatment	Total P (mg kg^{-1})	Total Zn (mg kg^{-1})
T1: Control	599.69^{f}	11.58^{f}
T2: 50% NPK	718.72^{e}	13.80^{e}
T3: 100% NPK	875.67^{d}	14.85^{d}
T4: 150% NPK	952.87^{b}	17.38^{b}
T5: 100% NPK+ 5 t ha^{-1} FYM	1,134.57^{a}	21.00^{a}
T6: 100% NPK+ Lime @ 600 kg ha^{-1}	903.06^{c}	16.00^{c}
C.D.	18.869	0.700
SE(m)	6.203	0.230

4.1.3 Influence of long term fertilizer application on P and Zn content and total uptake in paddy

Phosphorus and zinc content of grain and straw and total phosphorus and zinc uptake by paddy are presented in table 4.5.

4.1.3.1 Phosphorus content of paddy grain and straw

Phosphorus content (0.302%) in grain of paddy increased as the fertiliser dose increased with the highest value in treatment T5 which was on par with T4 and treatment T1 registered lowest content of 0.205 per cent. Higher straw P content (0.192%) was registered in treatment T5 followed by T4 and lowest phosphorus content (0.07%) was recorded in control T1. In both P content in grains and straw each treatments were on par.

4.1.3.2 Zinc content of paddy grains and straw

Higher Zn content of grain was recorded in treatment T5 (28.35 mg kg^{-1}) which was on par with T4 and significantly lower content was recorded in T1. With respect to zinc content of paddy straw, treatment T5 had significantly high zinc content (23.25 mg kg^{-1}) over T4. Significant lower straw zinc content was observed in control.

4.1.3.3 Total phosphorus uptake

Total phosphorus uptake increased significantly with increasing the dose of fertilisers and each treatment showed significant variation between treatments. The highest phosphorus uptake of 18.95 kg ha^{-1} and 17.35 kg ha^{-1} were recorded in T5 (100% NPK + FYM) and T4 (150% NPK) respectively. Significantly lowest uptake was noted in treatment T1.

4.1.3.4 Total zinc uptake

Data presented in the table revealed that each treatment showed statistically significant variation on total zinc uptake with highest uptake of 170.51 g ha^{-1} was noted for treatment T5 (100% NPK + FYM) and lowest zinc uptake for control plot.

Table 4.5. Effect of long term fertilizer application on concentration of phosphorus and zinc in grain and straw and total P, Zn uptake in paddy

Treatment	**Phosphorus (%)**		**Zinc (mg kg^{-1})**		**Total P uptake (kg ha^{-1})**	**Total Zn uptake (g ha^{-1})**
	Grain	**Straw**	**Grain**	**Straw**		
T1: Control	0.205^{f}	0.07^{f}	18.15^{f}	16.15^{f}	7.37^{f}	45.03^{f}
T2: 50% NPK	0.239^{ef}	0.102^{ef}	20.67^{e}	18.07^{e}	10.87^{e}	89.27^{e}
T3: 100% NPK	0.243^{def}	0.129^{de}	22.12^{de}	18.35^{de}	14.83^{d}	117.23^{c}
T4: 150% NPK	0.296^{bc}	0.165^{bcd}	24.37^{bc}	20.67^{b}	17.35^{b}	153.11^{b}
T5: 100% NPK+ 5 t ha^{-1} FYM	0.302^{abc}	0.192^{ab}	28.35^{a}	23.25^{a}	18.95^{a}	170.51^{a}
T6: 100% NPK+ Lime @ 600 kg ha^{-1}	0.262^{cde}	0.134^{cde}	23.17^{cd}	19.17^{cd}	15.53^{c}	100.15^{d}
C.D.	0.052	0.047	1.566	1.053	0.181	7.570
SE(m)	0.017	0.015	0.515	0.346	0.059	2.489

4.1.4 Influence of long term fertilizer application on zinc fraction

The data pertaining to influence of manures and fertilisers on zinc fractions like water soluble plus extractable, organically bound Zn, amorphous sesquioxide Zn and crystalline sesquioxide Zn in soil are presented in table 4.6.

4.1.4.1 Water soluble plus extractable zinc

The amount of water soluble and extractable Zn in the soil ranged from 1.02 mg kg^{-1} to 1.55 mg kg^{-1}. The treatment with 100% NPK+ FYM had significant higher value (1.55 mg kg^{-1}), whereas other treatments were on par and lower content of this fraction was noted in control.

4.1.4.2 Organically bound zinc

The organically bound zinc fraction increased from 1.78 to 2.21 mg kg^{-1} as a result of increased fertiliser application and treatment T5 registered significant effect on this form having value of 2.21 mg kg^{-1}. Except treatment T5 other treatments were on par and lowest value (1.78 mg kg^{-1}) was noted for control.

Table 4.6. Effect of long term fertilizer application on different fractions of zinc (mg kg^{-1})

Treatment	Water soluble + Extractable	Organically bound Zn	Amorphous sesquioxide Zn	Crystalline sesquioxide Zn
T1: Control	1.02^{f}	1.78^{f}	4.45^{a}	0.98^{f}
T2: 50% NPK	1.08^{ef}	1.80^{ef}	4.08^{bc}	1.01^{ef}
T3: 100% NPK	1.13^{de}	1.84^{def}	3.98^{cd}	1.08^{cdef}
T4: 150% NPK	1.25^{bc}	1.98^{bc}	3.87^{de}	1.12^{bcd}
T5: 100% NPK+ 5 t ha^{-1} FYM	1.55^{a}	2.21^{a}	3.71^{f}	1.34^{a}
T6: 100% NPK+ Lime @ 600 kg ha^{-1}	1.19^{cd}	1.89^{cde}	3.77^{ef}	1.06^{def}
C.D.	0.071	0.103	0.113	0.107
SE(m)	0.023	0.034	0.037	0.035

4.1.4.3 Amorphous sesquioxide zinc

The amorphous sesquioxide zinc fraction in soil ranged from 3.71 to 4.45 mg kg^{-1}. Increasing fertiliser dose decreased the amorphous sesquioxide zinc but the change was not significant. Significant highest content (4.45 mg kg^{-1}) of this fraction was registered in control plot and lowest in the treatment T5.

4.1.4.4 Crystalline sesquioxide zinc

Crystalline sesquioxide zinc fraction in the soil varied from 0.98 and 1.34 mg kg^{-1}. Significant highest value of 1.34 mg kg^{-1} was registered in treatment T5 (100% NPK + FYM) and lowest in the control plot. Except treatment T5 remaining treatments were on par.

4.1.5 Influence of long term fertilizer application on phosphorus fraction

The effects of long term application of manures and fertilisers on phosphorus fractions in soil, such as saloid-P, Al-P, Fe-P, sesquioxide occluded phosphate and Ca-P are presented in table 4.7.

4.1.5.1 Saloid bound P

Data in the table showed that concentration of saloid P varied from 6.26 to 8.88 mg kg^{-1}. Saloid bound P increased significantly from control to 50% NPK and significantly higher content (8.88 mg kg^{-1}) was recorded in T5 where 100% NPK+FYM was applied over 150% NPK.

Table 4.7. Effect of long term fertilizer application on different fractions of phosphorus (mg kg^{-1})

Treatment	Saloid P	Al-P	Fe-P	Sesquioxide occluded P	Ca-P
T1: Control	6.26^{f}	61.48^{f}	133.29^{f}	44.35^{f}	31.30^{f}
T2: 50% NPK	6.73^{e}	81.65^{d}	165.23^{e}	48.23^{ef}	34.69^{e}
T3: 100% NPK	6.98^{de}	87.36^{bc}	175.55^{cd}	52.24^{de}	36.25^{de}
T4: 150% NPK	7.99^{b}	100.45^{b}	183.35^{b}	58.11^{bc}	38.74^{c}
T5: 100% NPK+ 5 t ha^{-1} FYM	8.88^{a}	112.35^{a}	190.43^{a}	62.94^{ab}	38.80^{bc}
T6: 100% NPK+ Lime @ 600 kg ha^{-1}	7.48^{c}	71.69^{e}	171.49^{d}	52.77^{cde}	39.41^{abc}
C.D.	0.362	9.061	5.562	5.623	1.662
SE(m)	0.119	2.979	1.828	1.849	0.546

4.1.5.2 Aluminium phosphate

Perusal of the data revealed that Al-P fraction varied from 61.48 mg kg^{-1} to 112.35 mg kg^{-1} with a mean value 85.83 mg kg^{-1}. Higher Al-P fraction (112.35 mg kg^{-1}) was registered in 100% NPK + FYM treatment which was significant over 150% NPK and significant lower content was observed in T1.

4.1.5.3 Iron phosphate

With a mean value of 169.89 mg kg^{-1}, the iron phosphate ranged from 133.29 mg kg^{-1} to 190.43 mg kg^{-1}. The data in the table showed that increased fertiliser application had significant influence on Fe-P, but treatments T3 and T6 were on par. The higher content of Fe-P (190.43 mg kg^{-1}) form was observed in 100% NPK+FYM and the lower in control.

4.1.5.4 Sesquioxide occluded phosphate

Sesquioxide occluded phosphate ranged from 44.35 to 62.94 mg kg^{-1} with a mean value of 53.1. The higher occluded-P content (62.94 mg kg^{-1}) was observed in 100% NPK+FYM which was on par with treatment T4 and the lower content was observed in control. Each treatments were on par.

4.1.5.5 Calcium phosphate

Calcium phosphate fraction varied from 31.3 mg kg^{-1} to 39.41 mg kg^{-1}. Adding graded dose of fertilisers increased calcium phosphate form and higher content (39.41 mg kg^{-1}) was registered in treatment T6 where 100% NPK+ lime was applied and significant lower content was noted in control.

4.1.6 Correlation between various zinc fractions with different phosphorus fractions

Correlation coefficients between different phosphorus and zinc fractions is furnished in table 4.8. It is clear from the table that most of the phosphorus fractions are negatively and non-significantly correlated with different zinc fractions. However Fe-P fraction is positively and significantly correlated with amorphous sesquioxide zinc ($r = 0.961^{**}$), similarly occluded-P fraction is significantly correlated with water soluble plus extractable ($r = 0.819^{*}$) and crystalline sesquioxide zinc ($r = 0.973^{**}$) fraction. Calcium phosphate fraction is significantly correlated with water soluble plus extractable zinc fraction ($r = 0.937^{**}$).

Table 4.8. Correlation coefficient values between P fractions and Zn fractions

	Sal-P	**Al-P**	**Fe-P**	**Occl-P**	**Ca-P**	**WS+E Zn**	**Org-Zn**	**Amo-FeOZn**	**Cry-FeOZn**
Sal-P	1								
Al-P	0.473^{NS}	1							
Fe-P	-0.075^{NS}	0.544^{NS}	1						
Occl-P	-0.097^{NS}	-0.066^{NS}	0.319^{NS}	1					
Ca-P	0.028^{NS}	0.243^{NS}	-0.132^{NS}	0.600^{NS}	1				
WS+E Zn	0.070^{NS}	0.099^{NS}	-0.050^{NS}	0.819^{*}	0.937^{**}	1			
Org-Zn	-0.270^{NS}	0.711^{NS}	0.689^{NS}	0.152^{NS}	0.338^{NS}	0.180^{NS}	1		
Amo-FeOZn	-0.338^{NS}	0.387^{NS}	0.961^{**}	0.394^{NS}	-0.063^{NS}	0.011^{NS}	0.732^{NS}	1	
Cry-FeOZn	-0.124^{NS}	-0.120^{NS}	0.430^{NS}	0.973^{**}	0.402^{NS}	0.668^{NS}	0.108^{NS}	0.495^{NS}	1

* Significant at 5% level, **Significant at 1% level

4.2 INTERACTION OF PHOSPHORUS & ZINC UNDER DIFFERENT LEVELS OF NATIVE P & ZN SOILS WITH RESPECT TO NUTRIENT UPTAKE AND YIELD OF RICE

The findings of an experiment 2 to see how different levels of phosphorus and zinc affect rice development and yield are presented in different tables, highlighting salient features of relationships and trends.

4.2.1 Plant height

Data on mean values of plant height on varied application of phosphorus and zinc in different soil types are presented in table 4.9. The individual effect of soil types, phosphorus level and zinc level on plant height were found to be significant, but two way interactions like phosphorus x zinc, phosphorus x soil types, zinc x soil types and three way interaction with zinc x phosphorus x soil types were not significant.

Effect of soils

A preliminary examination of the data indicated that regardless of zinc and phosphorus levels, the second soil type S_2 had the highest plant height (108.8 cm), which was on par with soil type S_1 and the lowest plant height was recorded in soil type S_5.

Effect of phosphorus

The data from the table showed that increasing the phosphorus levels boosted plant height up to 100 mg kg^{-1} of P application which was on par over 50 mg kg^{-1} of P. The percent increase of plant height at 100 mg kg^{-1} were 0.8, 3.7 and 4.2 over control, 25 and 50 mg kg^{-1} respectively.

Effect of zinc

Mean values of plant height by the application of zinc found that increasing levels of zinc increased plant height significantly up to 10 mg kg^{-1} and further application decreased the plant height. Plant height increased by 2.5 and 7.2% when 5 and 10 mg kg^{-1} Zn were applied respectively over control.

Table 4.9. Effect of phosphorus and zinc application on plant height (cm) of paddy in different soil types

S_1		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	100.00	102.33	103.00	104.67	102.50
	Zn_5	102.00	105.00	109.00	106.67	105.67
	Zn_{10}	110.67	108.00	110.67	112.67	110.50
	Zn_{15}	107.33	108.00	110.33	111.67	109.33
	Mean	105.00	105.83	108.25	108.92	
S_2		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	102.33	104.67	106.00	108.00	105.25
	Zn_5	104.67	106.67	110.33	109.00	107.67
	Zn_{10}	111.67	109.00	112.33	114.00	111.75
	Zn_{15}	110.00	108.00	111.33	112.67	110.50
	Mean	107.17	107.10	110.00	110.92	
S_3		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	100.00	103.00	105.33	107.33	103.92
	Zn_5	102.00	106.33	109.67	108.33	106.58
	Zn_{10}	110.67	109.00	111.67	113.67	111.25
	Zn_{15}	107.33	108.00	110.67	110.67	109.17
	Mean	105.00	106.58	109.33	110.00	
S_4		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	96.67	99.33	100.33	102.33	99.67
	Zn_5	98.33	102.33	106.33	103.33	102.58
	Zn_{10}	107.00	105.33	108.33	110.33	107.75
	Zn_{15}	105.33	104.33	107.33	107.33	106.08
	Mean	101.83	102.83	105.58	105.83	
S_5		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	97.67	100.00	102.00	103.67	100.83
	Zn_5	99.67	102.67	107.33	105.00	103.67
	Zn_{10}	106.00	105.33	109.67	111.00	108.00
	Zn_{15}	104.67	105.33	111.00	110.00	107.75
	Mean	102.00	103.33	107.50	107.42	
Mean Table	**Soil**	**107.00**	**108.79**	**107.73**	**104.02**	**105.06**
	P	**104.20**	**105.13**	**108.13**	**108.62**	
	Zn	**102.43**	**105.23**	**109.85**	**108.57**	
Source of variation		**C.D**				
	Soil types	**2.132**	**SXP**	**NA**	**SXPXZn**	**NA**
	P levels	**1.907**	**SXZn**	**NA**		
	Zn levels	**1.907**	**PXZn**	**NA**		

4.2.2 Number of productive tillers per pot

The data regarding number of productive tillers per pot is furnished in the table 4.10. Variables like soil types, phosphorus and zinc levels had significant effects on the number of productive tillers. Remaining two and three way interactions including phosphorus x zinc, phosphorus x soil types, zinc x soil types and zinc x phosphorus x soil types were found to be non-significant.

Effect of soils

Influence of P and Zn application on different soil types revealed that mean value of different soil types had statistically significant effect on the number of productive tillers. Both P and Zn application increased the number of productive tillers (31.13) on soil type S_2, which was on par with soil type S_1.

Effect of phosphorus

According to the data from the table number of productive tillers (32.77) increased significantly as phosphorus levels increased with higher number obtained by addition of 100 mg kg^{-1}. The application of 0, 25 and 50 mg kg^{-1} P increased the number of productive tillers by 8, 17 and 58%, respectively over 100 mg kg^{-1} P.

Effect of zinc

Furthermore, data showed that number of productive tillers varied significantly by different zinc levels and application of 15 mg kg^{-1} zinc significantly increased the number of effective tillers over 5 or 10 mg kg^{-1} zinc. The increase in number of productive tillers per pot at 15 mg kg^{-1} Zn over control, 5 and 10 mg kg^{-1} was to the tune of 4.3, 7.9 and 59%, respectively.

4.2.3 Thousand grain weight

The mean values of variables including soil types, phosphorus level, zinc level, phosphorus and zinc interactions found all had statistically significant effect on the thousand grain weight. However, the interaction effect between zinc x soil types, phosphorus x soil types and phosphorus x zinc x soil types were not significant. Table 4.11 furnishes the information

Table 4.10. Effect of phosphorus and zinc application on number of productive tillers per pot in different soil types

S_1		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	26.67	30.00	30.00	30.00	29.17
	Zn_5	27.67	30.67	31.00	32.33	30.42
	Zn_{10}	28.67	31.33	32.33	33.67	31.50
	Zn_{15}	30.00	32.33	33.33	34.67	32.58
	Mean	28.25	31.08	31.67	32.67	
S_2		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	27.33	29.67	29.33	30.67	29.25
	Zn_5	28.33	30.33	30.33	33.33	30.58
	Zn_{10}	29.00	31.33	32.33	34.33	31.75
	Zn_{15}	30.33	32.33	33.33	35.67	32.92
	Mean	28.75	30.92	31.33	33.50	
S_3		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	27.00	29.33	29.33	30.33	29.00
	Zn_5	28.00	30.00	30.67	32.33	30.25
	Zn_{10}	28.33	30.33	32.33	33.33	31.08
	Zn_{15}	30.00	31.67	33.00	34.33	32.25
	Mean	28.33	30.33	31.33	32.58	
S_4		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	27.00	29.00	29.00	30.00	28.75
	Zn_5	27.67	29.67	30.33	32.67	30.08
	Zn_{10}	28.67	30.67	32.00	34.00	31.33
	Zn_{15}	29.33	32.00	32.33	34.33	32.00
	Mean	28.17	30.33	30.92	32.75	
S_5		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	26.67	29.00	29.00	30.00	28.67
	Zn_5	27.67	29.67	29.67	32.33	29.83
	Zn_{10}	28.00	30.67	31.33	33.00	30.75
	Zn_{15}	29.67	31.33	32.67	34.00	31.92
	Mean	28.00	30.17	30.67	32.33	
Mean Table	**Soil**	**30.92**	**31.12**	**30.65**	**30.54**	**30.29**
	P	**28.30**	**30.57**	**31.18**	**32.77**	
	Zn	**28.97**	**30.23**	**31.28**	**32.33**	
Source of variation		**C.D**				
	Soil types	**0.527**	**SXP**	**NA**	**SXPXZn**	**NA**
	P levels	**0.471**	**SXZn**	**NA**		
	Zn levels	**0.471**	**PXZn**	**NA**		

Effect of soils

The data on mean values of different soil types on thousand grain weight (21.63 g) of paddy grains presented in the table revealed that by applying varied quantities of phosphorus and zinc, soil type S_2 had significant effect on thousand gram weight over S_3.

Effect of phosphorus

The data from table revealed that adding varying quantities of phosphorus to paddy significantly increased the thousand grain weight (22.38 g). This increase was noted up to 100 mg kg^{-1} of phosphorus application. In general phosphorus level of 0, 25 and 50 mg kg^{-1} had a respective increase of 6.4, 11.2 and 13.9% on thousand gram weight of paddy compared to 100 mg kg^{-1} P.

Effect of zinc

Zinc application also resulted in statistically significant variation on thousand grain weight. The application of 15 mg kg^{-1} Zn resulted in the highest thousand grain weight (22.26 g) and percent increase in thousand grain weight of zinc at 15 mg kg^{-1} follows order 4, 8.1 and 11.1 by control, 5 and 10 mg kg^{-1}, respectively.

Interaction effect

The data on the combined influence of zinc and phosphorus on thousand grain weight is presented in table 4.12. The interaction effect of zinc and phosphorus on paddy thousand grain weight was found to be significant. Raising zinc levels increased thousand grain weight for the same quantity of phosphorus. Similarly, increasing phosphorus doses at the same level of zinc application resulted in an increase in thousand grain weight. By combining 15 mg kg^{-1} Zn + 100 mg kg^{-1} P and at control, *i.e.* zero levels of zinc and phosphorus, significant maximum (23.53 g) and minimum (18.47 g) values were obtained, respectively. 10 mg kg^{-1} Zn + 100 mg kg^{-1} P (22.74 g) and 15 mg kg^{-1} Zn + 50 mg kg^{-1} P (22.77 g) were on par with 10 mg kg^{-1} Zn + 50 mg kg^{-1} P (22.57 g).

Table 4.11. Effect of phosphorus and zinc application on thousand grain weight (g) in different soil types

S_1		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	18.33	19.53	20.50	21.47	19.96
	Zn_5	19.33	20.43	21.40	21.63	20.70
	Zn_{10}	19.47	21.53	22.33	22.60	21.48
	Zn_{15}	20.53	21.57	22.60	23.40	22.02
	Mean	19.42	20.77	21.71	22.27	
S_2		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	19.00	19.69	20.67	21.93	20.32
	Zn_5	20.19	20.89	21.69	22.20	21.24
	Zn_{10}	20.33	22.06	22.83	23.22	22.11
	Zn_{15}	21.56	22.52	23.3	23.97	22.84
	Mean	20.27	21.29	22.12	22.83	
S_3		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	18.33	19.67	20.67	21.50	20.04
	Zn_5	19.43	20.83	21.80	21.93	21.00
	Zn_{10}	19.73	21.70	22.63	22.83	22.73
	Zn_{15}	20.93	21.87	22.70	23.53	22.26
	Mean	19.61	21.02	21.95	22.45	
S_4		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	18.38	19.67	20.41	21.33	19.94
	Zn_5	19.33	20.33	21.13	21.33	20.53
	Zn_{10}	19.33	21.33	22.60	22.50	21.44
	Zn_{15}	20.67	21.67	22.67	23.40	22.10
	Mean	19.42	20.75	21.70	22.14	
S_5		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	20.47	21.83	22.60	23.33	19.82
	Zn_5	19.53	21.63	22.43	22.53	20.74
	Zn_{10}	19.67	20.00	21.63	21.67	21.53
	Zn_{15}	18.33	19.20	20.47	21.27	22.06
	Mean	19.50	20.67	21.78	22.20	
Mean Table	**Soil**	**21.04**	**21.63**	**21.26**	**21.00**	**21.04**
	P	**19.64**	**20.90**	**21.85**	**22.38**	
	Zn	**20.02**	**20.84**	**21.66**	**22.26**	
Source of variation		**C.D**				
	Soil types	**0.306**	**SXP**	**NA**	**SXPXZn**	**NA**
	P levels	**0.274**	**SXZn**	**NA**		
	Zn levels	**0.274**	**PXZn**	**0.547**		

Table 4.12. Combined effect of zinc and phosphorus levels on thousand grain weight (g)

	Zn_0	**Zn_5**	**Zn_{10}**	**Zn_{15}**
P_0	18.47	19.59	19.68	20.83
P_{25}	19.55	20.50	21.65	21.89
P_{50}	20.54	21.53	22.57	22.77
P_{100}	21.50	21.75	22.74	23.53

4.2.4 Grain yield

Grain yield of rice grown in different soil types as influenced by various levels of phosphorus and zinc revealed that individual effects including soil types, phosphorus level, zinc level and interaction effect of P and Zn had significant influence on grain yield. Remaining two way and three way interactions like phosphorus x soil types, zinc x soil types and phosphorus x zinc x soil types were statistically non-significant (Table 4.13).

