Influence of phosphorus and zinc on wheat yield and release behaviour of P and Zn in soils

By

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CERTIFICATE – I

This is to certify that this thesis entitled **"Influence of phosphorus and zinc on wheat yield and release behaviour of P and Zn in soils"** submitted for the degree of **Master of Science** in the subject of **Soil Science** of the **Chaudhary Charan Singh Haryana Agricultural University, Hisar** is a bonafide research work carried out by **Ms. Sunitha Fogat, Admission No. 2018A92M** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of these investigations have been fully acknowledged.

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CERTIFICATE – II

This is to certify that this thesis entitled **“Influence of phosphorus and zinc on wheat yield and release behaviour of P and Zn in soils”** submitted by **Ms. Sunitha Fogat**, **Admission no.2018A92M** to the **Chaudhary Charan Singh Haryana Agricultural University, Hisar** in partial fulfillment of the requirement for the degree of **Master of Science** in the subject of **Soil Science,** has been approved by the student's advisory committee after an oral examination on the same.

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CHAPTER- I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the world's most commonly consuming cereal grain crop. It is the cultural base or foundation of nourishment as it provides about 60% of proteins and 55% of the calories in the average human diet. It contains carbohydrate (60-80%), protein (approx.12%), also rich in catalytic elements, mineral salts and vitamins (B, K and E). During 2017-18, the total area, production and productivity of wheat in India were 29.65 million hectares, 99.87 million tonnes and 3368 kg ha^{-1}, respectively (Anonymous, 2020). Haryana is one of the leading wheat producing state of India and produced 10.76 million tonnes of wheat (10.77 % of total wheat production) from an area of 2.44 million hectares (8.22% of total area under wheat cultivation at national level) with productivity of 4412 kg ha^{-1} (2^{nd} highest after Punjab in India) during 2017-18. Yet, there is a wide difference between actual yield realized at farmer's field and potential yield of wheat. This gap can be bridged by maintaining deteriorating soil health through effective and judicious management of both macro and micronutrients in soil from organic and inorganic sources.

Indiscriminate and increased use of high analysis straight fertilizers in intensive cropping system, use of high yielding crop varieties, increase in cropping intensity and net negative nutrient balance leads to deficiency of not only the macronutrients (nitrogen, phosphorus and potassium), but also deficiency of micronutrients (%) in Indian soils like zinc (36.5), iron (12.8), copper (4.2), manganese (7.1) and boron (23.4) (Shukla and Behera, 2017). Phosphorus (P) is the 2^{nd} most deficient macronutrient after nitrogen in Indian soils. It has been found that nearly 5.7 billion hectares (40% of world arable land) worldwide is challenged by P deficiency (Heuer *et al.*, 2009), whereas in India, the deficiency of P is more pronounced in northern and western part of the country and soils of 51% of Indian districts were found low in available P, 40% in medium and 9% were in high available P category (Muralidharudu *et al.*, 2011). Phosphorus plays an important role in many physiological processes, *viz.* photosynthesis, respiration, storage of energy, cell enlargement and cell division *etc.* It is essential for the synthesis of nucleic acids, transformation of starch and sugars, promotes early root formation and auxin metabolism therefore, plays major role in achieving the maximum agricultural production. In wheat crop, deficiency of P reduces plant growth (vigour), number of tillers and plant leaf area by producing smaller and less number of leaves (Sato *et al.*, 1996).

Zinc (Zn) is one of the eight essential micronutrients. It is responsible for activating some enzymes (carbonic anhydrase, dehydrogenase, proteinase & peptidase), acts as an important cofactor in functioning of several enzymatic processes and in synthesis of nucleic acids. Zinc deficiency reduces the photosynthetic rate, chlorophyll content, activity of carbonic anhydrase and protein biosynthesis (Cakmak, 2008 and Fu *et al*., 2016). The most characteristics symptoms of Zn deficiency in wheat plant are reduction in plant height, leaf area, number of tillers and development of whitish-brown necrotic spots on middle-aged leaves. Therefore, when the supply of plant-available zinc is insufficient, crops yield reduced and the growth period is prolonged resulting in delayed maturity. Deficiency of Zn induced health challenges by impairing with the quality of crop (Jiang *et al.,* 2008). Deficiency of Zn is probably the most common micronutrient deficiency in crops worldwide. Nearly, 36.5% soils in India and 15.4% soils of Haryana were found deficient in zinc (Shukla and Behera, 2017).