Effect of soils

On diverse soil types, differing levels of phosphorus and zinc application were statistically significant on grain yield. Soil type S_2 had higher grain production (50.76 g pot^{-1}) and was on par with S_5.

Effect of phosphorus

According to the values from the table, increasing the amount of phosphorus increased significantly grain yield up to 100 mg kg^{-1} which was on par with 50 mg kg^{-1} of P application. The per cent increase in grain yield due to 100 mg kg^{-1} P application was 17.7, 25.6, and 32.35% over control, 20 and 40 mg kg^{-1} P, respectively.

Table 4.13. Effect of phosphorus and zinc application on grain yield (g pot^{-1}) in different soil types

S_1		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	20.90	37.93	39.03	36.53	33.60
	Zn_5	32.56	42.52	49.05	47.08	42.80
	Zn_{10}	46.36	49.61	49.87	49.80	48.91
	Zn_{15}	47.20	50.32	55.03	57.50	52.51
	Mean	36.75	45.10	48.25	47.73	
S_2		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	26.54	43.9	43.62	49.70	40.94
	Zn_5	37.50	49.45	53.74	54.13	48.71
	Zn_{10}	52.22	53.40	56.32	57.42	54.84
	Zn_{15}	52.86	57.84	64.50	59.09	58.57
	Mean	42.28	51.15	54.54	55.08	
S_3		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	28.10	34.68	39.88	39.88	35.63
	Zn_5	37.87	44.45	46.94	48.27	44.38
	Zn_{10}	47.23	48.08	49.20	54.15	49.67
	Zn_{15}	48.56	49.23	50.74	52.25	50.19
	Mean	40.44	44.11	46.69	48.64	
S_4		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	28.41	40.96	41.83	47.37	39.64
	Zn_5	37.52	44.58	50.73	48.68	45.38
	Zn_{10}	42.29	50.65	51.53	50.47	48.74
	Zn_{15}	47.20	47.24	49.70	51.17	48.83
	Mean	38.85	45.86	48.45	49.42	
S_5		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	22.87	34.71	42.27	55.45	38.83
	Zn_5	36.49	48.43	52.04	51.31	47.07
	Zn_{10}	47.53	49.67	54.51	54.80	51.63
	Zn_{15}	49.15	52.13	56.68	60.96	54.73
	Mean	39.01	46.23	51.37	55.63	
Mean Table	**Soil**	**44.46**	**50.76**	**44.97**	**45.65**	**48.06**
	P	**39.47**	**46.49**	**49.86**	**51.30**	
	Zn	**37.73**	**45.67**	**50.76**	**52.97**	
Source of variation		**C.D**				
	Soil types	**3.107**	**SXP**	**NA**	**SXPXZn**	**NA**
	P levels	**2.779**	**SXZn**	**NA**		
	Zn levels	**2.779**	**PXZn**	**5.558**		

Effect of zinc

Analysis of the data revealed that increasing zinc levels up to 10 mg kg^{-1} Zn significantly increased the grain yield. Zinc application at 10 mg kg^{-1} increased grain yield over control and 5 mg kg^{-1} Zn by 19.9 and 32.8% but was on par with 15 mg kg^{-1} Zn.

Table 4.14. Combined effect of zinc and phosphorus levels on grain yield of paddy (g pot^{-1})

	Zn_0	**Zn_5**	**Zn_{10}**	**Zn_{15}**
P_0	25.36	36.39	47.12	48.99
P_{25}	38.44	45.89	50.28	51.35
P_{50}	41.33	50.50	52.28	55.33
P_{100}	45.79	49.89	53.33	56.19

Interaction effect

Data on the combined influence of zinc and phosphorus on grain yield are furnished in table 4.14. The interaction effect of zinc and phosphorus on grain yield was found to be significant. Increased zinc doses increased grain yield for the same level of phosphorus. Similarly, increasing the doses of phosphorus while maintaining the same degree of zinc level also increased grain yield. The application of 15 mg kg^{-1} Zn + 100 mg kg^{-1} P and control, *i.e.* zero levels of zinc and phosphorus, resulted in higher (57.27 g pot^{-1}) and lower (25.36 g pot^{-1}) grain yields, respectively. Grain yield was significantly higher (50.5 g pot^{-1}) at treatment combination of 5 mg kg^{-1} Zn + 50 mg kg^{-1} P.

4.2.5 Straw yield

Statistical analysis of data on straw yield of paddy found statistically significant by the effects of soil types, phosphorus level and zinc level. But soil types x phosphorus, soil types x zinc, phosphorus x zinc, phosphorus x soil types x zinc had shown non-significant effect (Table 4.15).

Table 4.15. Effect of phosphorus and zinc application on straw yield (g pot^{-1}) in different soil types

S_1		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	22.55	32.16	42.14	45.62	35.61
	Zn_5	37.88	42.96	52.97	58.39	48.05
	Zn_{10}	39.99	49.21	51.27	62.06	50.63
	Zn_{15}	46.64	57.84	61.30	68.49	58.57
	Mean	36.77	45.54	51.92	58.64	
S_2		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	29.11	37.93	47.05	49.94	41.01
	Zn_5	42.92	51.46	57.40	61.97	53.44
	Zn_{10}	49.60	54.23	65.21	67.62	59.16
	Zn_{15}	52.27	55.41	65.71	68.90	60.57
	Mean	43.48	49.76	58.84	62.11	
S_3		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	31.93	46.72	51.06	50.73	45.11
	Zn_5	43.82	49.23	56.41	63.83	53.32
	Zn_{10}	45.07	49.33	57.65	66.55	54.65
	Zn_{15}	50.45	51.18	57.8	64.11	55.88
	Mean	42.82	49.12	55.73	61.30	
S_4		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	28.70	37.98	43.61	47.32	39.40
	Zn_5	38.49	45.80	54.21	57.01	48.87
	Zn_{10}	44.17	46.32	57.54	60.03	52.01
	Zn_{15}	47.69	49.77	59.63	62.65	54.93
	Mean	39.76	44.97	53.75	56.75	
S_5		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	25.67	37.98	47.47	51.91	40.76
	Zn_5	42.43	51.89	55.90	60.86	52.77
	Zn_{10}	46.60	56.87	64.73	66.48	58.67
	Zn_{15}	49.33	56.32	68.43	69.94	61.01
	Mean	41.01	50.77	59.13	62.30	
Mean Table	**Soil**	**48.22**	**53.55**	**52.24**	**48.81**	**53.30**
	P	**40.77**	**48.03**	**55.87**	**60.22**	
	Zn	**40.38**	**51.29**	**55.03**	**58.19**	
Source of variation		**C.D**				
	Soil types	**3.496**	**SXP**	**NA**	**SXPXZn**	**NA**
	P levels	**3.126**	**SXZn**	**NA**		
	Zn levels	**3.126**	**PXZn**	**NA**		

Effect of soils

Influence of P and Zn application on different soil types found that soil type S_2 produced greater straw yield (53.55 g pot^{-1}) than those grown on the other soil types by P and Zn application and these influence on different soil types were on par.

Effect of phosphorus

The data in the table showed that increasing phosphorus levels increased paddy straw yield (60.22 g pot^{-1}), significant increase was found when 100 mg kg^{-1} of P was applied thus raising straw yield by 17.8, 37 and 47.7% over control, 25 and 50 mg kg^{-1} of P, respectively. In the control group, the straw yield (40.77 g pot^{-1}) was significantly lower.

Effect of zinc

The application of zinc up to 15 mg kg^{-1} Zn significantly increased the straw production (58.19 g pot^{-1}), which was higher than the control, 5 mg kg^{-1} and 10 mg kg^{-1} Zn (Table 19). The addition of zinc at various levels 0, 5 and 10 mg kg^{-1} Zn raised straw yield by 27, 36.3 and 44.1%, respectively over 15 mg kg^{-1}.

4.2.6 Phosphorus content in grain

Information on the effects of soil types, zinc and phosphorus levels on the phosphorus content of paddy grain is presented in table 4.16. The types of soil, levels of zinc, levels of phosphorus and the interaction effect of phosphorus and zinc were found to be significant. Remaining two way interactions like soil types x phosphorus, soil types x zinc and three way interactions like soil types x phosphorus x zinc were non-significant.

Effect of soils

The higher phosphorus content of paddy grains (0.222%) was registered on soil type S_2 but on par over soil type S_5 at any phosphate or zinc level. The mean value of P content of soil types S_1 and S_4 were on par.

Table 4.16. Effect of phosphorus and zinc application on paddy grains P content (%) in different soil types

S_1		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.195	0.225	0.234	0.264	0.230
	Zn_5	0.193	0.216	0.227	0.254	0.222
	Zn_{10}	0.184	0.194	0.229	0.245	0.213
	Zn_{15}	0.154	0.185	0.204	0.224	0.192
	Mean	0.182	0.205	0.223	0.247	
S_2		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.207	0.238	0.244	0.263	0.238
	Zn_5	0.200	0.227	0.229	0.256	0.228
	Zn_{10}	0.195	0.214	0.233	0.247	0.222
	Zn_{15}	0.167	0.193	0.215	0.224	0.200
	Mean	0.192	0.218	0.230	0.248	
S_3		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.193	0.219	0.229	0.254	0.224
	Zn_5	0.190	0.210	0.215	0.247	0.216
	Zn_{10}	0.184	0.201	0.212	0.237	0.208
	Zn_{15}	0.163	0.185	0.205	0.222	0.194
	Mean	0.183	0.204	0.215	0.240	
S_4		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.199	0.223	0.231	0.255	0.227
	Zn_5	0.202	0.218	0.217	0.246	0.221
	Zn_{10}	0.192	0.204	0.229	0.238	0.215
	Zn_{15}	0.164	0.189	0.204	0.220	0.194
	Mean	0.189	0.208	0.220	0.240	
S_5		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.207	0.228	0.238	0.263	0.234
	Zn_5	0.205	0.218	0.221	0.252	0.224
	Zn_{10}	0.197	0.211	0.236	0.241	0.221
	Zn_{15}	0.173	0.194	0.209	0.225	0.200
	Mean	0.196	0.213	0.226	0.245	
Mean Table	**Soil**	**0.214**	**0.222**	**0.210**	**0.214**	**0.220**
	P	**0.188**	**0.210**	**0.223**	**0.244**	
	Zn	**0.230**	**0.222**	**0.216**	**0.196**	
Source of variation		**C.D**				
	Soil types	**0.005**	**SXP**	**NA**	**SXPXZn**	**NA**
	P levels	**0.004**	**SXZn**	**NA**		
	Zn levels	**0.004**	**PXZn**	**0.009**		

Effect of phosphorus

As can be seen from the table, there was significant difference between the treatments and phosphorus application significantly increased the phosphorus content in grain (0.244%) until last level P application. Phosphorus application at 100 mg kg^{-1} increased by 11.7, 18.6 and 29.7% compared to control, 25 and 50 mg kg^{-1}, respectively.

Effect of zinc

Perusal of the data found that zinc application had negative impact on phosphorus content of paddy grains and significantly reduced by phosphorus application. The higher P content was registered when no zinc was applied and application of 100 mg kg^{-1} P found 0.8 per cent reduction over control.

Table 4.17. Combined effect of zinc and phosphorus levels on phosphorus content of paddy grains (%)

	Zn_0	**Zn_5**	**Zn_{10}**	**Zn_{15}**
P_0	0.200	0.198	0.190	0.164
P_{25}	0.227	0.218	0.205	0.189
P_{50}	0.235	0.222	0.228	0.207
P_{100}	0.260	0.251	0.242	0.223

Interaction effect

It was also observed that the interaction of zinc and phosphorus on grain phosphorus content was significant (Table 4.17). Increasing the amount of zinc reduced phosphorus content in grain for the same level of phosphorus. While there was an increase in phosphorus content with increasing phosphorus levels at the same level of zinc. The application of 0 mg kg^{-1} Zn + 100 mg kg^{-1} P resulted in the highest grain phosphorus content (0.26%), but it was on par with 100 mg kg^{-1} P + 5 mg kg^{-1} Zn, and the lowest content (0.164%) was found in the control. The treatment combination of 10 mg kg^{-1} Zn + 100 mg kg^{-1} P had significant highest P concentration (0.242%).

4.2.7 Phosphorus content in straw

The influence of phosphorus level, zinc level and soil types were all significant, however interactions such as phosphorus x zinc, phosphorus x soil types, zinc x soil types and zinc x phosphorus x soil types had no effect on the phosphorus content of paddy straw. Table 4.18 displays the information.

Effect of soils

Mean values of different soil types on P content in straw found that highest paddy straw P content in soil type S_2. Whole soil types were on par as these soils cannot influence greatly on phosphorus content of paddy straw.

Effect of phosphorus

Phosphorus content raised with each phosphate level and each treatment had a significant effect on the amount of phosphorus in the straw (0.204%), with the maximum content at 100 mg kg^{-1} P. The increase in phosphorus concentration at 50 and 25 mg kg^{-1} P was 12.9 and 5.2% respectively over control.

Effect of zinc

Further analysis of the data revealed that applying zinc levels had a negative impact on zinc content of straw, which then lowered up to 15 mg kg^{-1}. The highest phosphorus content (0.199%) was registered at 0 mg kg^{-1} and lowest at 15 mg kg^{-1} Zn, the percent reduction in phosphorus content was 0.89.

4.2.8 Total phosphorus uptake

Soil types, phosphorus level, zinc level and interactions of phosphorus x zinc had significant effects on the total phosphorus uptake of paddy. But interactions of phosphorus x soil types, zinc x soil types, zinc x phosphorus x soil types were non-significant. The corresponding data are presented in table 4.19.

Table 4.18. Effect of phosphorus and zinc application on paddy straw P content (%) in different soil types

S_1		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.181	0.195	0.204	0.201	0.195
	Zn_5	0.167	0.181	0.188	0.196	0.183
	Zn_{10}	0.161	0.173	0.182	0.191	0.177
	Zn_{15}	0.156	0.168	0.171	0.185	0.170
	Mean	0.166	0.179	0.186	0.194	
S_2		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.190	0.202	0.226	0.230	0.212
	Zn_5	0.181	0.196	0.210	0.214	0.200
	Zn_{10}	0.170	0.192	0.202	0.203	0.192
	Zn_{15}	0.168	0.186	0.192	0.206	0.188
	Mean	0.177	0.194	0.208	0.213	
S_3		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.172	0.167	0.182	0.196	0.179
	Zn_5	0.164	0.166	0.181	0.195	0.176
	Zn_{10}	0.159	0.164	0.178	0.189	0.172
	Zn_{15}	0.155	0.158	0.169	0.182	0.166
	Mean	0.163	0.164	0.178	0.190	
S_4		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.195	0.190	0.200	0.213	0.200
	Zn_5	0.184	0.185	0.196	0.209	0.193
	Zn_{10}	0.180	0.181	0.192	0.205	0.190
	Zn_{15}	0.175	0.177	0.188	0.201	0.185
	Mean	0.184	0.183	0.194	0.207	
S_5		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.183	0.193	0.219	0.232	0.207
	Zn_5	0.163	0.180	0.195	0.222	0.190
	Zn_{10}	0.153	0.164	0.181	0.209	0.177
	Zn_{15}	0.143	0.154	0.177	0.200	0.169
	Mean	0.160	0.173	0.193	0.216	
Mean Table	**Soil**	**0.181**	**0.198**	**0.174**	**0.192**	**0.185**
	P	**0.170**	**0.179**	**0.192**	**0.204**	
	Zn	**0.199**	**0.189**	**0.181**	**0.176**	
Source of variation						
	Source	**C.D**				
	Soil types	**0.008**	**SXP**	**NA**	**SXPXZn**	**NA**
	P levels	**0.007**	**SXZn**	**NA**		
	Zn levels	**0.007**	**PXZn**	**NA**		

Effect of soils

The influence of phosphate and zinc application on mean values of total phosphorus uptake by paddy found that higher uptake of 24.96 mg pot^{-1} in soil type S_2 which was on par with soil type S_5. When mean values of P uptake was compared soil type S_1, S_4 and S_3 soil types were on par.

Effect of phosphorus

Phosphorus addition showed significant variation on total phosphorus uptake of paddy (26.38 mg pot^{-1}). P uptake increased significantly when phosphorus levels increased. The addition of 100 mg kg^{-1} P increased phosphorus uptake to a fold of 58.3, 47.47 and 31.4%, respectively over control, 25 and 50 mg kg^{-1} P.

Effect of zinc

Perusal of the data showed that rising zinc levels increased phosphorus uptake, but only up to 10 mg kg^{-1} Zn and there after P uptake was drastically reduced. However, maximal P uptake (24.72 mg pot^{-1}) was registered at a concentration of 10 mg kg^{-1} Zn, which raised P uptake by 17.6% and 29.3% over control and 5 mg kg^{-1} Zn, respectively and reduced P uptake by 7.9% at 15 mg kg^{-1} Zn.

Interaction effect

The interaction effect of zinc and phosphorus found to be significant on total phosphorus uptake (Table 4.20). Regardless of zinc levels, total phosphorus uptake increased as phosphorus dose increased. With respect to zinc levels, P uptake increased up to 10 mg kg^{-1}, after which it declined. With treatment combinations of 15 mg kg^{-1} Zn + 100 mg kg^{-1} P and at control, maximum (28.47 mg pot^{-1}) and minimum (11.55 mg pot^{-1}) P uptake was found. However application of 15 mg kg^{-1} Zn + 50 mg kg^{-1} P significant had highest phosphorus uptake (25.04 mg pot^{-1}).

Table 4.19. Effect of phosphorus and zinc application on total P uptake (mg pot^{-1}) after harvest of paddy in different soil types

S_1		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	10.39	18.97	20.30	21.44	17.77
	Zn_5	14.01	20.34	23.30	26.58	21.06
	Zn_{10}	19.00	21.15	26.07	27.13	23.34
	Zn_{15}	16.16	20.65	24.96	28.64	22.60
	Mean	14.89	20.28	23.66	25.94	
S_2		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	12.32	23.14	23.62	25.15	21.06
	Zn_5	17.31	24.94	27.39	30.84	25.12
	Zn_{10}	22.37	25.42	30.36	31.53	27.42
	Zn_{15}	19.58	24.92	28.27	32.14	26.23
	Mean	17.90	24.60	27.41	29.92	
S_3		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	12.62	20.32	21.45	21.19	18.90
	Zn_5	16.81	21.52	23.63	25.00	21.74
	Zn_{10}	20.61	21.45	24.72	25.11	22.97
	Zn_{15}	16.91	19.68	22.54	25.25	21.20
	Mean	16.74	20.74	23.09	24.14	
S_4		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	12.00	20.18	20.37	20.69	18.31
	Zn_5	16.01	20.86	22.38	24.67	20.98
	Zn_{10}	20.70	21.55	25.08	25.23	23.14
	Zn_{15}	17.41	20.24	23.11	25.89	21.66
	Mean	16.53	20.71	22.73	24.12	
S_5		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	10.43	22.60	22.33	22.63	19.50
	Zn_5	16.53	23.43	25.47	28.67	23.52
	Zn_{10}	23.60	24.33	29.63	29.37	26.73
	Zn_{15}	19.50	23.53	26.73	24.41	24.41
	Mean	17.27	23.18	25.94	27.78	
Mean Table	**Soil**	**21.19**	**24.96**	**21.18**	**21.02**	**23.54**
	P	**16.66**	**21.90**	**24.57**	**26.38**	
	Zn	**19.11**	**22.48**	**24.72**	**23.20**	
Source of variation		**C.D**				
	Soil types	**1.655**	**SXP**	**NA**	**SXPXZn**	**NA**
	P levels	**1.480**	**SXZn**	**NA**		
	Zn levels	**1.480**	**PXZn**	**2.960**		

Table 4.20. Combined effect of zinc and phosphorus levels on total phosphorus uptake of paddy (mg pot^{-1})

	Zn_0	**Zn_5**	**Zn_{10}**	**Zn_{15}**
P_0	11.55	16.13	21.26	17.71
P_{25}	21.04	22.22	22.78	21.57
P_{50}	21.61	24.43	27.17	25.04
P_{100}	22.22	27.15	27.67	28.47

Table 4.21. Correlation between added P and Zn on total phosphorus uptake

	S_1	**S_2**	**S_3**	**S_4**	**S_5**
Added P X Total P uptake	0.894^{**}	0.869^{**}	0.282^{NS}	0.976^{**}	0.717^{**}
Added Zn X Total P uptake	0.926^{**}	0.905^{**}	0.311^{NS}	0.984^{**}	0.758^{**}

The correlation coefficient values are presented in table 4.21 shows the relationship between phosphorus and zinc addition on total phosphorus uptake. Phosphorus and zinc addition had positive and significant correlation in all soil types except in soil type S_3 (r = 0.282) that showed non-significant correlation. Highest significant positive correlation was showed by S_4 (r = 0.976**) followed by S_1 (r = 0.894**) for the application of phosphorus, similarly by addition of zinc, highest correlation was observed in S_4 (r = 0.984**) followed by S_1 (r = 0.926**).

4.2.9 Zn content in grain

Individual effects of soil types, phosphorus and zinc level as well as interaction between phosphorus and zinc, found to have a significant effect on grain zinc concentration. Remaining two way and three way interactions like phosphorus x soil types, zinc x soil types and zinc x phosphorus x soil types were not significant. The information is shown in table 4.22.

Effect of soils

Influence of soil types on zinc content of paddy grains (55.56 mg kg^{-1}) showed that highest value for soil type S_3 which was on par with soil type S_2 and lowest zinc content was registered in soil type S_4.

Effect of phosphorus

Data from the table revealed that increasing phosphorus levels decreased zinc concentration of grain significantly up to 100 mg kg^{-1}. The highest Zn content (58.01 mg kg^{-1}) for paddy grains was recorded at 0 mg kg^{-1} P application and lowest at 100 mg kg^{-1}. Application of 100 mg kg^{-1} P decreased zinc content by 1, 0.91 and 0.84% over control, 25 and 50 mg kg^{-1} P, respectively.