Phosphorus and zinc are known to occur in soil in different forms differing in their solubility and thus their availability to plants. The nature and amounts of various forms of P depends upon soil texture, pH, and sesquioxides. Phosphorus is mainly absorbed by plants as primary orthophosphate ions ($H_2PO_4^-$) at low pH and secondary orthophosphate ions (HPO_4^{2-}) or PO_4^{3-} in neutral to alkaline pH range. Phosphorus in soil exists in both organic (20-80% of total P) and inorganic forms (54-84% of total P). Phosphorus bound to aluminium (Al-P), calcium (Ca-P), iron (Fe-P) and reductant soluble constitute the inorganic P whereas the organic P constitutes nucleotides, nucleic acids, inositol phosphates and sugar phosphates. Phosphorus concentration at a given time is mainly governed by the processes like fixation, adsorption, P release in soil solution and these processes occur in equilibrium, when plant removes P from soil solution, some of the P adsorbed to the solid phase is released into the soil solution in order to maintain equilibrium. Around 10-20% of total applied phosphatic fertilizers are available to plants. On the other side nature and availability of various forms of zinc depends upon the pH, soil texture, organic matter, calcium carbonate and other soil properties (Sharma *et al.,* 2004). It is mainly absorbed by the plants in form of Zn^{2+} ion and its deficiency is more common in sandy soils having low organic matter, high pH or high P levels (Rattan and Sharma, 2004). Zn is present in different forms in soil like carbonate bound, sesquioxides bound, water soluble plus exchangeable, residual and organically bound Zn. Only a small fraction of total Zn is available to crops (1% as water soluble and exchangeable Zn), about 13% bounded to sesquioxides, 1.6% as organically bound and more than 84% Zn is bounded to structurally lattices (Hazra *et al*., 1987).Application of higher doses of phosphatic fertilizers increases the severity of Zn deficiency in soil (Norvell *et al*., 1987) and also increased level of P interferes with plant metabolism involving plant uptake and utilization of Zn (Haldar and Mandal, 1981), resulting in metabolic disorders within plant cells. Improper use of P and Zn has become a major constraint to production and productivity of cereals or more specifically of wheat.

Judicious use of these two most widespread deficient nutrient elements is the need of hour for sustaining the productivity. The information regarding effect of different doses of P and Zn on wheat yield in different P status soil and their release behaviour pattern is not widely available in literature. Therefore, the present study entitled **"Influence of phosphorus and zinc on wheat yield and release behaviour of P and Zn in soils"** was carried out to find the optimum level of phosphorus and zinc and their interaction for better wheat growth and yield in different soils with the following objectives:

1. Effect of phosphorus and zinc on wheat yield and nutrient uptake
2. The release behaviour and fractions of P and Zn in different P status soils

CHAPTER- II

REVIEW OF LITERATURE

The literature available related to present study entitled "Influence of phosphorous and zinc on wheat yield and release behaviour of phosphorous and zinc in different soils" has been reviewed in this chapter. It includes a brief review of work done by different researchers in India and abroad on effect of different levels of P and Zn on wheat yield, nutrient uptake, protein content, different P and Zn fractions and their release behaviour in different soils, presented here under following heads.

2.1 Effect of different levels of P and Zn on yield, nutrient uptake and protein content in wheat

2.1.1 Wheat yield

Jain and Dahama (2006) studied the requirement of phosphorus and zinc in wheat crop under pearl millet-wheat cropping system at Navgaon and found that application of 60 kg P_2O_5 along with 6 kg Zn ha^{-1} significantly increased the biological yield and apparent recovery of both P and Zn. They also found that combination of P and Zn at their higher level (P at 90 kg ha^{-1} and Zn at 12 kg ha^{-1}) shows antagonistic effect whereas concentration of P and Zn increased significantly along with their increasing dose. Similarly, Kaleem *et al.* (2009) conducted experiment at Adaptive Research Farm, Pakistan to study the effect of graded levels of phosphorus (32, 42, 84, 96 and 128 kg P ha^{-1}) keeping N constant (128 kg N ha^{-1}) on yield parameters of wheat crop. They found that application of the highest dose of phosphorus (128 kg ha^{-1}) in combination with fix nitrogen, *i.e.* in 1:1 ratio contributed maximum towards the yield attributes in wheat crop and therefore maximum phosphorus dose helped in achieving highest number of grains per spike, 1000 grain weight and obviously the yield of wheat (3558 kg ha^{-1}).

Keram *et al.* (2012) conducted a field experiment at Jabalpur to study the effect of application of Zn along with macronutrients (NPK) on wheat yield and nutrient uptake. They found that the wheat yield (4666 kg ha^{-1}), total nutrient uptake (123 kg ha^{-1}- N, 90.86 kg ha^{-1}- K and 327.74 g ha^{-1}- Zn) and quality increased significantly with the application of recommended doses of NPK (150:60:40 kg ha^{-1}) along with Zn at 20 kg ha^{-1} as compared to NPK alone. The yield, harvest index, total nutrient uptake and quality increased up to highest level of Zn (20 kg ha^{-1}), except total P uptake which declined with increasing levels of zinc. Similar results were also recorded by Ghulam *et al.* (2009) from Peshawar, Pakistan. Xin-Kai *et al.* (2012) conducted experiment at Jiangsu Province China to study the effects of different rates of P (0, 72, 108, 144 and 180 kg ha^{-1}) on grain yield and protein content in wheat crop. They concluded that highest grain yield was achieved when P was applied at 108 kg ha^{-1}, but at this level protein content in grain was lower than 11.5%. They further concluded that the optimum P fertilizer dose increased grain yield and improved grain quality of wheat crop.

Arshad *et al*. (2016) conducted a field experiment in order to study the interactive effect of phosphorus and zinc on wheat crop at Peshawar, Pakistan. The experiment have four levels of zinc (0, 5, 10 and 15 kg ha^{-1}) and three levels of phosphorus (45, 90 and 135 kg ha^{-1}) and it was found that wheat spike length, total dry matter, test weight, and biological yield of wheat crop showed more significant response in plots which were treated with P dose of 90 kg ha^{-1} along with Zn application at10 kg ha^{-1}. Mishra *et al.* (2017) carried out an experiment at Agronomy Research Farm, Faizabad to study the effect of P and Zn on growth, yields, yield attributes and economics of late sown wheat and found that application of 60 to 120 kg P_2O_5 ha^{-1} enhanced the growth, yield attributes, yields and nutrient uptake. The maximum gross return and net return was obtained when P applied @ 120 kg ha^{-1}. Similarly Zn application @ 10 kg ha^{-1} produced the maximum values of growth, yields and nutrient uptake. The gross return increased with increasing rate of applied Zn from 0 -10 kg Zn ha^{-1} but the net return was highest with 5 kg Zn ha^{-1}.

Jat *et al*. (2018) conducted field experiment for two consecutive years to find out the effect of phosphorus, zinc and iron on yield and quality of wheat crop in soils of western Rajasthan. The experiment comprised 4 levels of phosphorus (0, 20, 40 and 60 kg ha^{-1}) and three levels of zinc (0, 3 and 6 kg ha^{-1}) in main plots and 3 levels of iron (0, 3 and 6 kg ha^{-1}) in subplots. They reported that application of P up to 40 kg P_2O_5 ha^{-1} significantly increased the biological yields beyond which it increased non-significantly. Application of phosphorus and Zn significantly improved the available phosphorus status of the soil after harvest of wheat crop.

2.1.2 Nutrient uptake and protein content

Reddy and Yadav (1994) conducted a pot culture experiment at Deoria district of Uttar Pradeshin order to study the effect of different levels of P (0, 25, 50 and 100 mg kg^{-1}) and Zn (0, 5, 10 and 20 mg kg^{-1}) on their concentration and uptake by wheat biomass in a highly calcareous soil and concluded that application of P decreased the concentration of Zn in soil but increased the uptake of Zn in grain and straw. Zinc availability in soil after crop harvest was also enhanced with application. However, P concentration in plants or soil is not significantly affected by application of zinc. Rupa *et al.* (2003) studied the effects of phosphorus and farm yard manure on zinc uptake by wheat crop and concluded with the addition of FYM alone at 10 t ha^{-1} (1.95-2.38%) gives highest percentage utilization of Zn by wheat crop *i.e.* the highest uptake of Zn takes place in this treatment.

Abbas *et al*. (2009) reported that the combined application of NPK and Zn significantly improves yield parameters and biological yield of wheat. Application of Zn results in increased total uptake by wheat crop and there is higher concentration of Zn in upper 15 cm layer of soil which is available for succeeding crop. Mousavi (2011) conducted a research in Iran to study the influence of zinc in crop production and its interaction with phosphorus. He reported that in high pH calcareous soils solubility of micronutrient was less and this resulted in lower uptake of Zn element and hence, requirement of plants to this element is increasing. Crop yields and quality was also impaired with inadequate zinc in soil. He also found that zinc adsorption capacity is reduced by high phosphorus utilization and zinc in plant and soil has an antagonism state with phosphorus.

Yang *et al.* (2011) conducted a research at Shangxi Province, China and concluded that high level of P decreased the concentration of Zn in grain. They reported that combined application of P and Zn fertilizer increases the P and Zn concentration and bioavailability of Zn in wheat grain. Keram *et al*. (2012) also reported that with application of recommended doses of N, P, K and Zn (120:60:40:20 kg ha^{-1}) significantly increased nutrient uptake and quality of wheat as compared to NPK alone. Total N, K and Zn uptake were 123.19, 90.86 kg ha^{-1} and 327.74 g ha^{-1} respectively

Arshad *et al*. (2016) conducted experiment at Peshawar, Pakistan to examine interactive effect of phosphorus and zinc and concluded that the concentration of P in soil, plant and its uptake significantly improved with increase in P application rate at each Zn level and decreased with increasing rate of Zn application. Similarly, soil and plant Zn concentration and uptake increased with increasing Zn application however at each Zn rate, Zn uptake decreased by increasing application rate of P. Akgun *et al*. (2016) conducted an experiment to examine the effects of different zinc application doses on Zn uptake and some quality parameters of wheat crop. They found that Zn application increased protein, Zn content and P content in bran. However, the Zn application decreased the amount of P in flour.