Effect of zinc

Influence of application of different levels of zinc increased zinc content of paddy grains significantly up to 15 mg kg^{-1} of zinc. Zn content at 15 mg kg^{-1} increased grain zinc content to a tune of 11.7, 17.9 and 20.6% by application of 0, 5 and 10 mg kg^{-1}, respectively.

Interaction effect

The interaction of zinc and phosphorus on grain zinc content was also found to be significant (Table 4.23). Increasing phosphorus levels reduced the zinc content of grain for the same level of zinc. While there was an increase in zinc content with increasing zinc levels at the same level of phosphorus application. The application of 15 mg kg^{-1} Zn + 0 mg kg^{-1} P and control resulted in the highest (61.28 mg kg^{-1}) and lowest (43.61 mg kg^{-1}) zinc content in grain, respectively and significant increase in P uptake (60.04 mg kg^{-1}) was registered at 15 mg kg^{-1} Zn + 25 mg kg^{-1} P treatment combination.

Table 4.22. Effect of phosphorus and zinc application on paddy grain Zn content (mg kg^{-1}) in different soil types

S_1		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	53.27	51.47	44.19	43.53	48.11
	Zn_5	56.96	55.69	54.76	44.53	52.98
	Zn_{10}	59.91	58.09	57.26	52.33	56.90
	Zn_{15}	61.63	61.26	57.26	54.44	58.65
	Mean	57.94	56.63	53.37	48.71	
S_2		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	49.60	48.30	40.40	45.53	45.96
	Zn_5	56.93	54.47	53.93	49.50	53.71
	Zn_{10}	58.73	56.80	56.03	52.00	55.89
	Zn_{15}	61.50	60.40	57.00	52.17	57.77
	Mean	56.69	54.99	51.84	49.80	
S_3		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	57.30	55.47	46.04	44.03	50.71
	Zn_5	60.83	57.73	55.67	46.74	55.24
	Zn_{10}	61.23	58.56	57.01	53.30	57.52
	Zn_{15}	62.20	60.05	58.50	54.33	58.77
	Mean	60.39	57.95	54.30	49.60	
S_4		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	56.04	54.77	46.64	44.59	50.51
	Zn_5	59.03	56.62	56.06	45.31	54.26
	Zn_{10}	58.84	57.47	57.56	52.87	56.68
	Zn_{15}	60.06	59.10	58.04	54.68	57.97
	Mean	58.49	56.99	54.57	49.36	
S_5		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	49.80	48.93	41.47	40.37	45.14
	Zn_5	56.00	54.13	54.03	45.73	52.47
	Zn_{10}	59.30	57.67	56.77	52.40	56.53
	Zn_{15}	61.03	59.4	53.80	53.23	56.87
	Mean	56.53	55.03	51.52	47.93	
Mean Table	**Soil**	**54.16**	**53.33**	**55.56**	**54.85**	**52.75**
	P	**58.01**	**56.32**	**53.12**	**49.08**	
	Zn	**48.09**	**53.73**	**56.71**	**58.01**	
Source of variations		**C.D**				
	Soil types	**1.430**	**SXP**	**NA**	**SXPXZn**	**NA**
	P levels	**1.279**	**SXZn**	**NA**		
	Zn levels	**1.279**	**PXZn**	**2.557**		

Table 4.23. Combined effect of zinc and phosphorus levels on zinc content of paddy grains (mg kg^{-1})

	Zn_0	Zn_5	Zn_{10}	Zn_{15}
P_0	53.2	57.95	59.6	61.28
P_{25}	51.79	55.73	57.72	60.04
P_{50}	43.75	54.89	56.92	56.92
P_{100}	43.61	46.36	52.58	53.77

4.2.10 Zinc content in straw

Variables like phosphorus level, zinc level, phosphorus x zinc had significant effect on zinc content in paddy straw and interactions like phosphorus x soil types, zinc x soil types, phosphorus x zinc x soil types and individual effect of soils were found to be non-significant (Table 4.24).

Effect of phosphorus

The data in the table revealed that increasing phosphorus levels had a negative impact on the zinc content of paddy straw, reducing it by up to 100 mg kg^{-1}. With no P application and 100 mg kg^{-1} P, the maximum and minimum Zn content of 40.37 mg kg^{-1} and 36.56 mg kg^{-1}, respectively were registered. The percent decrease in zinc content by application of 100 mg kg^{-1} P over control, 25 and 50 mg kg^{-1} was 0.96, 0.92 and 0.9, respectively.

Effect of zinc

A close study of the data in the table revealed that increasing zinc levels increased the zinc content of straw (42.27 mg kg^{-1}) up to 15 mg kg^{-1} but addition of 5 mg kg^{-1} Zn do not have significant effect on the zinc content over control. Application of 15 mg kg^{-1} Zn over control, 5 and 10 mg kg^{-1} followed order of 1.6, 6.2 and 17.4%, respectively.

Table 4.24. Effect of phosphorus and zinc application on paddy straw Zn content (mg kg^{-1}) in different soil type

S_1		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	37.57	35.34	34.49	33.85	35.31
	Zn_5	39.48	36.11	35.92	31.30	35.70
	Zn_{10}	40.84	40.05	34.67	37.12	38.17
	Zn_{15}	45.37	43.56	40.94	41.55	42.85
	Mean	40.82	38.76	36.52	35.96	
S_2		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	37.90	35.34	34.60	33.85	35.42
	Zn_5	39.48	36.44	36.25	35.64	36.95
	Zn_{10}	41.51	40.72	34.91	33.79	37.73
	Zn_{15}	46.37	43.89	41.27	40.95	43.12
	Mean	41.32	39.10	36.76	36.06	
S_3		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	37.73	37.63	35.33	35.77	36.62
	Zn_5	39.93	38.73	36.23	35.13	37.51
	Zn_{10}	42.97	40.33	36.87	37.47	39.41
	Zn_{15}	44.87	44.33	41.33	42.53	43.27
	Mean	41.37	40.26	37.44	37.72	
S_4		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	37.22	36.61	36.05	35.43	36.33
	Zn_5	38.61	36.69	36.63	32.62	36.14
	Zn_{10}	39.39	39.59	36.85	37.46	38.32
	Zn_{15}	42.71	42.01	40.06	39.10	40.97
	Mean	39.48	38.72	37.40	36.15	
S_5		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	36.87	36.08	36.40	35.57	36.23
	Zn_5	38.33	36.13	39.01	33.06	36.64
	Zn_{10}	38.61	38.08	35.33	38.00	37.51
	Zn_{15}	41.64	40.84	40.95	41.05	41.12
	Mean	38.86	37.78	37.92	36.92	
Mean Table	**Soil**	**38.01**	**38.31**	**39.20**	**37.94**	**37.87**
	P	**40.37**	**38.92**	**37.20**	**36.56**	
	Zn	**35.98**	**36.59**	**38.23**	**42.27**	
Source of variation		**C.D**				
	Soil types	**NA**	**SXP**	**NA**	**SXPXZn**	**NA**
	P levels	**0.903**	**SXZn**	**NA**		
	Zn levels	**0.903**	**PXZn**	**1.806**		

Table 4.25. Combined effect of zinc and phosphorus levels on zinc content of paddy straw (mg kg^{-1})

	Zn_0	Zn_5	Zn_{10}	Zn_{15}
P_0	37.46	39.17	40.66	44.19
P_{25}	36.20	36.82	39.75	42.92
P_{50}	35.37	36.81	35.73	40.91
P_{100}	34.89	33.55	36.77	41.04

Interaction effect

The interaction effect of zinc and phosphorus on straw zinc content was also found to be significant (Table 4.25). For the same level of zinc, increasing levels of phosphorus reduced the zinc content in grain. While, there was increase in zinc content with the increasing levels of zinc at the same level of phosphorus application. Combined application of 15 mg kg^{-1} Zn + 0 mg kg^{-1} P and 0 mg kg^{-1} Zn + 100 mg kg^{-1} P, respectively resulted in the highest (44.19 mg kg^{-1}) and lowest (34.89 mg kg^{-1}) zinc content. The treatment combination of 15 mg kg^{-1} Zn + 25 mg kg^{-1} P had significant highest zinc content in paddy straw (42.92 mg kg^{-1}).

4.2.11 Total zinc uptake

The influence of phosphorus and zinc application on total zinc uptake by paddy found that variables like soil types, phosphorus and zinc level were statistically significant. Remaining two and three way interactions were not significant (Table 4.26).

Effect of soils

When mean values of different soil types were compared, different treatment application had a significant impact on total zinc uptake by paddy. The soil type S_3 (0.458 mg pot^{-1}) recorded significantly highest total zinc uptake over soil type S_1.

Table 4.26. Effect of phosphorus and zinc application on total Zn uptake (mg pot^{-1}) after harvest of paddy in different soil types

S_1		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.435	0.441	0.451	0.448	0.444
	Zn_5	0.447	0.447	0.459	0.456	0.452
	Zn_{10}	0.453	0.456	0.463	0.461	0.458
	Zn_{15}	0.452	0.449	0.457	0.455	0.453
	Mean	0.447	0.448	0.458	0.455	
S_2		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.411	0.416	0.434	0.424	0.422
	Zn_5	0.419	0.422	0.443	0.428	0.428
	Zn_{10}	0.429	0.429	0.449	0.436	0.436
	Zn_{15}	0.427	0.427	0.445	0.433	0.433
	Mean	0.422	0.424	0.443	0.43	
S_3		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.442	0.448	0.456	0.455	0.450
	Zn_5	0.450	0.453	0.465	0.462	0.458
	Zn_{10}	0.457	0.462	0.469	0.466	0.464
	Zn_{15}	0.455	0.456	0.464	0.462	0.459
	Mean	0.451	0.455	0.463	0.461	
S_4		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.429	0.434	0.445	0.442	0.437
	Zn_5	0.435	0.439	0.454	0.445	0.444
	Zn_{10}	0.444	0.445	0.458	0.453	0.450
	Zn_{15}	0.441	0.443	0.456	0.449	0.447
	Mean	0.437	0.440	0.453	0.447	
S_5		**P_0**	**P_{25}**	**P_{50}**	**P_{100}**	**Mean**
	Zn_0	0.409	0.421	0.433	0.425	0.422
	Zn_5	0.411	0.429	0.441	0.434	0.429
	Zn_{10}	0.415	0.435	0.449	0.443	0.436
	Zn_{15}	0.415	0.432	0.447	0.438	0.433
	Mean	0.413	0.43	0.443	0.435	
Mean Table	**Soil**	**0.452**	**0.430**	**0.458**	**0.445**	**0.430**
	P	**0.434**	**0.439**	**0.452**	**0.446**	
	Zn	**0.435**	**0.442**	**0.449**	**0.445**	
Source of variation		**C.D**				
	Soil types	**0.005**	**SXP**	**NA**	**SXPXZn**	**NA**
	P levels	**0.004**	**SXZn**	**NA**		
	Zn levels	**0.004**	**PXZn**	**NA**		

Effect of phosphorus

The addition of phosphorus to paddy showed significant variation on zinc uptake. Total Zn uptake (0.452 mg pot^{-1}) increased significantly with increasing phosphorus levels up to 50 mg kg^{-1} and then declined by addition of 100 mg kg^{-1} P. The use of 50 mg kg^{-1} P raised phosphorus uptake by 1.1, 4.1% over control and 25 mg kg^{-1} but a reduction of 1.4 percent was observed when 100 mg kg^{-1} P was used.

Effect of zinc

A close examination of the data in the table revealed that increasing zinc levels increased zinc uptake (0.449 mg pot^{-1}) until it reached 10 mg kg^{-1} Zn and then decreased significantly. The application of 10 mg kg^{-1} Zn increased zinc uptake by 1.6 and 3.2% over control and 5 mg kg^{-1} Zn respectively and then decreased to a tune of 1% over 15 mg kg^{-1} Zn.

The 'r' values presented in table 4.27 shows the relationship between added phosphate and added zinc and total zinc uptake. Addition of phosphorus and zinc were having non-significant correlation on S_2 (r = 0.374 and r = 0.487) and had significant and positive correlation with S_1, S_3, S_4 and S_5.

Table 4.27. Correlation between added P and Zn on total zinc uptake

	S_1	**S_2**	**S_3**	**S_4**	**S_5**
Added P X Total Zn uptake	0.555^{*}	0.374^{NS}	0.683^{**}	0.705^{**}	0.628^{**}
Added Zn X Total Zn uptake	0.517^{*}	0.487^{NS}	0.754^{**}	0.678^{**}	0.736^{**}

Discussion

5. DISCUSSION

The findings of the current study in section 4 are critically addressed, along with supporting data and related studies from the literature.

The impact of long-term application of organic and inorganic sources of nutrients on changes in phosphorus and zinc fractions is discussed under section 5.1. The interaction of Phosphorus & Zinc under different levels of native P & Zn soils with respect to nutrient uptake and yield of rice is discussed under section 5.2.

5.1 FRACTIONS OF ZN UNDER DIFFERENT P LEVELS IN LONG TERM FERTILIZER EXPERIMENT (LTFE)

5.1.1Effect of long-term fertilizer application on nutrient content of soil

5.1.1.1 Available nitrogen

The result of available nitrogen content showed that significantly higher nitrogen content of 245 kg ha^{-1} was recorded in treatment T5 (100% NPK + FYM) and lower content in no fertiliser applied plot (Table 4.1). The increase in available nitrogen with the application of chemical fertilisers alone (50, 100, and 150% NPK levels) can be justified by application of direct fertiliser input to the available N pool, as well as accelerated breakdown of organic nitrogenous materials (Bansal *et al*., 1980).

5.1.1.2 Available phosphorus

The results of available phosphorus showed that treatment T4 with 150% NPK had significantly higher available phosphorus content (19.35 kg ha^{-1}) over100% NPK + FYM (Table 4.1). The application of NPK fertilisers alone or in combination with organics increased available P in the soil. The accumulation of P in the fertilised and organically treated plots may be attributable to the fixing of applied P in the soil as Al and Fe-P, as these soils are rich in sesquioxides and so phosphorus accumulates over time and hence contributes to the overall pool of available P in the soil (Katyal *et al.*, 2000). Suresh *et al.* (1999) reported that increase in available P was attributed due to P dissolution during organic matter decomposition by combined use of FYM and fertilisers. Babhulkar *et al.* (2000) reported that using FYM in conjunction with fertilisers resulted in larger increase in available P.

5.1.1.3 Available potassium

Application of 150%NPK in treatment T4 had significant effect on potassium content (85.99 kg ha^{-1}) than treatment T5 (100% NPK + FYM) (Table 4.1). Application of fertiliser increased available K compared to control due to direct potassium addition to the soil available pool. The highest content of available potassium in T5 can be justified as farmyard manure is not only a direct and readily available supply of K (Bansal, 1992), but it also helps to reduce K leaching by holding K ions on the exchange sites of its degraded products. Higher crop removal, uneven nutrition, or no fertiliser application all contributed to soil potassium depletion. The use of lime and FYM on a regular basis resulted in the increase of potassium. The current findings were similar to the findings of Jaskulska *et al.* (2014).

5.1.1.4 Exchangeable calcium

The exchangeable calcium content (171.7 mg kg^{-1}) of the soil was significantly higher in the lime treated plot where 100% NPK + lime was applied (Table 4.2). The direct result of adding calcium in the form of calcium carbonate over time resulted in an increase in the exchangeable calcium content of soil in lime applied plots. The FYM applied plots had greater calcium content than fertiliser treated plot because FYM is a good source of calcium and during decomposition it increases the amount of calcium in the soil (Prasad *et al.*, 1996). Treatments that only received chemical fertilisers above had lower calcium values. Yaduvanshi *et al*. (1985) and Suresh Lal *et al*. (1990) both found a decrease in the exchangeable Ca content of soil in plots that solely received chemical fertilisers.

5.1.1.5 Exchangeable magnesium

Significant differences with respect to exchangeable magnesium content (30.64 mg kg^{-1}) of soil was observed by the application of fertilisers alone or with FYM or lime. The treatments that received 100% NPK + FYM had the highest magnesium content 30.64 mg kg^{-1}, whereas the control plot had the lowest (Table 4.2). Farm yard manure has been reported to be a rich source of magnesium and added significant amount of magnesium to the soil when decomposed (Suresh Lal *et al*., 1990; Prasad *et al*., 1996). Considerably higher amount of Mg found in lime applied plots compared to non-lime applied plots as lime contains some Mg as an impurity that can supply Mg to some extent.

5.1.1.6 Available sulphur

There was significant increase in the available sulphur content (6.57 mg kg^{-1}) of the soil in the FYM treated plots over T4 (Table 4.2). This indicated that regular supply of plant-available organically bound sulphur to the soil by FYM. According to Jagadeesh (2000) the increase in sulphur concentration in treatment T5 could be attributed to FYM addition. Nambiar and Abrol (1989) from the long term fertiliser experiment study also reported that the treatment involving un-interrupted yearly FYM application could maintain adequate status of sulphur to guard against its deficiency in soil. The absence of sulphur-containing fertilisers may have resulted in a significant decrease in sulphur concentration in the remaining treatments.

5.1.1.7 Available iron

Treatment that received FYM in T5 had significantly higher available iron content (254.74 mg kg^{-1}) over T4 and lowest content in control plot (Table 4.3). According to Hemalatha and Chellamuthu (2012) by continuous fertiliser application in long term fertiliser experiment plots, micronutrients such as iron were significantly higher in the treatment receiving 100% NPK + FYM, indicating that the integrated nutrient management practice maintained soil fertility and soil health.

5.1.1.8 Available copper

The treatment with combined application of organic and inorganic fertilisers in T5 showed a greater increase in available copper content (8.78 mg kg^{-1}) as compared to control (Table 4.3). This fully corroborate with the finding of Hemalatha and Chellamuthu, 2012.

5.1.1.9 Available zinc

Long-term fertiliser application of both organic and inorganic fertilisers found higher zinc content (1.32 mg kg^{-1}) in 100% NPK+FYM applied plot whereas all other treatments had lower zinc content (Table 4.3). The decrease in HCl extractable Zn of soil observed in all treatments except T5 suggested that crops cultivated continuously without replenishing from external sources were removing available Zn from the soil as reported by Hemalatha and Chellamuthu, 2012.

5.1.1.10 Total phosphorus

The results showed that when 100% NPK+FYM was applied to the soil, the total phosphorus content (1134.57 mg kg^{-1}) was significantly higher than when 150% NPK and other treatments were applied (Table 4.4 and fig. 5.1). This large rise in total P could be related to the addition of P from both inorganic and organic sources, such as rajphos and FYM. Prasad and Mathur (1997) reported an increase in the overall P reserve on organic manuring, favoured the release of P from organic manures through mineralization. Sharma and Paliyal (2014) found that P fertiliser added to the soil increased the total P content.

5.1.1.11 Total zinc

Total Zn content of 21 mg kg^{-1} was found to be significantly higher in FYM treated plot compared to non-treated plot (Table 4.4, fig. 5.2). Supporting these results the findings of Kher (1993) found that FYM contains Zn that is released during decomposition, contributing to its greater availability in soil. Krishnakumar and Patty (1992) highlighted that variation in total Zn could be mainly due to varied application of fertiliser and organic manure.

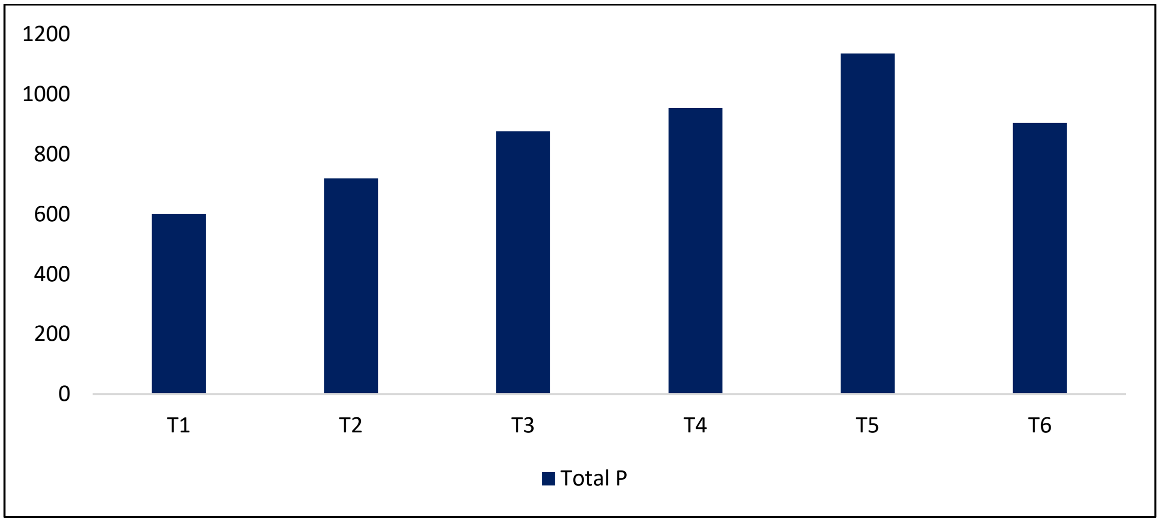


Fig. 5.1. Effect of long term fertilizer application on total P in soil

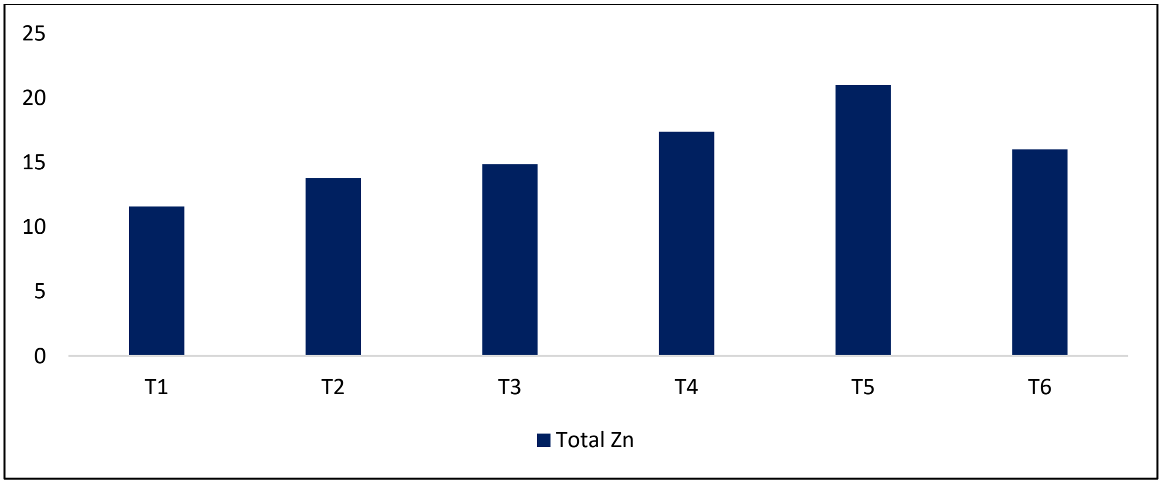


Fig. 5.2. Effect of long term fertilizer application on total Zn in soil

5.1.2 Influence of long-term fertilizer application on the P and Zn content and total uptake by paddy

5.1.2.1 Phosphorus content

Impact of long-term fertiliser application found that treatments that received 100% NPK + FYM registered higher P content in grain and straw with respective values are 0.302 and 0.192% (Table 4.5). Low P content was reported in the plot where no fertilisers were applied.

5.1.2.2 Zinc content

Data on the impact of long-term fertiliser application on paddy zinc content in table 4.5 showed that addition of optimal dose of fertilisers with FYM changed the zinc nutritional content of paddy grain, straw and their respective values are 28.35 mg kg^{-1} and 23.25 mg kg^{-1}.

5.1.2.3 Total phosphorus uptake

Influence of long term application on total phosphorus uptake found significantly higher value of 18.95 kg ha^{-1} in T5 (100% NPK+ FYM) and lower value in control (Table 4.5). This shows the positive impact of using organic and inorganic materials. The enhanced nutrient content is related to higher absorption of native nutrients, chelation of complex intermediate organic compounds formed during decomposition of added organic manures and mobilisation and accumulation of various nutrients in different plant parts (Sharma *et al*., 2013).

5.1.2.4 Total zinc uptake

Total zinc uptake of paddy differed significantly and highest value of 170.51 g ha^{-1} was noted for treatment T5 and lowest for control plot (Table 4.5). This suggests that the use of FYM aided in the absorption of micronutrients through the formation of soluble complexes. In addition to enhancing availability of micronutrients in soil, the complexing qualities of manure (FYM) with micronutrients may have inhibited precipitation, fixation and leaching, thus keeping them in soluble form and resulting in better crop absorption of these elements (Gupta *et al*., 2000).

5.1.3 Influence of long term fertilizer application on various zinc fractions

The effect of long-term fertiliser studies on various zinc fractions found that plot that received FYM had the highest content of all fractions except amorphous sesquioxide zinc form. Shambhavi *et al*. (2020) reported that availability of zinc pools as well as crop yield and zinc uptake were significantly greater in FYM treated plots compared to plots that did not received fertiliser that is control plot. The higher concentration of zinc fractions in plots receiving organics, such as FYM, could be due to the formation of metallo-organic complexes with ligands, mineralization and solubilisation from FYM. Organic ligands produced from manure decomposition can alter Zn forms through a number of mechanisms, including surface complexation of the residual Zn form by organic ligands, inhibition of Fe and Al crystallisation, which provides reactive surfaces and effective sinks for Zn, enhancing further dissolution of residual Zn and adsorption of organic ligands to the oxide surface.

5.1.3.1 Water soluble plus extractable zinc

The water soluble plus extractable zinc fraction was significantly higher in FYM treated plot and remaining treatments were on par to each other even though a slight increase was noted by increasing the dose of fertiliser (Table 4.6 and fig. 5.3). Agbenin (2003) found that FYM fertilised field maintained total and extractable Zn levels significantly higher than the natural site. Because this is the fraction that is most bioavailable and mobile in soil, its low concentration as compared to other fractions could be attributable to losses through leaching and plant absorption (Filgueiras *et al.,* 2002). Similar results have also been observed by Kumar and Babel (2011) and Sharma and Subehia (2014). This fractions showed a slight decrease in their contents in control compared to chemical fertilizer treatments, due to removal of Zn from these fractions by the crops. Since no external Zn was applied in these treatments, whatever Zn was removed by crops was mobilized from other Zn fractions.

5.1.3.2 Organically bound zinc

The addition of FYM in treatment T5 resulted in the highest amount of this fraction, indicating that organic manure played significant role in Zn availability in soil systems (Rathore *et al*., 1980; El- Fouly *et al*., 2015). Sharad and Verma (2001) opined that zinc is known to create strong compounds in the soil with organic materials (Table 4.6, fig. 5.4). In comparison to the control, organically bound Zn increased significantly when chemical fertilisers were applied alone. The increased organic carbon content in the fertilizer-treated treatments could explain the higher organic matter bound zinc levels in these treatments and zinc is known to create strong compounds in the soil with organic materials.

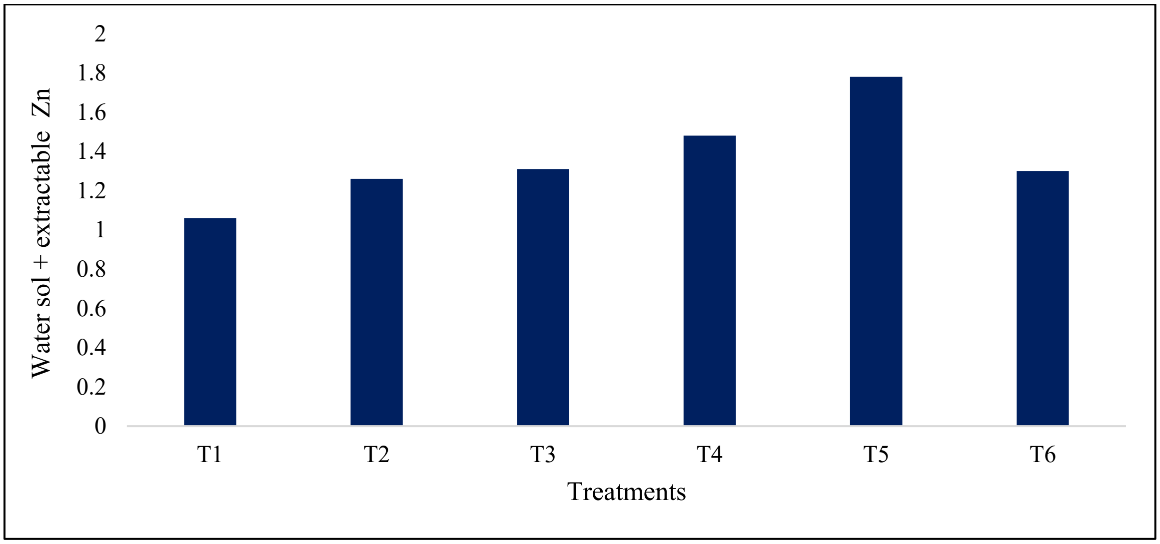


Fig. 5.3. Effect of long term application of fertilizers and manure on distribution of water soluble plus extractable Zn (mg kg^{-1})

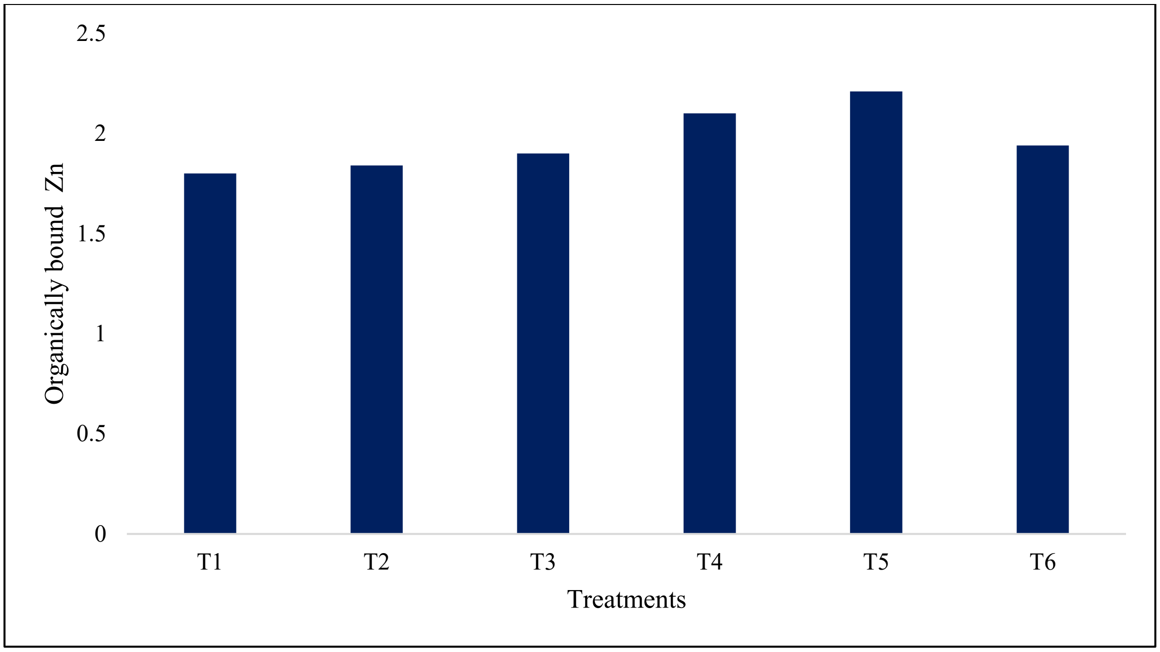


Fig. 5.4. Effect of long term application of fertilizers and manure on distribution of organically bound Zn (mg kg^{-1})

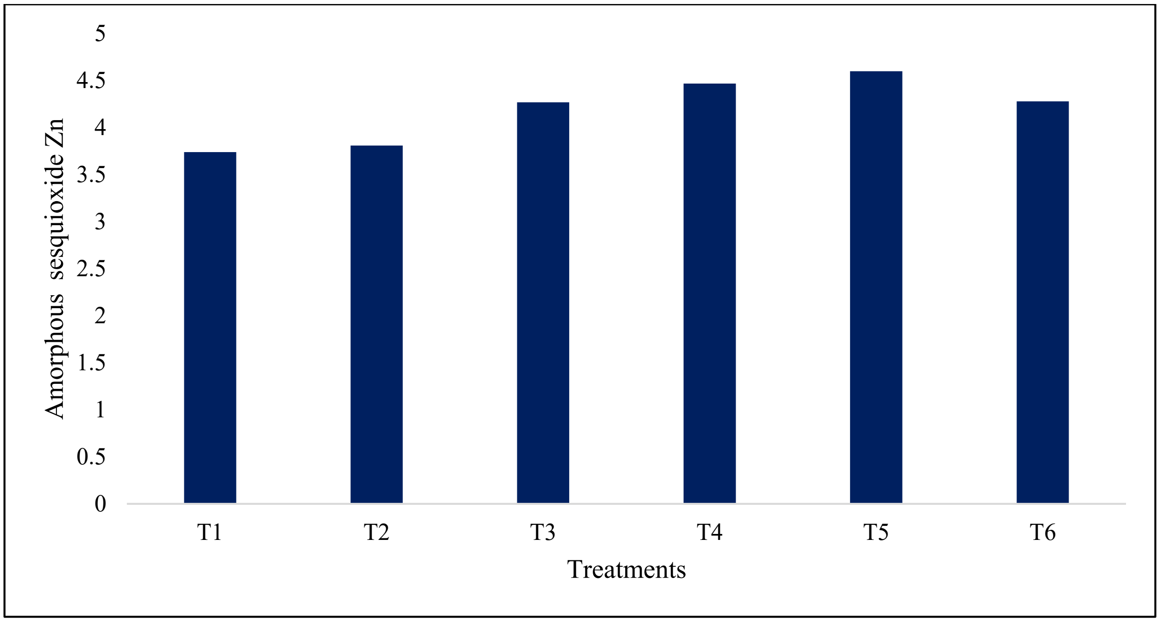


Fig. 5.5. Effect of long term application of fertilizers and manure on distribution of amorphous sesquioxide zinc (mg kg^{-1})

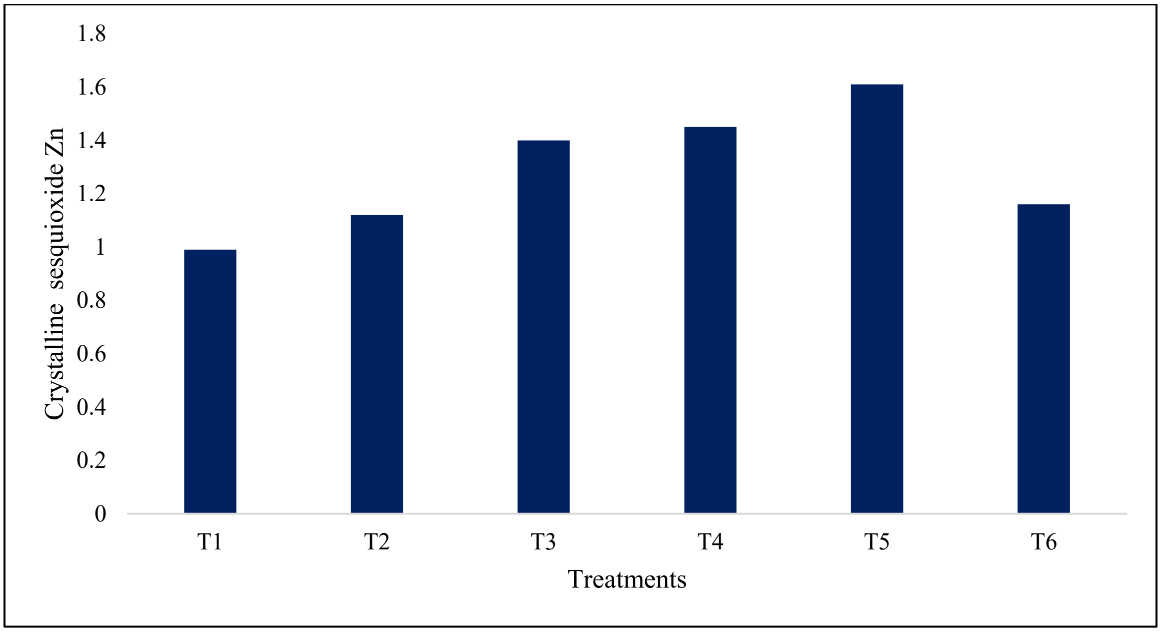


Fig. 5.6. Effect of long term application of fertilizers and manure on distribution of crystalline sesquioxide zinc (mg kg^{-1})

5.1.3.3 Amorphous sesquioxide zinc

Amorphous sesquioxide zinc fraction was significantly higher in control plot (Table 4.6 & fig. 5.5). In acid soils, the FYM played a critical role in Fe and Al activity and these iron and aluminium forms strong compounds with biological materials (Sharad and Verma, 2001; Dhiman, 2007; Shambhavi, 2011). Because fertilisers improved root biomass in soil by raising crop yields thus resulting in higher organic matter content. Most of the Fe and Al in the soil may have formed strong complexes with the increased organic matter, leaving little oxides for zinc adsorption. Apart from that, the Zn released during the synthesis of organic compounds with Fe and Al could be converted into other Zn fractions. This explains why the content of this fraction decreases when fertilisers are applied to the soil (Adhikari and Rattan, 2007; Shambhavi, 2011; Spalbar *et al*., 2017). In an acidic environment, Mandal *et al*. (1986) found higher quantity of amorphous Fe oxides than crystalline Fe oxides implying that more of the free Fe oxides content of these soils is present in amorphous form than crystalline form.

5.1.3.4 Crystalline sesquioxide zinc

Crystalline sesquioxide zinc fraction registered significant higher value in Treatment T5 whereas control had the lowest content (Table 4.6 and fig. 5.6). According to Nolovic (1978), the low amount of this fraction is attributable to the crystallinity of Fe oxides, which may have interfered with trace elements like Zn.

5.1.4 Influence of long term fertilizer application on various phosphorus fractions

5.1.4.1 Saloid bound P

The influence of continuous cropping and fertiliser treatments on saloid-P content revealed that this fraction contributed least about 2% of total inorganic P (Table 4.7 and fig. 5.7). Lower content of this fraction (6.26 mg kg^{-1}) was recorded in control, which can be explained based on absence of fertiliser application (Garg and Milkha, 2010). Subsequent additions of P from 50% NPK to 150% NPK proportionally increased this fraction in soil due to transformation of applied P into sol-P in the soil system both from inherent and applied sources (Kaushal, 1995; Tomar, 2003; Badrinath *et al.*, 2005). However, when 100% NPK with FYM was applied significantly greater content (8.88 mg kg^{-1}) was reported, showing that organic manure had synergistic effect on speeding the rate of transformation into this fraction for future consumption by crop plants (Bahl and Singh, 1997; Prasad and Mathur, 1997; Singh *et al.*, 2003).

5.1.4.2 Aluminuium phosphate

Aluminium phosphate form in the soil raised as fertiliser doses were increased (table 4.7 and fig. 5.8). Decrease in Al-P (61.48 mg kg^{-1}) in the control plot is due to the lack of P (Kaushal, 1995). On the other hand, greater P accumulation was observed when fertiliser levels were increased from optimal to super optimal and even significantly more P accumulation was observed when 100% NPK was applied in conjunction with FYM as this combination enhanced the transformation process that resulted in the accumulation of Al-P form (112.35 mg kg^{-1}) in the soil (Brar and Vig, 1989; Jaggi, 1991; Sheela *et al.*, 1991).

5.1.4.3 Iron phosphate

Iron bound phosphate occurred in greatest percentage among total inorganic P, accounting for 48.16%. This was comparable to the study of Bhattacharyya *et al.* (2015). High Fe content present in the acid soil may have fixed the P applied by an inorganic P source. The Fe-P content increased with repeated greater P fertiliser application over no additions (133.29 mg kg^{-1}), which could be related to higher transformation of added fertiliser P in soil equilibrium to Fe-P retention in soil (Table 4.7 and fig. 5.9) (AI-Abbas and Barber, 1964; Kumar and Ramalu, 1991; Parmavsivan and Udaysoorian, 1991). However, using FYM in conjunction with optimal dose resulted in significant increase of Fe-P (190.43 mg kg) in T5 due to the release of organic acids during the decomposition of organic matter, resulting in the resolution of both applied and native P into Fe-P compounds, resulting in enrichment of Fe-P pools in soil solution Singaram and Kothandraman (1994). Additionally, FYM hastened mineralization of soil P reserves which indirectly increased Fe-P accumulation (Sugito *et al*., 2001; Sen *et al*., 2002).

5.1.4.4 Sesquioxide occluded phosphate

The sesquioxide occluded P fraction constitute about 10% to total inorganic P in the current investigation (Table 4.7 and fig. 5.10) Following the addition of graded fertiliser, the content of occluded-P increased from 50 to 150% NPK. However, increasing the P fertiliser dose did not significantly increased the occluded-P fraction (62.94 mg kg^{-1}) of T5 over T4, implying that Fe and Al played a major role in fixing the applied inorganic P by fertiliser (Prasad and Mathur, 1997; Sihag *et al*., 2005; Mahmood and Samadi, 2003).

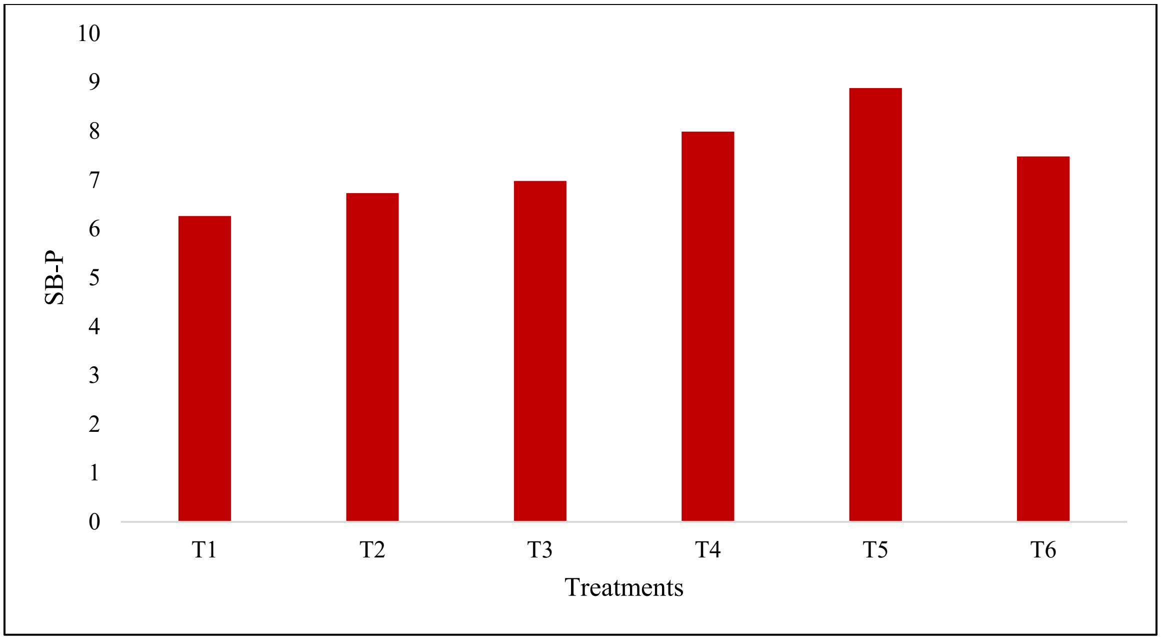


Fig. 5.7. Effect of long term application of fertilizers and manure on distribution of Saloid-P (mg kg $^{-1}$)

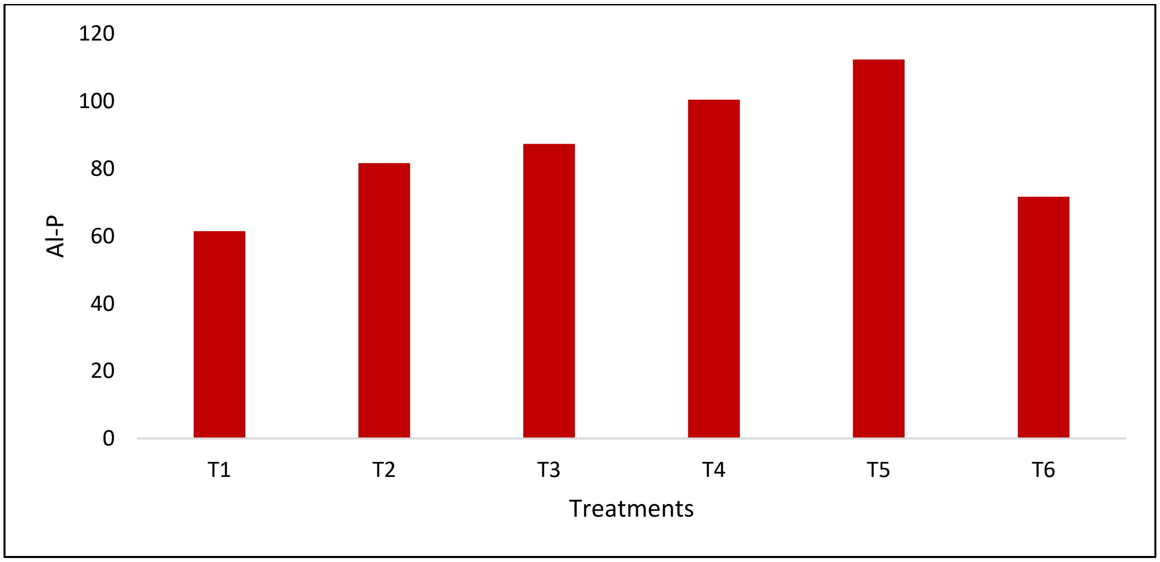


Fig. 5.8. Effect of long term application of fertilizers and manure on distribution of Al-P (mg kg $^{-1}$)

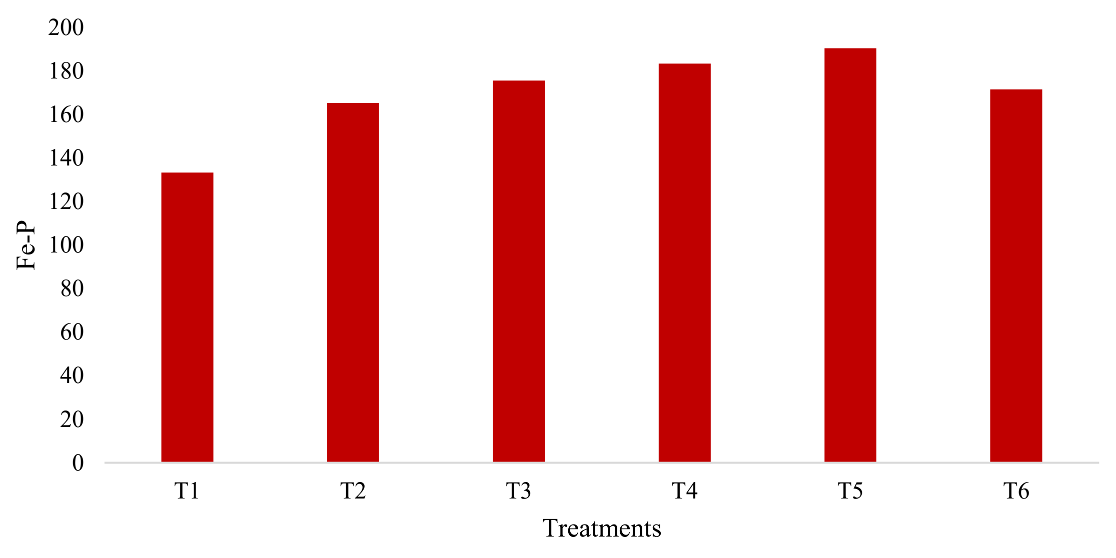


Fig. 5.9. Effect of long term application of fertilizers and manure on distribution of Fe-P (mg kg $^{-1}$)

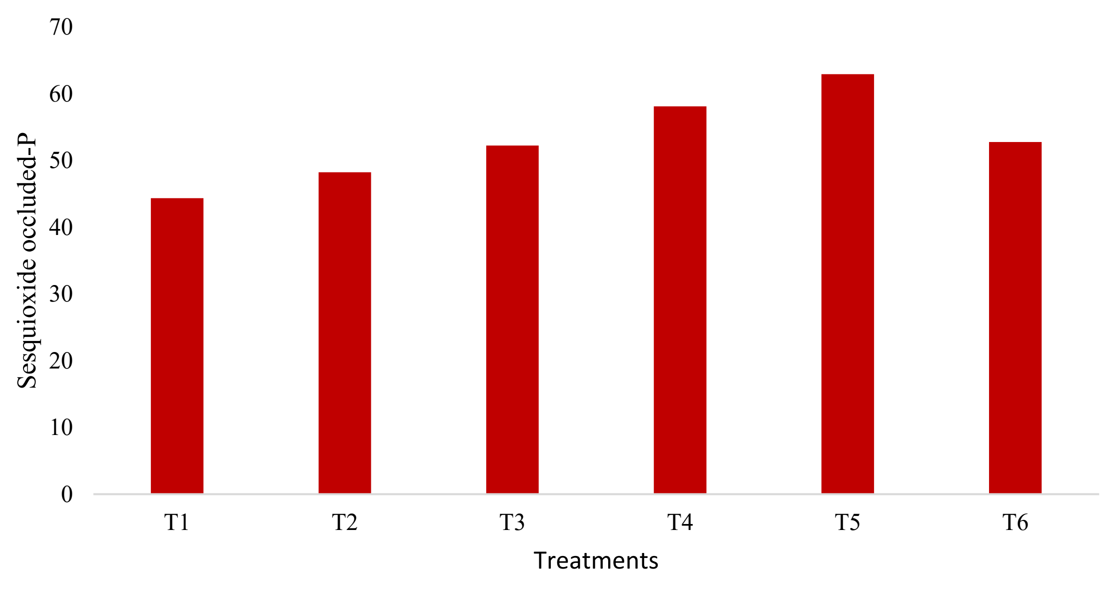


Fig. 5.10. Effect of long term application of fertilizers and manure on distribution of sesquioxide occluded-P (mg kg $^{-1}$)

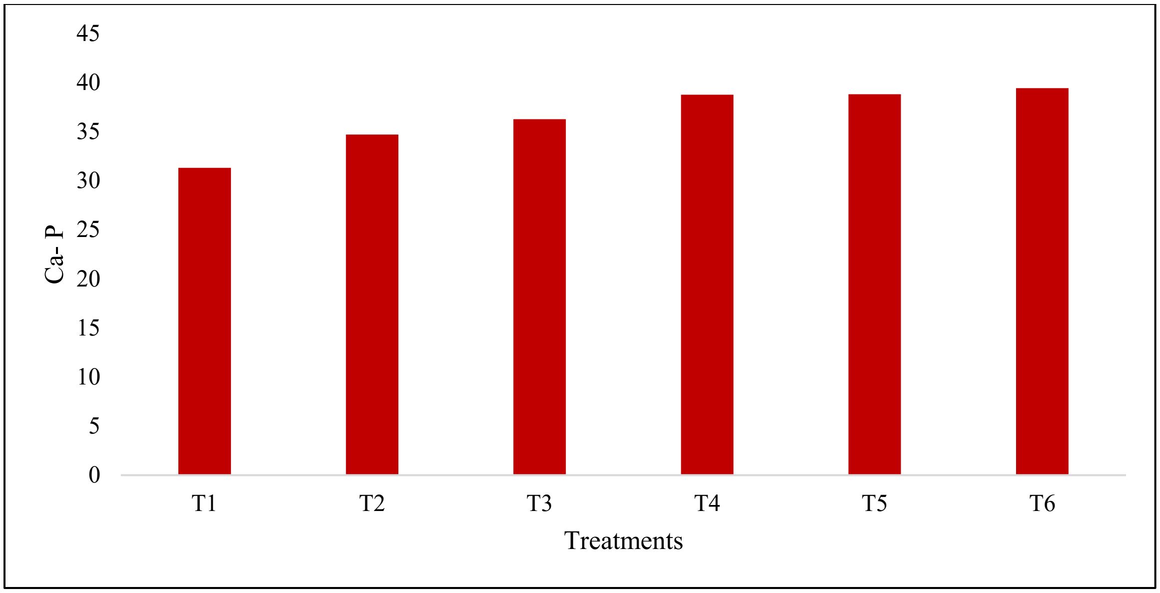


Fig. 5.11. Effect of long term application of fertilizers and manure on distribution of Ca-P (mg kg^{-1})

5.1.4.5 Calcium phosphate

Except for saloid bound phosphorus, Ca-P fraction ranked last among the total inorganic P fractions because of the acidic pH of the experimental soil. The effect of liming in treatment T6 raised Ca-P fraction over FYM applied plot which may produce large variety of organic acids and caused a frequent solubilisation of native as well as applied P, as shown in table 4.7 and fig. 5.11. Bhattacharyya *et al*., 2015, reported similar finding. Sharma *et al*. (2009) also reported an increase in the Ca-P fraction as a result of continual manuring.

5.1.5 Relationship between different fractions of phosphorus and zinc

Correlation analysis was carried out with the values of different fractions of zinc and different fractions of phosphorus in order to understand the relative effect of different P fractions adversely on zinc fractions (Table 4.8). Correlation analysis concluded that most of the P fraction is negatively correlated with various Zn fractions. Operation of dynamic equilibrium between different soil phosphorus and zinc fractions indicates that the depletion of phosphorus concentration in the pools which are readily available to plants *viz.* water soluble plus extractable is replenished from the other pools phosphorus like calcium phosphate and sesquioxide occluded phosphate. Mandal and Mandal (1990) investigated the effect of different levels of P application on the transformation of native and applied zinc and, found a decrease in the water soluble plus exchangeable and organic complexed forms of native soil zinc, as well as an increase in the amorphous and crystalline sesquioxide bound forms. Results of our experiment also corroborate with the findings of Mishra *et al*. (2009), Shambhavi (2011) and Okoli *et al*. (2016).

5.2 INTERACTION OF PHOSPHORUS & ZINC UNDER DIFFERENT LEVELS OF NATIVE P & ZN SOILS WITH RESPECT TO NUTRIENT UPTAKE AND YIELD OF RICE

This section discusses the findings of a pot culture experiment done at the Regional Agricultural Research Station, Pattambi.

5.2.1 Growth and yield parameters

5.2.1.1 Effect of soil, phosphorus and zinc on growth parameters

Phosphorus and zinc application influenced diverse soil types and had significant effect on soil type S_2 in terms of growth parameters such as plant height and the number of productive tillers. The remaining soil types were on par to the second soil. These findings corroborate those of Pongrac *et al*. (2018), who reported that plants grown in Mylnefield soil grew the best while those cultivated in Hartwood soil grew the worst.

The application of phosphorus up to 50 mg kg^{-1} had significant effect on plant height but higher paddy height of 108.62 cm was noted at 100 mg kg^{-1} of P application (Table 4.9 and fig. 5.12). Zinc levels influenced plant height significantly and 10 mg kg^{-1} zinc application resulted in higher (109.85 cm) value and height dropped after that. Plant height was not affected by the interaction of P and Zn. However treatment combination of $P_{100}Zn_{10}$ registered highest height (112.3 cm). Because of the differing phosphorus levels, there was a significant difference in the number of productive tillers (Table 4.10 and fig. 5.13). The number of productive tillers increased significantly up to 100 mg kg^{-1} of phosphorus application and the application of 15 mg kg^{-1} zinc also resulted in the greatest number of productive tillers. The interaction effect of phosphorus and zinc on the number of productive tillers had no significant effect, however, the application of 100 mg kg^{-1} P + 15 mg kg^{-1} Zn produced higher number of productive tillers (34.6).

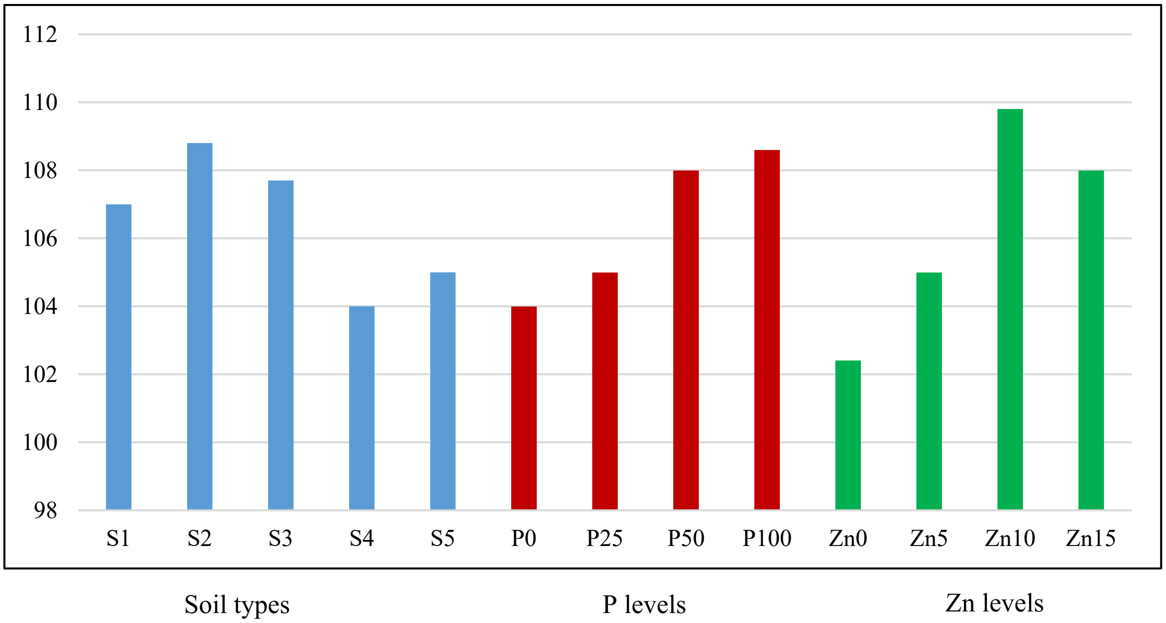


Fig. 5.12. Effect of soil, phosphorus and zinc levels on plant height of paddy

Higher phosphorus levels stimulated better root growth and proliferation, allowing for better nutrient and water absorption from the larger soil volume. This resulted in an increase in plant height and the number of productive tillers, which helped in the effective interception of light, resulting in an increase in dry matter production. These findings are consistent with Lu and Barber (1985) found that increasing the P level resulted in increased wheat tiller density, leaf number and area, plant height, grains spike^{-1} and eventually biomass production.

The increased plant height and number of tillers due to zinc application could be related to increased meristematic cell activity and cell elongation, which enhances the formation of growth-promoting substances like auxin at various growth stages and aids in rice growth and yield (Devarajan and Krishnasamy, 1996). Plant height was also reported to be greater with Zn and nitrogen application by Yadav and Verma (1991). It is possible that the increased shoot length in zinc-treated plots is due to auxin production. Role of zinc as an activator of many enzymes which affect carbohydrate and protein synthesis directly or indirectly thus attributed to its increased plant height as a result of its application.

5.2.2 Effect of phosphorus and zinc on yield attributes and yield

The impact of phosphorus and zinc on soil revealed that thousand grain weight, grain yield and straw yield all had significant effect on soil type 2 (S_2). These findings are consistent with those of Pongrac *et al.* (2018) who reported that plants grown in Hartwood soil differed from those grown in Mylnefield or Balruddery soils more than plants grown in Mylnefield and Balruddery soil which differed from each other after principal component analysis, which took all measured plant responses like dry matter.

The application of various levels of phosphorus significantly increased thousand grain weight up to 100 mg kg^{-1} P. (Table 4.11 and fig. 5.13). Zinc application at 15 mg kg^{-1} produced similar results outperforming the control, 5 and 10 mg kg^{-1}. The interaction effect on thousand grain weight (23.53 g) was significant by combining phosphorus and zinc at 100 mg kg^{-1} P + 15 mg kg^{-1} Zn. The remaining two and three level interactions were considered to be non-significant.

Increasing P levels increased paddy grain yield up to 100 mg kg^{-1}, while significant higher grain yield was noted at 50 mg kg^{-1}, similarly, the influence of zinc levels on grain yield was highest at 15 mg kg^{-1} which was on par with 10 mg kg^{-1} Zn (Table 4.13 and fig. 5.14). The combined effect of zinc and phosphorus significantly increased paddy grain production (Table 4.14). The treatment combination of 5 mg kg^{-1} Zn with 50 mg kg^{-1} P significantly increased grain yield (50.5 g pot^{-1}) compared to lower levels of Zn and P, but the highest grain yield P (57.27 g pot^{-1}) was observed in 15 mg kg^{-1} Zn + 100 mg kg^{-1}, which could be due to a synergistic effect between these two nutrients at desired concentrations in soil.

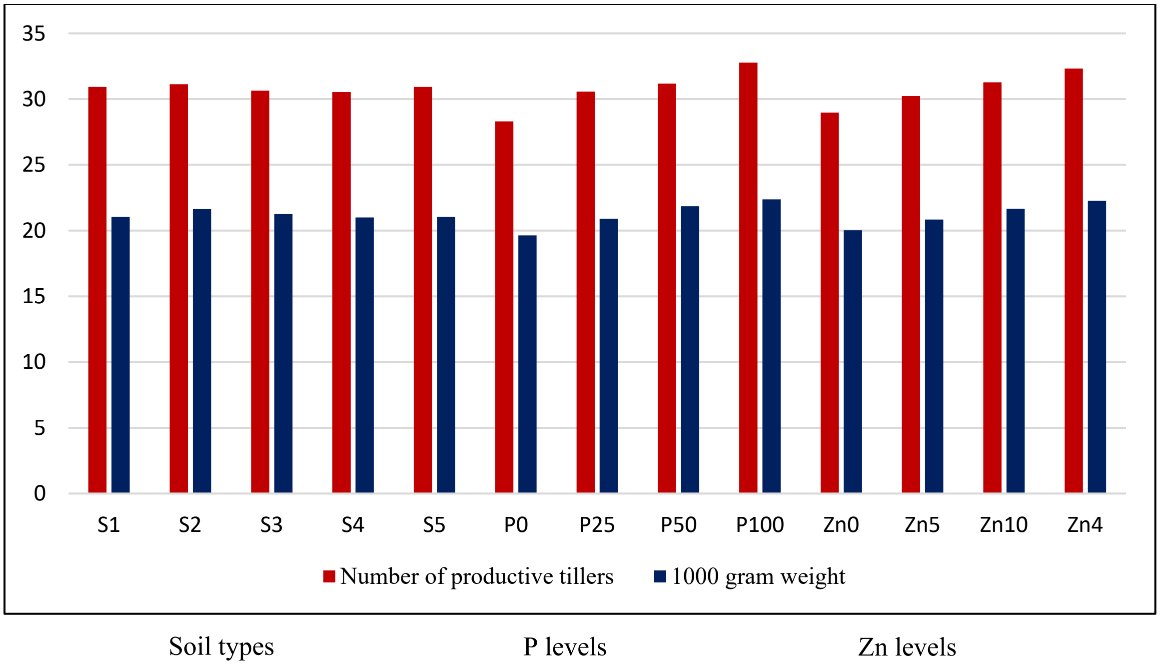


Fig. 5.13. Effect of soil, phosphorus and zinc levels on number of productive tillers per plant and test weight of paddy

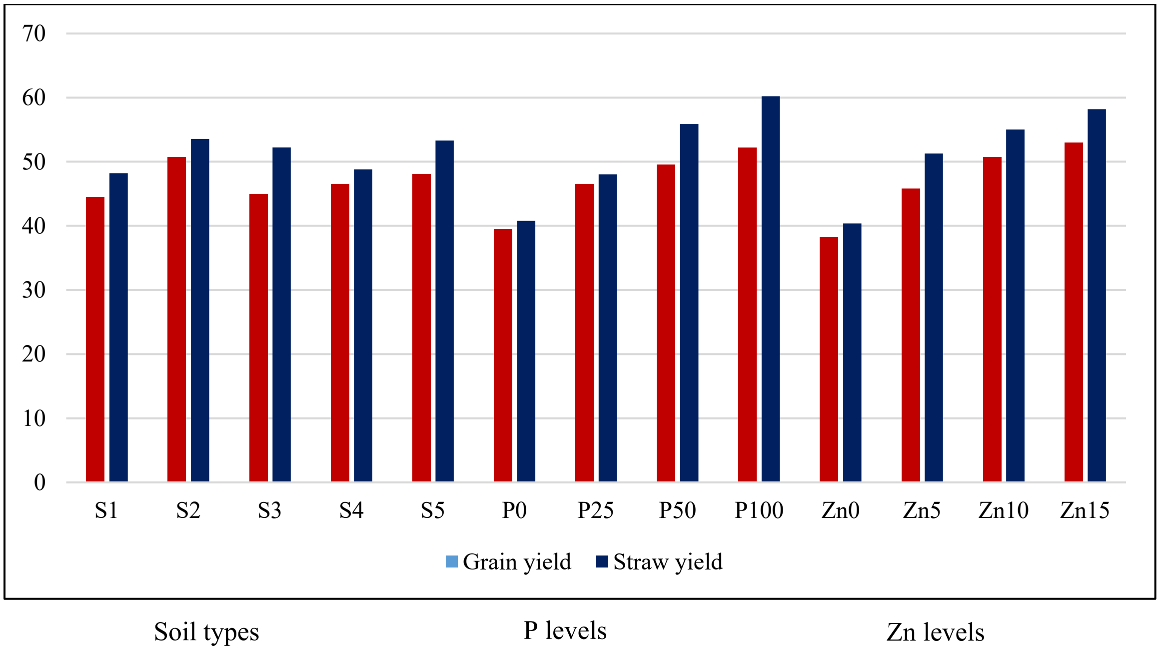


Fig. 5.14. Effect of soil, phosphorus and zinc levels on grain and straw yield of paddy

The application of 100 mg kg^{-1} phosphorus resulted in significantly higher straw production (60.22 g pot^{-1}). Similarly, increasing zinc levels increased the straw yield significantly, and applying zinc at 15 mg kg^{-1} resulted in a greater straw yield (58.19 g pot $^{-1}$). Computation of analysis of variance found significance on individual effects of soil type, P and Zn level and non-significance on remaining two way and three way interactions (Table 4.15 and fig. 5.14).

The increase in 1000 grain weight may be attributable to an increase in accessible phosphorus during the early stages of growth, when it is most needed. Thus, higher phosphorus levels ensure that it is available in sufficient quantities and plays a vital role in carbohydrate synthesis more efficiently. The findings are consistent with those obtained by Sharma and Bhardwaj (1998).

The increasing thousand grain weight due to increased zinc doses can be explained as zinc addition increased zinc availability, also zinc is a key substrate in photosystem II of photosynthesis and plays a significant role in the energy metabolism process of plants. Thus, enhanced zinc availability and efficient absorption resulted in a vigorous metabolism in the wheat plant, thus raising seed test weight. Verma and Minhas (1987) found similar results.

Phosphorus application had significant effect on yield attributes and higher phosphorus levels boosted yield components by increasing plant height and increasing the number of tillers. As a result, favoured the development of big sinks. The findings of the current investigation are consistent with those of Mahapatra and Srivastava (1984), Latchanna *et al*. (1989), Annadurai and Palaniappan (1994) and Singh *et al*. (1999). Higher phosphorus doses aided in generating better root growth and proliferation, resulting in increased nutrient uptake and a higher number of productive tillers and higher yields. (Annadurai and Palaniappan, 1994).

The greater grain yield attained with higher Zinc levels in this study is similar to the finding of Jena *et al*. (2006), Khanda and Dixit (1996) who found that applying zinc to the soil enhanced yield and yield characteristics, possibly due to better N, P and other nutrient absorption. Thus in turn increased metabolic activity by activation of many enzymes involved in the plant growth.

The combined effect of zinc and phosphorus significantly increased paddy grain production (Table 4.14). In comparison to lower levels of Zn and P, applying 15 mg kg^{-1} of Zn with 100 mg kg^{-1} of P enhanced grain production. This could be due to a synergistic effect among two nutrients in the soil at the right concentration. In terms of higher plant development, plants respond to a better nutritional environment. The cumulative influence of plant growth parameters and yield qualities such as number of productive tillers and number of filled grains can be linked to higher grain production. Physiological role of different nutrient enhanced yield and yield characteristics. Similar findings were also discovered by Sachdev *et al*. (1992), Ahmed *et al*. (1986), Gupta and Vyas (1994), Choudhary *et al*. (1998) in crops like chickpea, soyabean and cowpea.

5.2.3 Influence of varied levels of soil, phosphorus and zinc on nutrient content and their uptake by paddy

Nutrient management requires a thorough understanding of the nutrient composition of rice at various phases of development.

Considering phosphorus content in straw and grain of paddy, total P uptake soil type 2 (S_2) recorded highest values and remaining soil types were on par (Table 4.16, 4.18, 4.19 and fig. 5.15, 5.16). Similarly Pongrac *et al*. (2018) found that plants grown in Mylnefield soil had the best growth and the highest shoot P concentrations, which was due to the highest soil P concentration. Higher zinc content on paddy grain and straw and total Zn uptake were more in the third soil type (S_3), this could be attributable to high zinc availability in the soil, and there was significant difference on zinc content in paddy grain and uptake by the application of various quantities of phosphorus and zinc in different soil types but zinc content in straw was statistically non-significant. Pongrac *et al*. (2018) opined that zinc concentration in three different soil types showed even more complex relationships. Balruddery soil had the lowest total Zn and DTPA-Zn concentrations although plants growing in Balruddery soil did not have the lowest shoot Zn concentrations. Mylnefield soil, on the other hand, had the highest total Zn content and

DTPA-Zn values, which were similar to those found in Hartwood soil. They also suggested that low shoot Zn concentration could be due to low organic matter concentration in Mylnefield soil, these findings are in consistent with previous findings that low organic matter content limits plant Zn concentration. (Ward *et al.* 1963; Broadley *et al*. 2007).

With increasing amounts of phosphorus up to 100 mg kg^{-1}, significant increase was observed on phosphorus content of paddy grain and straw. This could be justified as increased phosphorus concentration in soil solution as a result of increased phosphorus application increased biological activity as a result of solubilisation. Increased phosphorus uptake is due to higher phosphorus concentration in grain and straw, as well as higher crop yields. Similar results have also been reported by Nandal *et al*. (1986), Raju *et al*. (1991), Enania and Vyas (1994).

Zinc application had a negative impact on the phosphorus content of paddy grains and straw. The use of zinc reduced the amount of phosphorus in straw and grains. It could be related to antagonistic action of zinc on phosphorus. Higher soil Zn concentrations generate insoluble zinc phosphate, which reduces phosphorus uptake by grain and straw thus lowering phosphorus content in grain and straw. These findings were similar to those reported in previous investigations by Gupta and Gupta (1984), Singh and Tiwari (1992), Enania and Vyas (1994).

The addition of phosphorus improved total phosphorus uptake up to 100 mg kg^{-1} P, which was significantly higher than the control, 25 and 50 mg kg^{-1} but it had a negative effect on higher zinc level. It could be related to antagonistic action of phosphorus on Zn (Table 4.19 and fig. 5.16).

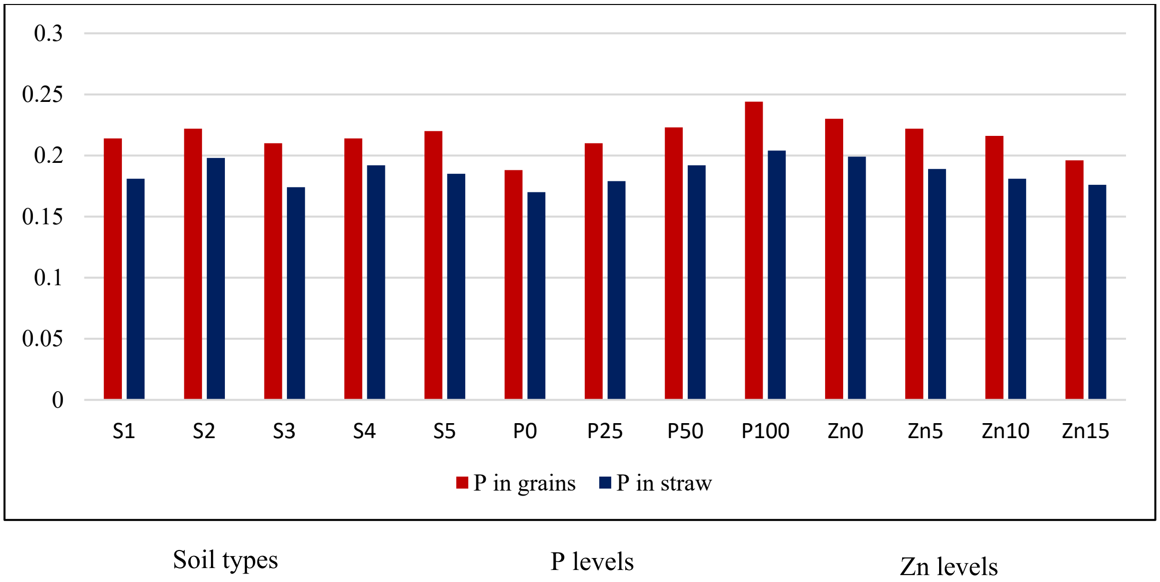


Fig. 5.15. Effect of soil, phosphorus and zinc levels on phosphorus content in grain and straw of paddy

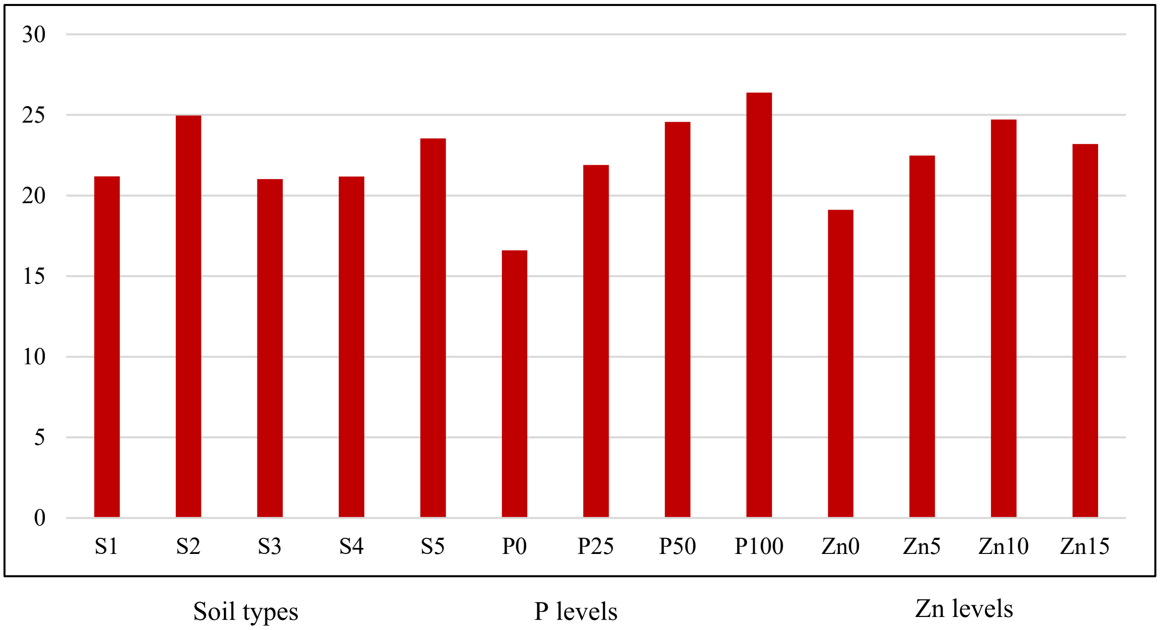


Fig. 5.16. Effect of soil, phosphorus and zinc levels on total phosphorus uptake of paddy

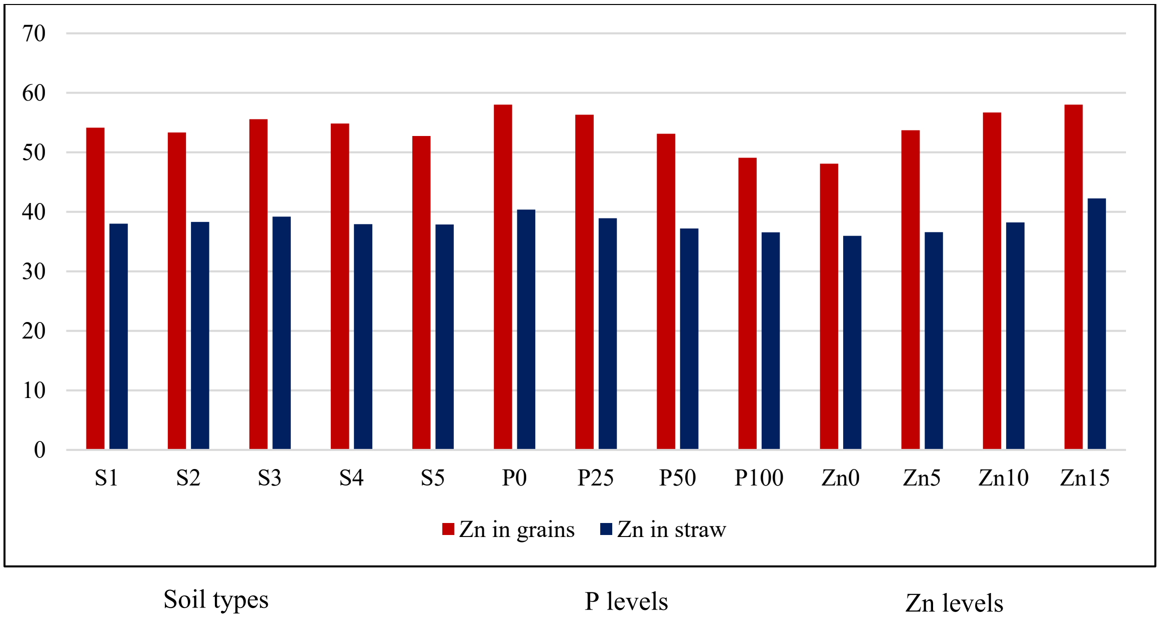


Fig. 5.17. Effect of soil, phosphorus and zinc levels on zinc content in grain and straw of paddy

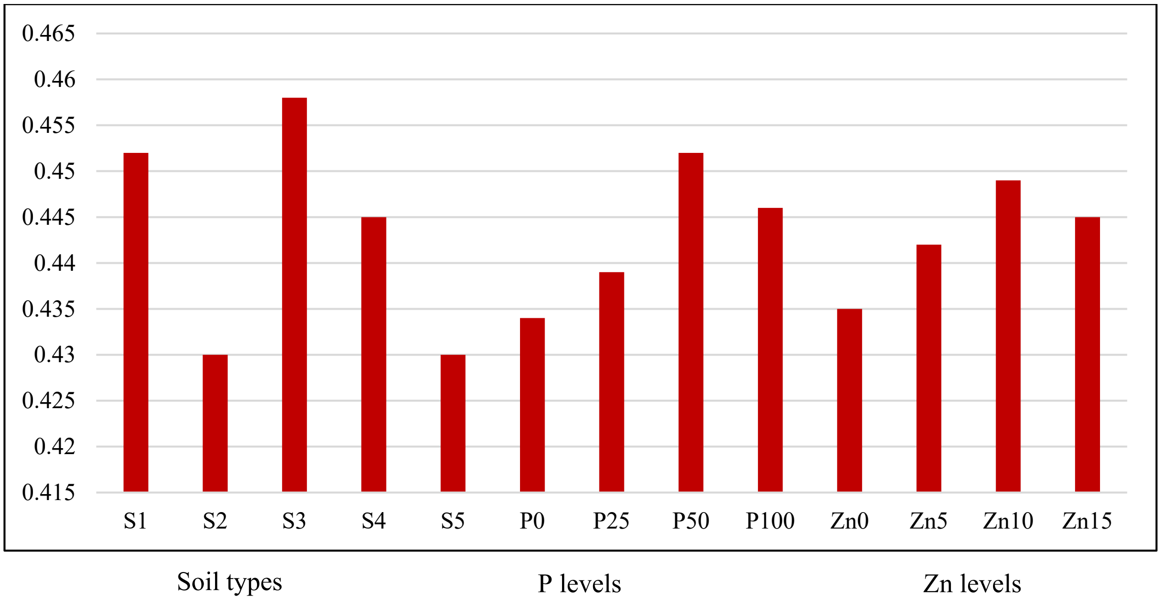


Fig. 5.18. Effect of soil, phosphorus and zinc levels on total zinc uptake of paddy

Higher concentration of P in the soil produce insoluble zinc phosphate, which reduces zinc uptake and as a result lowers zinc content in grain and straw. Zinc uptake increased to some extent due to increased crop biomass and decreased zinc phosphate formation. Similar findings have been reported by Enania and Vyas (1994), Reddy and Ahlawat (1998), Singh and Ram (1992). The retention of greater Zn in the roots at high P levels was likely due to inactivation of Zn in roots, as reported by Dwivedi and Randhawa (1974) or enhanced binding of Zn in root cell walls, resulting in less Zn transport to the upper portion of the plant (Youngdahl *et al*., 1977).

With increasing zinc levels up to 15 mg kg^{-1} Zn a significant rise in zinc content was observed in grain and straw of paddy (Table 4.22, 4.24 and fig. 5.17). This is due to an increase in the zinc concentration in soil solution, which resulted in increased zinc uptake from the solution and as a result increased zinc content in grain and straw. With the application of zinc, the overall uptake of zinc increased significantly as the content of grain and straw increased and indirectly increase in grain and straw yield. Similar findings have been reported by Malewar *et al.* (1990), Gangwar and Singh (1991), Devarajan and Palaniappan (1995), Singhal and Rattan (1999).

The interaction of zinc and phosphorus had significant effect on phosphorus content of paddy grains and the zinc content of both grains and straw (Table 4.17, 4.20, 4.23 and 4.25). P content in grain increased as P levels was raised, but Zn content declined and when Zn levels increased, Zn content in grain increased while P content in grain decreased. Similarly, total P uptake is influenced by the Zn-P interaction. Positive P uptake was observed up to higher levels of P and negative effect at higher Zn levels. This can be explained by antagonistic effect of nutrients have on one another. These findings are identical to Gupta and Gupta (1984), Yadav *et al.* (1985), Enania and Vyas (1994), Reddy and Ahlawat (1998).

Correlation examining on the effect of phosphorus and zinc addition on total phosphorus uptake in paddy showed significant positive correlations in all types of soil, except for soil type S_3, which had a non-significant positive correlation (Table 4.21). This can be explained based on high zinc content of the soil, thus application of phosphorus leads to formation insoluble zinc phosphate complex that reduce the phosphorus availability to plants and thus reducing uptake (Nair *et al*., 1992 and Gour 1994). Application of zinc to already containing high zinc fertility gradient is not going to play any favorable response in phosphorus uptake that was confirmed by Singhal and Rattan (1999). S_2 had non-significant influence on zinc uptake, which could be attributed to the presence of high phosphorus content, which affects zinc uptake (Table 4.27). The magnitude of total zinc uptake due to applied P reduced rapidly when soil available P status and applied P levels both increased. Similar results were achieved by Dhillon *et al*. (1987). The lower uptake per unit increase in applied P in high P soils could be ascribed to a higher P concentration in the soil-plant system, which has an antagonistic effect on Zn availability to plants, as well as an imbalance in nutrient availability and absorption. Cakmak and Marschner (1987) investigated the effect of varying P and Zn supplies on uptake and concentrations of P and Zn in cotton (*Gossypium hirsutum* L) and found a similar result by increasing P levels had no significant influence on total Zn concentrations in plants at a given Zn supply.

Application of different phosphorus levels helps to study transformation of various zinc fractions under P application especially transformation to plant available zinc fraction that helps in their nutrition under long term fertilizer experiment. Also studying optimal dose of zinc and phosphorus helps to obtai maximum grain yield under different native phosphorus and zinc content.

Summary

6. SUMMARY

A field experiment was conducted to study the effect of fractions of zinc under different phosphorus levels under long term fertilizer and manure application in soil. The experiment consisted of six treatments laid out in randomised block design with four replications. In addition a pot culture experiment was also carried out to study the interactions of phosphorus and zinc in soils of different fertility gradient that is soil containing low, medium and high phosphorus content and soil containing low, medium and high zinc content. The salient findings of the field experiment are summarised below.

- Significantly higher available nitrogen content of (245 kg ha^{-1}) soil was registered in T5 which received 100% NPK+ FYM and lowest available nitrogen content (181 kg ha^{-1}) was noted in control plot T1.
- The available phosphorus content in soil varied significantly in all the treatment combination and treatment T4 (150% NPK) registered higher phosphorus content 19.35 kg ha^{-1}.
- Available potassium content (85.99 kg ha^{-1}) registered significant highest value in treatment T4 followed by T5 which received 150% NPK and 100% NPK+FYM, respectively. Lowest potassium content was observed in control.
- Plots treated with lime in T6 registered significantly higher amount of exchangeable calcium (171.7 mg kg^{-1}) in the soil. The exchangeable magnesium content varied significantly among treatments and highest content was noted in treatment T5 with application of FYM (30.64 mg kg^{-1}) than those treated with chemical fertilisers alone.
- Significantly higher available sulphur content of 6.57 mg kg^{-1} was observed in T5 (100% NPK+ FYM) and lowest in T1 where no fertilisers was applied.
- The micronutrient contents were higher in T5 where integrated application of organic and inorganic sources of nutrients was applied and respective values for Fe, Cu and Zn are 254.74, 8.78 and 1.32 mg kg^{-1} and significantly lower values were observed in control plot.

- Long term fertilizer application influenced phosphorus content of grain and straw and total P and Zn uptake of paddy. Higher P content in grain and straw were recorded in the treatment T5 (100% NPK + FYM) and their respective values are 0.302%, 0.192%. Similarly zinc content of grain and straw were higher in T5 and respective values are 28.35 mg kg^{-1}, 23.25 mg kg^{-1}. Total P (18.95 kg ha^{-1}) and Zn uptake (170.51 g ha^{-1}) of paddy were found to be significantly higher in FYM applied plot.
- Among different Zn fractions water soluble plus extractable (1.55 mg kg^{-1}), organically bound Zn (2.21 mg kg^{-1}), crystalline sesquioxide Zn (1.34 mg kg^{-1}) and total zinc (17.38 mg kg^{-1}) significantly increased with conjoint application of fertilisers with FYM (T5). While amorphous sesquioxide Zn registered higher value of 4.45 mg kg^{-1} in control plot.
- Different P fractions increased with increasing graded dose of fertiliser and higher content of saloid-P (8.88 mg kg^{-1}), Al-P (112.35 mg kg^{-1}), Fe-P (190.43 mg kg^{-1}) and sesquioxide occluded P (62.94 mg kg^{-1}) were observed in treatment T5 (100% NPK + FYM). However greater amount of calcium phosphate fraction of 39.11 mg kg^{-1} was noted lime treated plot T6.

The findings of pot culture experiment are summarised below

- Higher plant height of 108.79 cm was noted on soil sample 2 (S_2) due to application of phosphorus at the rate of 100 mg kg^{-1}. Similarly, the significant increase in plant height of 97 cm was registered due to application of zinc at the rate of 10 mg kg^{-1}.
- Significantly higher number of productive tillers per pot (30.92) was noted on soil sample 2 (S_2) by addition of phosphorus at the rate of 100 mg kg^{-1}. Similarly, the higher number of tillers (21.4) was registered due to application of zinc at 15 mg kg^{-1} Zn.
- Significantly more thousand grain weight (21.63 g) was recorded on soil sample 2 (S_2) due to application of phosphorus at 100 mg kg^{-1} and zinc at 15 mg kg^{-1} having respective values of 22.38 and 22.26 g. Interaction of phosphorus and zinc 100 mg

kg^{-1} P +15 mg kg^{-1} Zn was found to be significant on thousand grain weight (23.53 g).

- Highest grain yield was noted on soil sample 2 (S_2) by the application of 100 mg kg^{-1} (52.24 g pot^{-1}) of phosphorus but highest significant yield was obtained at 50 mg kg^{-1} of phosphorus application. The effect of zinc on grain yield (52.97 g pot^{-1}) was significantly higher at 10 mg kg^{-1} of zinc. Interaction effect of P and Zn was significant on grain yield and highest grain yield (57.27 g pot^{-1}) was registered with 100 mg kg^{-1} P + 15 mg kg^{-1} Zn application.
- The straw yield registered high value on soil sample (S_2) due to application of phosphorus at 100 mg kg^{-1} and zinc application of 10 mg kg^{-1} with respective values of 60.22 g pot^{-1} and 58.19 g pot^{-1}. Two way phosphorus and zinc interaction were non-significant on paddy straw yield along with soil x phosphorus, soil x zinc and phosphorus x soil x zinc.
- The phosphorus content of grain and straw of paddy was highest on soil sample 2 (S_2) and application of higher phosphorus levels varied significantly on P content in grain and paddy and respective values are 0.244%, 0.204% due to application of 100 mg kg^{-1} P. Zinc application had antagonistic effect and adversely affected paddy straw and grain P content and highest values for grain (0.23%) and straw (0.199%) were registered for control. P and Zn interaction had statistical significance on P in grains (0.26%) at combination of $P_{100}Zn_0$, remaining two way and three way interactions were non-significant.
- Influence of P and Zn on different soil types found that mean values of zinc content of paddy straw was statistically non-significant, but zinc content of third soil sample (S_3) were 55.56 mg kg^{-1} and 39.2 mg kg^{-1}, respectively on grain and straw. Zinc addition increased significantly Zn content of both grain and straw up to 15 mg kg^{-1} with respective values of 58.01 mg kg^{-1} and 42.27 mg kg^{-1}. Increasing P levels adversely affected zinc content in grains and straw with highest values were registered in control. Irrespective of individual effects, when P and Zn interaction

was considered treatment combination of P_0Zn_{15} gave high zinc content in grains 61.28 mg kg $^{-1}$ and 44.19 mg kg^{-1} in paddy straw.

- Total phosphorus and zinc uptake of paddy significantly increased with both application of phosphorus and zinc. Highest phosphorus uptake (26.38 mg pot^{-1}) was observed at highest phosphorus level 100 mg kg^{-1}, but more zinc uptake (0.452 mg pot^{-1}) was observed at 50 mg kg^{-1} of P application. Irrespective of phosphorus levels 10 mg kg^{-1} zinc gave highest phosphorus and zinc uptake of 24.72 mg pot^{-1} and 0.449 mg pot^{-1}, respectively. Due to interaction effect highest phosphorus uptake (28.47 mg pot^{-1}) was noted in $P_{100}Zn_{15}$.

References

REFERENCES

Adhikari, T. and Rattan, R. K. 2007. Distribution of zinc fractions in some major soils of India and the impact on nutrition of rice. *Commun. Soil Sci. Plant Anal.* 38 (19-20): 2779-2798.

Agbenin, J. O. 2003. Zinc fractions and solubility in a tropical semi-arid soil under long-term cultivation. *Biol. Fertile. Soil* 37(2): 83-89.

Agrawal, S. and Singh, T. A. 1987. Inorganic soil phosphorus fraction and available phosphorus as affected by long term fertilization and cropping pattern in National Tarai. *J. Indian Soc. Soil Sci.* 35(1): 25-28.

Ahmed, U. I., Rahman, S., Begum, N., and Islam, M. S. 1986. Effect of P and Zn application on the growth, yield, P, Zn and protein content of mungbean. *J. Indian Soc. Soil Sci*. 34(2): 305-308.

Aiyer, R. S., Rajagopal, C. K., and Money, N. S. 1975. Available zinc, copper, iron and manganese status of the acid rice soils of Kuttanad, Kerala State. *J. Trop. Agric.* 13(1): 15-19.

AI-Abbas, A. H. and Barber, S. A. 1964. A Soil Test for Phosphorus Based upon Fractionation of Soil Phosphorus. Development of the soil test. *Soil Sci. Soc. Am. Proc*. 28(2): 221-224.

Alam, M. M., Ali, M. H., Amin, A. K. M. R., and Hasanuzzaman, M. 2009. Yield attributes, yield and harvest index of three irrigated rice varieties under different levels of phosphorus. *Adv. Boil. Res.* 3(3-4): 132-139.

Ali, S., Shah, A., Arif, M., Miraj, G., Ali, I., Sajjad, M., Farhatullah, M., Khan. Y., and Khan, N. M. 2009. Enhancement of wheat grain yield and yield components through foliar application of Zinc and Boron. *Sarhad J. Agric*. 25(1): 15-19.

Amanullah, I., Alwahibi, M. S., Elshikh, M. S., Alkahtani, J., Muhammad, A., Khalid, S., Ahmad, M., Khan, N., Ullah, S., and Ali, I. 2020. Phosphorus and Zinc Fertilization Improve Zinc Biofortification in Grains and Straw of Coarse vs. Fine Rice Genotypes. *Agron.* 10(8): 1155-1158.

Amanullah, I. and Inamullah, X. 2016. Residual phosphorus and zinc influence wheat productivity under rice–wheat cropping system. *Springer Plus* 5: 255-264.

Amanullah, I., Nawab, K. H., and Shah, Z. A. 2015. Preceding rice genotypes, residual phosphorus and zinc influence harvest index and biomass yield of subsequent wheat crop under rice-wheat system. *Pak. J. Bot.* 47(14): 265-273.

Anju, P. S., Susan, J., and Ray, S. B. 2020. Weighted Average Method in Evolving the Nutrient Status of Soils Under Cropping Systems Involving Tuber Crops in AEU 3 and AEU 9 of Kerala. *J. Root Crops* 45(2): 33-41.

Annadurai, K. A. and Palaniappan, S. P. 1994. Effect of phosphorus levels and DAP spray on lowland rice yield. *Madras Agric. J.* 81(11): 633-639.

Aparna, B. and Arya, N. V. 2014. A comparative study on soil chemical and biological regimes under coconut ecosystem in red loam and laterite soils of Trivandrum district-a farmer participatory active research. *Indian J. Sci. Res. Tech.* 2(5): 14-17.

Asadi, M., Saadatmand, S., Khavari-Nejad, R. A., Ghasem-Nejad, M., and Fotokian, M. H. 2012. Effect of Zinc (Zn) on some physiological characteristics of rice seedling. *Indian J. fundam. Appl. Life Sci*. 2(4): 89-96.

Babhulkar, P. S., Wandile, R. M., Badole, W. P., and Balpande, S. S. 2000. Residual effect of long-term application of FYM and fertilizers on soil properties (Vertisols) and yield of soybean. *J. Indian Soc. Soil Sci.* 48(1): 89-92.

Badrinath, M. S., Niranjana, K. S., and Nandkishore, T. G. 2005. Distribution and fractionation of phosphorus in soils of different agro-climatic zones of Karnataka (India). *Soil Sci. Soc. Am. J.* 43(3): 523-528.

Bahl, G. S. and Singh, A. 1997. The inorganic soil phosphorus fractions and available P as influenced by green manuring, cropping and P fertilisation. *J. Indian Soc. Soil Sci.* 45(1): 19-53.

Bansal, K. L. 1992. Potassium balance in multiple cropping system in Vertisol at Jabalpur. *J. Potassium Res*. 85(1): 52-58.

Bansal, S. K., Omanwar, P. K., and Bhardwaj, V. 1980. Effect of intensive cropping and fertilizer on organic carbon and total and available nitrogen in a soil from Pantnagar. *J. Indian Soc. Soil Sci*. 28(4): 519-521.

Begum, M. K., Kader, M. K., Hussain, S. M. A., and Hassan, K. N. 2002. Effect of seedling raising method & fertilizer combination on the yield of late boro rice. *Pak. J. Agron.* 1(2): 89-91.

Bhardwaj, G., Sharma, U., and Brar, P. S. 2019. A Review on Interactive Effects of Phosphorous, Zinc and Mycorrhiza in Soil and Plant. *Int. J. Curr. Microbiol. Appl. Sci.* 8(4): 2525-2530.

Bhardwaj, G., Sharma, U., Brar, P. S., and Kaushal, R. 2020. Effect of phosphorus, zinc and mycorrhizae application on growth and nutrient uptake in capsicum under protected conditions. *Int. J. Chem. Stud.* 8(2): 1993-1998.

Bhattacharyya, P., Nayak, A. K., Shahid, M., Tripathi, R., Mohanty, S., Kumar, A., Raja, R., Panda, B. B., Lal, B., Gautam, P., Swain, C. K., Roy, K. S., and Dash, P. K.

2015. Effects of 42-year long-term fertilizer management on soil phosphorus availability, fractionation, adsorption–desorption isotherm and plant uptake in flooded tropical rice. *Crop J.* 3(5): 387-395.

Bingham, F. T. 1963. Relation between phosphorus and micronutrients in plants. *Soil Sci. Soc. Am. J.* 27(4): 389-391.

Brar, B. S. and Vig, A. C. 1989. Forms of inorganic phosphorus in some benchmark soil of Punjab. *J. Agric. Biol.* 19(1): 17-21.

Bray, R. H. and Kurtz, L. T. 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil Sci.* 59(1): 39-45.

Brown, K. H. and Wuehler, S. E. 2000. Zinc and human health: results of recent trials and implications for program interventions and research. The Micronutrient Initiative, Ottawa, Canada.

Broadley, M. R., White, P. J., Hammond, J. P., Zelko, I., and Lux, A. 2007. Zinc in plants. *New Phytol*. 173(4): 677-702.

Bukvic, G., Antunovic, M., Popovic, S., and Rastija, M. 2003. Effect of P and Zn fertilisation on biomass yield and its uptake by maize lines (*Zea mays* L.). *Plant Soil Environ.* 49(11): 505–510.

Burleson, C. A. and Page, N. R. 1967. Phosphorus and zinc interactions in flax. *Soil Sci. Soc. Am. J.* 31(4): 510-513.

Burleson, C. A., Dacus, A. D., and Gerard, C. J. 1961. The effect of phosphorus fertilization on the zinc nutrition of several irrigated crops. *Soil Sci. Soc. Am. Proc.* 25(5): 365-368.

Cakmak, I. and Marschner, H. 1987. Mechanism of phosphorus-induced zinc deficiency in cotton. III. Changes in physiological availability of zinc in plants. *Physiologia Plantarum* 70(1): 13-20.

Chandrakala, M., Ramesh, M., Sujatha, K., Hegde, R., and Singh, S. K. 2018. Soil fertility evaluation under different land use system in tropical humid region of Kerala, India. *Int. J. Plant Soil Sci.* 24(4): 1-13.

Choudhary, M. M. U., Aktar, S. M. B., Hoque, M. S., and Hossan, M. M. 1998. Response of cowpea to N, P, K, S and Zn fertilization. *Ann. Bangladesh Agric.* 74(1): 35-40.

Confalonieri, R. and Bocchi, S. 2005. Evaluation of cropsyst for simulating the yield of flooded rice in northern Italy. *Eur J. Agron*. 23(5): 315–332.

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

Debnath, S., Pachauri, S. P., and Srivastava, P. C. 2015. Improving use efficiency of applied phosphorus fertilizer by zinc fertilization in Basmati rice-wheat cropping system. *Indian J. Agric. Res.* 49(5): 414-420.

Devarajan, R. and Krishnasamy, R. 1996. Effect of enriched organic manures on rice yield. *Madras Agric. J.* 83(5): 280-283.

Devarajan, R. and Palaniappan. 1995. Zinc and molybdenum on yield and nutrition of soybean. *Madras Agri. J.* 82(3): 188-189.

Dhillon, K. S., Yagodeen, B. A., and Vernichenko, V. A. 1987. Micronutrients and nitrogen metabolism. *Plant Soil* 103(1): 51-55.

Dhiman, S. 2007. Long term effect of integrated nutrient supply on zinc dynamics in rice-wheat cropping system in an acid Alfisol of Himachal Pradesh. M.Sc. (Ag.) Thesis, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, 147p.

Dwivedi, R. S. and Randhawa, N. S. 1974. Phosphorus response in relation to distribution and uptake of zinc in maize crop. In: Proceedings of Symposium on use of radioisotopes in studies of plant productivity, G.B. Pant Univ. Agric. Technology, Pantnagar, India. 14(1): 356–365.

El-Fouly, M. M., Fawzi, A. F. A., Abou El-Nour, E. A. A., Zeidan, M. S., and Firgany, A. H. 2015. Impact of long-term intensive cropping under continuous tillage and unbalanced use of fertilizers on soil nutrient contents in a small holding village. *African. J. Agric. Res*. 10(53): 4850-4857.

Enania, A. R. and Vyas, A. K. 1994. Effect of phosphorus and zinc application on growth, biomass and nutrient uptake by chickpea in calcareous soil. *Ann. Agric. Res.* 15(4): 397-399.

Fageria, N. K. 2007. Yield physiology of rice. *J. Plant Nutr*. 30(6): 843–879.

Fageria, N. K., Dos Santos, A. B., and Cobucci, T. 2011. Zinc nutrition of lowland rice. *Comm. Soil Sci. Plant Anal*. 42(14): 1719-1727.

Filgueiras, A. V., Lavilla, I., and Bendicho, C. 2002. Chemical sequential extraction in environmental solid samples. *J. Environ. Monit*. 4(6): 823-857.

Gangwar, K. S. and Singh, N. P. 1991. Influence of zinc application on concentration and uptake of zinc in lentil. *Indian J. Pulses Res*. 4(1): 57-64.

Garg, A. K. and Milkha, S. A. 2010. Effect of long term fertilizer management and crop rotation on accumulation and downward movement of phosphorous in semi-arid subtropical irrigated soil. *Commun. Soil Sci. Plant Anal*. 41(7): 848-864.

Geetha, T. and Balagopalan, M. 2010. A comparative evaluation of the soil micronutrient status in Eucalypt plantations of different rotations in Kerala. *Indian J. For.* 33(1): 49-54.

Ghanem, S. A. and Mikkelsen, D. S. 1987. Effect of organic matter on changes in soil zinc fractions in wetland soils. *Commun. Soil Sci. Plant Anal.* 18(11): 1217-1234.

Gharib, H. S., Zayed, B. A. A., Sorour, S. G. R., and Okasha, A. M. 2011. Effect of zinc and phosphorus fertilization on rice crop under saline soil conditions. *J. Plant Prod.* 2(5): 755-771.

Gladis, R., Joseph, B., Aparna, B., and Nagula, S. 2016. An Assessment of Micronutrients in Rice Ecosystems of Kasaragode District in Kerala. *Adv. Life Sci.* 5(20): 9271-9276.

Gour, S. L. 1994. Study of zinc and iron effect in growth and yield of fennel crop. M.Sc. (Ag.) Thesis, Rajasthan Agricultural University, Bikaner, 108 p.

Gupta, P. K. and Vyas, K. K. 1994. Effect of P, Zn and Molybdenum on yield and quality of soybean*. Leg. Res.* 17(1): 5-7.

Gupta, R. K., Arora, B. R., Sharma, K. N., and Ahluwalia, S. K. 2000. Influence of biogas slurry and farm yard manure application on changes in soil fertility under rice-wheat sequence. *J. Indian Soc. Soil Sci*. 48(3): 500-505.

Gupta, S. P. and Gupta, V. K. 1984. Influence of Zn on Ca, Mg, Na, K, P. nutrition of soybean (*Glycine max*) in sodic soils. *Indian J. Ecol*. 11(2): 236-242.

Hao, X. J., Cho, E. C., Scardera, G., Shen, Y. S., Bellet-Amalric, E., Bellet, D., Conibeer, G., and Green, M. A. 2009. Phosphorus-doped silicon quantum dots for all-silicon quantum dot tandem solar cells. *Sol. Energy Mater. Sol. Cells* 93(9): 1524-1530.

Hemalatha, S. and Chellamuthu, S. 2012. Impacts of long term fertilization on soil nutritional quality under finger millet: maize cropping sequence. *J. Environ. Res. Develop.* 7(4): 1571-1576.

Hye, M. A., Rahman, K. M. M., and Das, P. P. 2019. Contribution of zinc and phosphorus on yield phosphorus and zinc content in aman rice and distribution in post-harvest soil. *Horticult. Int. J*. 3(5): 209-212.

Islam, M. A., Islam, M. R., and Sarker, A. B. S. 2008. Effect of phosphorus on nutrient uptake of Japonica and Indica rice. *J. Agric. Rural Dev.* 6(1): 7-12.

Islam, M. N., Hoque, S., and Islam, A. 2005 Interactive effects of phosphorus and zinc in wheat, rice and mungbean. *J. Indian Soc. Soil Sci*. 53(2): 221-227.

Iwasaki, K. and Yoshikawa, G. 1990. Fractionation of copper and zinc in greenhouse soils. In *Proceedings of the Transactions of the 14th Internation Congress of Soil Science*. 2: 363-364.

Jackson, M. L. 1973. Soil chemical analysis. Prentice hall Pvt. Ltd., New Delhi.

Jagadeesh, B. R. 2000. Chemical and biochemical properties of soil subjected to permanent manurial and cropping schedule. M.Sc. (Ag.) Thesis, University of Agricultural Science, Bengaluru, 132p.

Jaggi, R. C. 1991. Inorganic phosphorus as related to soil properties in some representative soils of Himachal Pradesh*. J. Indian Soc. Soil Sci.* 39(3): 567-568.

Jaskulska, I., Jaskulski, D., and Kobierski, M. 2014. Effect of liming on the change of some agrochemical soil properties in a long-term fertilization experiment. *Plant Soil Environ*. 60(4): 146-150.

Jena, P. K., Rao, C. P., and Subbaiah, G. 2006. Effect of zinc management practices on growth, yield and economics in rice. *Crop Res.* 43(4): 326-328.

John, K. S., Bharathan, R., Nair, M. M., and Suja, G. 2012. Soil Based Nutrient Management Plan for Tuber Crops in Pathanamthitta District of Kerala. *J. Root Crops* 38(1): 51-51.

Katyal, V., Gangwar, K. S., and Gangwar, B. 2000. Yield stability in rice-wheat system under long-term fertilizer use. *Indian J. Agric. Sci.* 70(5): 277-281.

KAU [Kerala Agricultural University]. 2016. Package of practices Recommendations: Crops (15th Ed.). Kerala Agricultural University, Thrissur, 363p.

Kaushal, A. 1995. Forms of phosphorus in Typic Haplusterts and their availability to wheat under long term fertilizer application and intensive cropping. Ph.D. Thesis. Jawaharlal Nehru Krishi Vishwa Vidyalaya, 212p.

Kavitha, C. and Sujatha, M. P. 2015. Evaluation of soil fertility status in various agro ecosystems of Thrissur District, Kerala, India. *Int. J. Agric. Crop Sci.* 8(3): 328-338.

Khampuang, K., Lordkaew, S., Dell, B., and Prom-u-thai, C. 2020. Foliar zinc application improved grain zinc accumulation and bioavailable zinc in unpolished and polished rice. *Plant Prod. Sci.* 24(1): 94-102.

Khanda, C. M. and Dixit, L. 1996. Effect of zinc and nitrogen fertilization on yield and nutrient uptake of summer rice. *Indian J. Agron.* 41(3): 368-372.

Khan, S. U. T., Iqbal, A., and Fahad, S. 2016. Growth and productivity response of hybrid rice to application of animal manures, plant residues and phosphorus. *Front. Plant Sci.* 18(7): 1440-1446.

Khan, P. A., Memon, M. Y., Imtiaz, M. U., Depar, N. I., Aslam, M. U., Memon, M. S., and Shah, J. A. 2012. Determining the zinc requirements of rice genotype Sarshar evolved at NIA, Tandojam. *Sarhad J. Agric*. 28(1): 1-7.

Kher, D. 1993. Effect of continuous liming, manuring and cropping on DTPA extractable micronutrients in an Alfisol. *J. Indian Soc. Soil Sci.* 41(2): 366-367.

Krishnakumar, A. K. and Patty, S. N. 1992. Nutrition of Hevea. In: Sethuraj, M. R. and Mathew, N. M. (Eds.), Natural Rubber: Biology, Cultivation and Technology Elsevier, Amsterdam.

KSPB [Kerala State Planning Board]. 2013. Soil Fertility Assessment and Information Management for Enhancing Crop Productivity in Kerala. Kerala State Planning Board. Thiruvananthapuram, 514p.

Kumar, M. and Babel, A. L. 2011. Available micronutrient status and their relationship with soil properties of Jhunjhunu Tehsil, District Jhunjhunu, Rajasthan. *Indian J. Agric. Sci*. 3(2): 20-31.

Kumar, S. and Ramalu, S. 1991. Relative contribution of inorganic phosphorus fraction to the labile phosphorus status of soil and uptake by rice. *J. Indian Soc. Soil Sci*. 39 (2): 308-315.

Kumar, S. P., Rattan, R. K., and Singh, A. K. 2004. Chemical forms of zinc in soils and their contribution to available pool. *J. Indian Soc. Soil Sci.* 52(4): 421-425.

Langin, E. J., Ward, R. C., Olson, R. A., and Rhoades, H. F. 1962. Factors responsible for poor response of corn and grain sorghum to phosphorus fertilization: II. Lime and P placement effects on P-Zn relations. *Soil Sci. Soc. Am. J.* 26(6): 574-578.

Latchanna, A., Narasimhulu, H., and Satyanarayana, V. 1989. Effect of rates and source of phosphorus on wetland rice. *Indian J. Agron.* 34(2): 243-245.

Lu, N. and Barber, S. A. 1985. Phosphorus uptake rate and growth characteristics of wheat roots. *J. Plant Nutr.* 8(5): 449-456.

Mafi, S., Sadeghi, S. M., and Doroodian, H. 2013. Effect of zinc and phosphorus fertilizers on yield and component yield of rice (Hashemi). *Persian Gulf Crop Protect.* 2(2): 30-36.

Mahapatra, I. C. and Srivastava, V. C. 1984. Management of rainfed upland rice: problems and prospectus. *Oryza* 21(2): 20-37.

Mahmood, I. A. and Arshad, A. 2015. Response of direct seeded rice and wheat crops to phosphorus application with crop residue incorporation in saline-sodic soil. *Int. J. Agric. Biol.* 17(6): 1219-1224.

Mahmood, S. S. and Samadi, A. 2003. Determination of phosphorus fraction in some calcareous soil in tars province and their relationships with soils physic-chemical properties. *J. Sci. Technol. Agric. Natural Res.* 7(3): 119-114.

Malewar, G. V., Mangnale, M. M., and Malewar, V. 1990. Chemical composition and quality of mung genotype as influenced by zinc fertilization. *Leg. Res*. 13(2): 59-64.

Mandal, B. and Mandal, L. N. 1990. Effect of phosphorus application on transformation of zinc fraction in soil and on the zinc nutrition of lowland rice. *Plant Soil* 121(1): 115-123.

Mandal, B., Chatterjee, J., Hazra, G. C., and Mandal, L. N. 1992. Effect of preflooding on transformation of applied zinc and its uptake by rice in lateritic soils. *Soil Science* 153(3): 250-257.

Mandal, B., Haider, B. R., and Mandal, L. N. 1986. Distribution of different forms of zinc in some rice growing soils. *J. Indian Soc. Soil Sci*. 34(1): 488-492.

Mandal, B., Hazra, G. C., and Pal, A. K. 1988. Transformation of zinc in soils under submerged condition and its relationship with zinc nutrition in rice. *Plant Soil* 106(1): 121-126.

Mauriya, A. K., Maurya, D. C., Maurya, V. K., and Verma, R. K. 2015. Effect of zinc application methods on yield attributes, yield and nutrient uptake in wheat (*Triticum aestivum*) varieties under sodic soil. *Indian J. Agron.* 60(1): 82-86.

Miller, W. P., Martens, D. C., and Zeolazincy, L. W. 1986. Effect of sequence in extraction of trace metals from soils. *J. Soil Sci. Soc. Am*. 50(3): 598-601.

Mini, V. and Usha, M. 2015. Soil based nutrient management plan for Onattukara sandy tract of Kerala. *Asian. J. Soil Sci.* 10(1): 99-103.

Mishra, G. I., Sapre, S., and Tiwari, S. 2017. Zinc solubilizing bacteria from the rhizosphere of rice as prospective modulator of zinc biofortification in rice. *Rhizosphere* 3(1): 185-190.

Mishra, P., Singh, R., Srivastava, P. C., and Bali, R. 2009. Effect of continuous cropping and fertilization on zinc fractions and their contribution to plant uptake under rice-wheat system. *J. Indian Soc. Soil Sci.* 57(6): 167-171.

Mishra, S., Ali, A., Singh, A. K., Singh, G., and Singh, R. R. 2017. Response of late sown wheat to phosphorus and zinc nutrition in eastern Uttar Pradesh. *Ann. Plant Soil Res.* 19(1): 23-28.

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

Mousavi, S. R. 2011. Zinc in crop production and interaction with phosphorus. *Aust. J. Basic Appl. Sci.* 5(9): 1503-1509.

Nair, A. K., Subrahmanyan, K., Verma, B. S., and Singh, D. V. 1992. Response of Japanese mint to Fe and Zn at two fertility levels. *J. Indian Soc. Soil Sci.* 40(1): 873-875.

Nambiar, K. K. M. and Abrol, I. P. 1989. Long term fertilizer experiments in Indian overview. *Fertil. News* 34(4): 11-26.

Nandal, D. P., Malik, D. S., and Singh, K. P. 1986. Effect of phosphorus levels on nitrogen and phosphorus uptake by *kharif* pulses and available N and P content of the soil after harvest. *Agric. Sci. Digest* 6(3): 153-155.

Nandha, B., Srinivasan, R., and Jambulingam, P. 2014. Cutaneous leishmaniasis: knowledge, attitude and practices of the inhabitants of the Kani forest tribal settlements of Tiruvananthapuram district, Kerala, India. *Health Educ. Res.* 29(6): 1049-1057.

Nathan, A. S., Norman, R. J., and Wilson, C. E. 2005. Effect of zinc source and time of application time on zinc uptake and grain yield of flood- irrigated rice. *Agron. J.* 97(1): 272-278.

Nolovic, L. 1978. Geochemical studies on transition events in soils. Experimental study on the influence of trace elements on the behavior of iron and the evolution of fervic compounds in pedogenesis. *Soil Fertil*. 4(5): 580-593.

Okoli, N. H., Uzoho, B. U., Onweremadu, E. U., Nkwopara, U. N., and Irokwe, I. F. 2016. Zinc fractionation of soils of different parent materials and their relationships with some soil properties. *Malaysian J. Soil Sci.* 20(1): 49-66.

Olsen, S. R. and Sommers, L. E. 1982. Phosphorus methods of soil analysis part 2. Page, A. L. (Ed.). Am. Soc. Agron. Inc. Madison, Wisconsin, U.S.A.

Ozkutlu, F., Torun, B., and Cakmak, I. 2006. Effect of zinc humate on growth of soybean and wheat in zinc-deficient calcareous soil. *Commun. Soil Sci. Plant Anal.* 37(15-20): 2769-2778.

Parmavsivan, P. and Udaysoorian, C. 1991. Phosphorus status and distribution of different forms of phosphorus in major soil series of Madurai district, Tamiladu, Mysore. *J. Agric. Sci*. 25(1): 44-48.

Pathak, H. 2010. Trend of fertility status of Indian soils. *Curr. Adv. Agric. Sci.* 2(1): 10-12.

Pauli, A. W., Ellis J. R., and Moser, H. C. 1968. Zinc Uptake and Translocation as Influenced by Phosphorus and Calcium Carbonate. *Agron. J.* 60(4): 394-396.

Perez-Novo, C., Fernandez-Calvino, D., Bermudez-Couso, A., Lopez-Periago, J. E., and Arias-Estevez, M. 2011. Phosphorus effect on Zn adsorption–desorption kinetics in acid soils. *Chemosphere* 83(7): 1028-1034.

Peterson, G. W. and Corey, R. B. 1966. A modified Chang and Jackson procedure for routine fractionation of inorganic soil phosphates. *Soil Sci. Soc. Am. J.* 32(5): 73-76.

Phogat, V., Dahiya, D. J., and Singh, J. P. 1994. Effect of organic matter and water content on the transformation of native soil zinc. *J. Indian Soc. Soil Sci.* 42(2): 239-243.

Piper, C. S. 1966. Soil and plant Analysis, Hans Publications, Bombay.

Pongrac, P., McNicol, J. W., Lilly, A., Thompson, J. A., Wright, G., Hillier, S., and White, P. J. 2018. Mineral element composition of cabbage as affected by soil type and phosphorus and zinc fertilisation. *Plant Soil* 434(1): 151-165.

Prasad, B. and Sinha. N. P. 1980. Soil physical properties as influenced by long term use of chemical fertilizers under intensive cropping. *J. Indian Soc. Soil Sci*. 28(4): 516-518.

Prasad, J. and Mathur, B. S. 1997. Influence of long-term use of fertilizers, manures and lime on phosphate adsorption parameters in acid Afisols of Ranchi. *J. Indian Soc. Soil Sci.* 45(1): 24-27.

Prasad, J., Srivastava, N. C., and Mathur, B. S. 1996, Available nutrient status of continuously fertilized and cropped acid soil. *J. Indian Soc. Soil Sci*. 44(1):171-173.

Rahman, K. M., Chowdhury, M. A. K., Sharmeen, F., Sarkar, A., Hye, M. A., and Biswas, G. C. 2011. Effect of zinc and phosphorus on yield of *Oryza sativa* (cv. br-11). *Bangladesh Res. Pub. J.* 5(4): 315-358.

Rajasekharan, P. Nair, K. M. Rajasree, G. Sureshkumar, P., and Narayanan Kutty, M. C. 2013. Soil Fertility Assessment and Information Management for Enhancing Crop Productivity in Kerala. Kerala State Planning Board, Thiruvananthapuram, 514p.

Rajasekharan, P., Nair, K. M., Susan John, K., Suresh Kumar, P., Narayanan Kutty, M. C., and Ajith, R. N. 2014. Soil fertility-related constraints to crop production in Kerala. *Indian J. Fertil.* 10(11): 56-62.

Raju, M. S., Varma, S. C., and Ramaish, N. V. 1991. Effect of phosphorus in relation to FYM Vs Rhizobium inoculation on nutrient uptake by chickpea cultivars under rainfed condition. *Indian J. Agric. Res.* 25(1): 43-48.

Rasavel, M. and Ravichandran, M. 2013. Effect of zinc phosphorus and sulphur interactions on growth and yield of rice under neutral and alkali soils. *Int. J. Curr. Res*. 5(1): 65-67.

Rathore, G. S., Khamparia, R. S., Gupta, G. P., and Sinha, S. B. 1980. Availability of micronutrients in some alluvial soil and their effect on wheat. *J. Indian Soc. Soil Sci.* 28(2): 248-250.

Reddy, N. R. N. and Ahlawat, I. P. S. 1998. Response of chickpea (*Cicer arietinum* L.) genotypes to irrigation and fertilizers under late sown conditions. *Indian J. Agron*. 43(1): 95-101.

Rehim, A., Zafar-ul-Hye, M., Imran, M., Ali, M. A., and Hussain, M. 2014. Phosphorus and zinc application improves rice productivity. *Pak. J. Sci.* 66(2): 134-139.

Rupa, T. R., Rao, C. S., Rao, A. S., and Singh, M. 2003. Effects of farmyard manure and phosphorus on zinc transformations and phyto-availability in two Alfisols of India. *Bioresour. Technol*. 87(3): 279-288.

Sachdev, P., Chatterjee, S. R., and Deb, D. L. 1992. Seed yield, harvest index, protein content and amino acids composition of chickpea as affected by sulphur and micronutrient. *Ann. Agric. Res.* 13(1): 7-11.

Safak, C., Hikmet, S., Bulent, B., Huseyin, A., and Bihter, C. E. 2009. Effect of zinc on yield and some related traits of alfalfa. *Turk. J. Field Crops* 14(2): 136-143.

Sainio, P. P., Kontturi, M., and Peltonen. J. 2006. Phosphorus seed coating enhancement on early growth and yield components in oat. *Agron. J.* 98(1): 206-211.

Sarkunan, V. and Misra, A. K. 2006. Effect of Phosphorus and Zinc on yield and their uptake by rice. *Indian J. Agric. Chem*. 43(4): 233-237.

Sen, S. K., Dubey, P. N., and Chatterji, S. 2002. Forms and distribution phosphorus in some acid soil of Manipur and Assam. *Agropedology* 12(9): 122-126.

Shahane, A. A. and Shivay, Y. S. 2018. Effect of Rate and Sources of Nitrogen, Phosphorus and Zinc Fertilization on Potassium Nutrition of Rice in Different Cultivation Methods. *Int. J. Bioresour. Stress Manage*. 9(4): 460-467.

Shambhavi, S. 2011. Dynamics of micronutrient cations in soil-plant system as influenced by long-term application of chemical fertilizers and amendments in an acid Alfisol. Ph D. (Ag.) Thesis, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. 222p.

Shambhavi, S., Kumar, R., Padbhushan, R., Verma, G., Sharma, S. P., Sharma, S. K., and Sharma, R. P. 2020. Dynamics of Zinc under Long-Term Application of Chemical Fertilizers and Amendments by Maize–wheat Cropping Sequence in Typic Hapludalfs. *Soil Use Manag*. 36(3): 507-523.

Sharad, N. and Verma, T. S. 2001. Improvement in soil productivity with long-term lantana (*Lantana camara*) additions in rice-wheat cropping: Effects on some soil properties and zinc fractions. *J. Indian. Soc. Soil Sci.* 499(3): 462-466.

Sharma, A., Rawat, U. S., and Yadav, B. K. 2012. Influence of phosphorus levels and phosphorus solubilizing fungi on yield and nutrient uptake by wheat under sub-humid region of Rajasthan, India. *Int. Scholarly Res. Notices*, 9 p.

Sharma, C. M. and Bhardwaj, S. K. 1998. Effect of phosphorus and zinc fertilization on yield and nutrient uptake in wheat (*Triticum aestivum* L.). *Indian J. Agron.* 43(3): 426-430.

Sharma, G. D., Risikesh Thakur., Som Raj., Kauraw, D. L., and Kulhare, P. S. 2013. Impact of integrated nutrient management on yield, nutrient uptake, protein content of wheat (*Triticum aestivam*) and soil fertility in a typic haplustert. *Bioscan*. 8(4): 1159-1164.

Sharma, S., Verma, T. S., and Chander, G. 2009. Effect of Long-term Lantana Addition on Soil Phosphorus Fractions and their Relationship with Crop Yield and Phosphorus Uptake in Rice-Wheat Cropping in North West Himalayan Acid Alfisol. *J. Indian Soc. Soil Sci.* 579(2):161-166.

Sharma, U. and Paliyal, S. S. 2014. Effect of long-term use of fertilizers and organics on phosphorus dynamics in rainfed maize-wheat cropping system. *J. Indian Soc. Soil Sci.* 62(3): 216-223.

Sharma, U. and Subehia, S. K. 2014. Chemical fractions of zinc and their contribution toward its availability under long-term integrated nutrient management in rice–wheat sequence in an acidic Alfisol. *Commun. Soil Sci. Plant Anal*. 45(22): 2898-2910.

Sheeba, S. S., Pillai, P. S., and Mini, V. 2019. Assessment and rating of available nutrient status of rice soil in the southern laterites (AEU 8) of Kerala. *J. pharmacogn. Phytochem.* 36(9): 269-272.

Sheela, S., Koshi, M. M., and Korah, P. A. 1991. Distribution and forms of phosphorus in the kole soils. *Agric. Res. J. Kerala* 29(1-2): 150-200.

Shivay, Y. S. and Kumar, D. 2004. Micronutrients in South and South East Asia. *Proceedings of an International Workshop on Micronutrients in South and South-East Asia*, 8-11 September 2004, Kathmandu, Nepal. International Centre for Integrated Mountain Development, Nepal, pp. 199-204.

Shivay, Y. S. and Prasad, R. 2012. Zinc-coated urea improves productivity and quality of basmati rice (*Oryza sativa* L.) under zinc stress condition. *J. Plant Nutr.* 35(6): 928-951.

Sihag, O., Singh, J. P, Mehta, O. S., and Bhardwaj, K. K. 2005. Effect of integrated use of inorganic fertilizer and organic material on the distribution of different forms of phosphorus in soil. *J. Indian Soc. Soil Sci.* 53(1): 80-84.

Sims, J. R. and Johnson, G. V. 1991. Micronutrient soil tests. In: Mortvedt, J. J., Cox, F.R., Shuman, L. M., and Welch, R. M. *Micronutrient in Agriculture* (2nd ed.), SSSA, Madiosn, USA, pp 427-476.

Singaram, P. and Kothandaraman, G. V. 1994. Phosphorus fraction studies in the utilization of residual phosphorus forms important phosphorus source. *Madras Agric. J.* 81(6): 305-308.

Singhal, S. K. and Rattan, R. K. 1999. Zinc nutrients of soybean and mustard in relation to sources of zinc. *Ann. Agric. Res*. 20(1): 4-8.

Singh, A. K., Khan, S. K., and Nongkynrih, P. 1999. DTPA Extractable Zn, Cu, Mn and Fe in wet land rice soils and their availability to rice under submergence. *J. Indian Soc. Soil Sci.* 47(2): 381-386.

Singh, J. P., Phogat, V., and Dahiya, D. J. 1993. Effect of water regimes and organic matter on the transformation of applied zinc in soils. *J. Indian Soc. Soil Sci.* 41(3): 477-481.

Singh, L., Sharma, P. K., Jajoria, M., Deewan, P., and Verma, R. 2017. Effect of phosphorus and zinc application on growth and yield attributes of pearl millet (*Pennisetum glaucum* L.) under rainfed condition. *J. Pharmacogn. Phytochem.* 6(1): 388-391.

Singh, P. N. and Ram, H. 1992. Effect of phosphorus and sulphur on concentration and uptake of micronutrients in chickpea. *J. Indian Soc. Soil*. Sci. 40(2): 307-312.

Singh, S. K., Baser, B. L., Shyampura, R. L., and Narain, P. 2003. Phosphorus fraction and their relationship to weathering indices in Vertisols. *J. Indian Soc. Soil Sci*. 51(3): 247-251.

Singh, T. and Tiwari, K. N. 1992. Effect of zinc application on yield and nutrient content in chickpea. *Maharashtra Agric. J.* 79(2): 87-91.

Singh, V. P. and Sharma, Y. K. 2014. Phosphorus and Zinc Requirement of Rice under Saline Condition. *Int. J. Bioresour. Stress Manage.* 5(3): 395-399.

Sood, R. D. and Bhardwaj, R. K. 1992. Effect of liming and phosphorus fertilization on the P fractions in an acid Alfisol. *J. Indian Soc. Soil Sci.* 40(2): 299-301.

Spalbar, E., Mondal, A. K., and Rai, A. P. 2017. Distribution of zinc fractions and its association with soil properties in some rice-wheat growing soils of Jammu Region, India. *Int. J. Curr. Microbiol. Appl. Sci.* 6(4): 711- 721.

Stukenholtz, D. D., Olsen, R. J., Gogan, G., and Olson, R. A. 1966. On the mechanism of phosphorus-zinc interaction in corn nutrition. *Soil Sci. Soc. Am. J.* 30(6): 759-763.

Subbiah, B. V. and Asija, G. L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.* 25(6): 259-260.

Sugito, T., Yashida, K., and Nitta, T. 2001. Change of phosphorus forms in soils with organic matter application. *Jpn. J. Soil Sci. Plant Nutr.* 72(2): 195-205.

Suresh, L., Mathur, B. S., and Sinha, K. 1990. Effect of long term fertilization, manuring and liming of an Alfisoil on maize, wheat and soil properties – III. Forms of potassium. *J. Indian Soc. Soil Sci*. 38(1): 21-26.

Suresh, S., Subramanian, S., and Chitdeshwari, T. 1999. Effect of Long Term Application of Fertilizers and Manures on Yield of Sorghum (*Sorghum bicolor*)-Cumbu (*Pennisetum glaeum*) in Rotation on Vertisol under Dry Farming and Soil Properties. *J. Indian Soc. Soil Sci.* 47(2): 272-276.

Susan, J. K. and Venugopal, V. K. 2005. Optimizing the nutritional status of a Typic Kandiustult of Kerala, India, using sorption study. *Commun. Soil Sci. Plant Anal. 36*(17-18): 2329-2342.

Swaminathan, M. S. 2007. Can science and technology feed the world in 2025? *Field Crop Res*. 104(1): 3-9.

Tomar, V. K. 2003. Spatial distribution of inorganic and organic content of P and S as influenced by long term application of fertilizers and manure in Typic Haplustert. M.Sc. (Ag.) Thesis, Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur, 142 p.

Verma, T. S. and Minhas, R. S. 1987. Zinc and phosphorus interaction in a wheat-maize cropping system. *Fert. Res*. 13(1): 77-86.

Ward, R. C., Langin, E. J., Olson, R. A., and Stukenholtz, D. D. 1963. Factors responsible for poor response of corn and grain sorghum to phosphorus fertilization: III. Effects of soil compaction, moisture level and other properties on P-Zn relations. *Soil. Sci. Soc. Proc.* 27(3): 326–333.

Weldua, Y., Haileb, M., and Habtegebrielb, K. 2012. Effect of zinc and phosphorus fertilizers application on yield and yield components of faba bean (*Vicia faba* L.) grown in calcaric cambisol of semi-arid northern Ethiopia. *J. Soil Sci. Environ. Manage. 3*(12): 320-326.

Wei, Y., Shohag, M. J. I., and Yang, X. 2012. Biofortification and Bioavailability of Rice Grain Zinc as Affected by Different Forms of Foliar Zinc Fertilization. *PLoS ONE* 7(9): 421-428.

Wei, Y., Zhao, Y., Shi, M., Cao, Z., Lu, Q., Yang, T., Fan, Y., and Wei, Z. 2018. Effect of organic acids production and bacterial community on the possible mechanism of phosphorus solubilization during composting with enriched phosphate-solubilizing bacteria inoculation. *Bioresour. Technol.* 247(1): 190-199.

Wijebandara, D. M. D. I., Dasog, G. S., Patil, P. L., and Hebbar, M. 2011. Zinc fractions and their relationships with soil properties in paddy growing soils of northern dry and hill zones of Karnataka. *J. Indian Soc. Soil Sci.* 59(2): 141-147.

Williams, C. H. and Steinbergs, A. 1959. Soil sulphur fractions as chemical indices of available sulphur in in some Australian soils. *Aust. J. Agric. Res.* 10(3): 340-353.

Yadav, D. S., Antil, R. S., Kumar, V., and Singh, M. 1985. Effect of P and Zn application on drymatter yield and uptake of nutrient in cowpea (*Vigna unguiculata) Zeitschriff fiir P Flanzenernahruvg, Bodenkhde*. 148(3): 233-240.

Yadav, G. L. and Verma, J. K. 1991. Effect of irrigation regime, nitrogen and zinc fertilization on growth and yield of late- sown wheat (*Triticum aestivum*). *Indian J. Agron.* 36(7): 50-53.

Yaduvanshi, H. S., Tripathy, B. R., and Kanwar, B. S. 1985. Effect of continuous manuring on some soil properties of an Alfisol. *J. Indian Soc. Soil Sci*. 33(2): 700-703.

Yoseftabar, S. 2013. Effect of nitrogen and phosphorus fertilizer on spikelet structure and yield in rice *(Oryza sativa* L). *Int. J. Agric. Crop Sci.* 5(11): 1204-1208.

Youngdahl, L. J., Svec, L. V., Liebhardt, W. C., and Teel, M. R. 1977. Changes in ^{65}Zn distribution in corn root tissue with phosphorus variable. *Crop Sci*. 10(5): 66–69.

Zayed, B. A., El-Rafaee, I. S., and Sedeek, S. E. M. 2010. Response of Different Rice Varieties to Phosphorous Fertilizer Under Newly Reclaimed Saline Soils. *J. Plant Prod.* 1(11): 1479-1493.

Zhu, Y. G., Smith, S. E., and Smith, F. A. 2001. Zinc (Zn)-phosphorus (P) interactions in two cultivars of spring wheat (*Triticum aestivum* L.) differing in P uptake efficiency. *Ann. Bot.* 88(5): 941-945.

TRANSFORMATION OF ZINC IN SOIL AND ZINC NUTRITION IN LOWLAND RICE UNDER DIFFERENT LEVELS OF PHOSPHORUS

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ABSTRACT

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ABSTRACT

Phosphorus and zinc are two important essential elements required by the plants for various metabolic activities, functions and associated with membrane structure. Continuous use of phosphatic fertilisers with less zinc, aggravates zinc shortage also phosphorus applied will be accumulated in the soil leading to formation of zinc phosphate complex that affect zinc translocation to various plant parts. There are contradictions regarding phosphorus zinc interaction that is controlled by native P and Zn status.

In this context an investigation entitled “Transformation of zinc in soil and zinc nutrition in lowland rice under different levels of phosphorus” was conducted. Two separate experiments were carried out at Regional Agricultural Research Station, Pattambi. In the first experiment, fractions of Zn under different P levels was studied in Long Term Fertilizer Experiment (LTFE) with six treatments on rice in RBD with four replications. The soil samples were taken after the paddy harvest of *kharif* 2020 and sequential extraction of Zn (water soluble + extractable, organically bound Zn, amorphous sesquioxide Zn and crystalline sesquioxide Zn) and P (sol-P, Al-P, Fe-P, sesquioxide occluded P and Ca-P) were carried out. In the second experiment phosphorus and zinc interactions was studied using pot culture experiment on rice in factorial CRD with 3 replications. Samples from different locations of Palakkad district having native P <12, 12-24, >24 kg ha^{-1} and native Zn <1, 1-3, >3 mg kg^{-1} were collected. Sixteen treatment combinations were applied with 4 levels of P (0, 25, 50,100 mg kg^{-1}) as KH_2PO_4 and 4 levels of Zn (0, 5, 10, 15 mg kg^{-1}) as $ZnSO_4.7H_20$ through solution for studying the nutrient uptake and yield.

The results of fractionation study showed that continuous use of inorganic fertilisers with organic manures in T5 (100% NPK + FYM) increased various Zn fractions except amorphous sesquioxide Zn fraction which was highest in the control. Even though the increase in P application increased different P fractions significantly higher content was observed in 100% NPK+ FYM and these were proved to be beneficial towards increasing

different P fractions. But Ca-P fraction was more in the lime treated plot. Correlation study concluded that most of the phosphorus fractions have negative impact on different zinc fractions.

The results of the pot experiment elucidated that P and Zn application increased number of productive tillers and thousand grain weight but higher zinc application decreased plant height. Among different soils, soil type S_2 (P > 24 kg ha^{-1}) registered higher grain and straw yield, P in grain and straw, total P uptake of paddy, but Zn uptake and Zn in grain and straw were more in soil type S_3 (Zn > 3 mg kg^{-1}). Combined application of 100 mg kg^{-1} P and 10 mg kg^{-1} Zn recorded higher grain (57.27 g pot^{-1}) and straw yield (66.82 g pot^{-1}). Phosphorus application significantly increased the P content in grain and straw but zinc addition had antagonistic effect on them and treatment combination of $P_{100}Zn_0$ registered higher P content in grain (0.26%) and straw (0.214%). The Zn in grain and straw significantly increased by the application of zinc, but phosphorus was having an adverse effect and treatment combination of P_0Zn_{15} registered higher Zn content in grain (61.28 mg kg^{-1}) and straw (44.19 mg kg^{-1}). Total P and Zn uptake of paddy increased by the application of both phosphorus and zinc with higher content obtained at $P_{100}Zn_{15}$ (28.47 mg pot^{-1}) and $P_{50}Zn_{10}$ (0.458 mg pot^{-1}) treatment combination. Correlation study concluded that phosphorus and zinc application affected P and Zn uptake in high zinc containing soil (S_3) and high P soil (S_3), respectively.

In future this work can be used to study the changes in various P and Zn fractions under continuous crop removal, various management practices to mobilise fixed P in high phosphorus containing soil and also to study Q/I relationship of both phosphorus and zinc.