2.2 Effect of different levels of P and Zn on nutrient fractions in soil

2.2.1 P fractions

Tomar (2000) found that in Indian soils, the organic phosphorus fraction ranged in between 0 to 216 ppm and its contribution to total phosphorus ranged from 0% in desert dunes of Rajasthan (sandy soil) to 92.8% in high land of Assam (new alluvial soil). Vig *et al.* (2000) conducted a greenhouse experiment on ten soils collected from nine well established soil series of Punjab and found that calcium bound phosphorus (Ca-P) was the dominant inorganic P fraction (92 .8%) followed by Al-P (5.4 %), Fe-P (1.4 %) and saloid-P (0.4 %) Singh and Sharma (2007), Kaur *et al.* (2015) also reported similar trend of P fractions in soil of Punjab.

Brady and Weil (2002) found that the levels of organic P in soils vary widely, ranging from 0 to 0.2 per cent in soil mass. The organic fraction generally constitutes 20 to 80% of the total P in surface soil horizons. Sarkar *et al*. (2014) carried experiment in West Bengal to characterize different forms of soil phosphorus in relation to soil properties. They found that minimum amount of P was saloid bound-P (1.9 mg kg^{-1}) and maximum amount of P was reductable soluble-P (109.9 mg kg^{-1}). Based on mean relative abundance soil inorganic P fractions were found in following order: Saloid-P < Aluminium-P < Calcium-P = Occluded-P < Iron-P < Reductable soluble-P.

Mahmood *et al*. (2003) found the lower concentration of total phosphorus in light soil (482 mg kg^{-1}) as compared with the heavy soil (690 mg kg^{-1}). Calcium bound phosphorus (Ca-P) was the dominant form of soil P and comprised of 71% of inorganic P. Organic-P constituted about 27% of total-P. Simple regression analysis indicates a significant positive relationship between Fe-P, organic-P, Ca-P and Al-P values with clay content of the soil. Samadi (2006) conducted chemical analysis on 13 calcareous soils (six agriculture and seven virgin soil sites). Four rates of P (0, 15, 30, 60 mg kg^{-1} soil) were applied as reagent-grade KH_2PO_4 to the soils. Inorganic phosphorus fractions induced by cropping in the absence of added P were Ca_{10}-P > Al-P > Ca_2-P > Ca_8-P > Occluded-P > Fe-P for the virgin soils and Ca_2-P > Al-P > Ca_{10}-P > Ca_8-P > Fe-P > occluded-P for the agricultural soils. The order of abundance of Pi fractions for P treated -soils was non-occluded Al and Fe phosphate (Al-P + Fe P) > secondary Ca-bound P (Ca_2-P + Ca_8-P) > acid-extractable P (Ca_{10}-P) > occluded-P for both Virgin and agricultural soils. Laxsminarayana (2007) found that minimum amount of phosphorus found in saloid fraction, whereas maximum amount is in reductant soluble form in the soil. This high value is due to high content of Fe_2O_3 and neutral to slightly acidic soil reaction.

Garg and Aulakh (2010) recordedthat inorganic phosphorus pool is the major sink for fertilizer P as majority of residual fertilizer P accumulated as inorganic P (74-89%) followed by organic P (11-26%) and Olsen P (9-19%). Badrinath *et al.* (2011) studied the distribution and fractionation of phosphorus in all the ten agro-climatic zones of Karnataka. The following P abundance order of different phosphorus fractions was recorded- Ca-P (140 mg kg^{-1}) > Fe-P (89 mg kg^{-1}) > Occluded-P (71 mg kg^{-1}) > Red-P (61 mg kg^{-1}) > Al-P (46 mg kg^{-1}) > Saloid P (21 mg kg^{-1}). The total phosphorus ranged in between 429 to 1315 mg kg^{-1}. In which inorganic-P and organic-P constitute 63 and 37% of total, respectively.

Kumar *et al*. (2013) carried out a field experiment in soybean-wheat cropping system at IARI, New Delhi to examine the residual effect of various treatments and they found that application of manure showed significant increase in available phosphorus over control. Among the different P fractions organic P, Fe-P and Ca-P fractions remained almost unaltered in soil while Saloid-P and Al-P fractions were recorded with higher concentration in comparison to their initial concentration. The extent of increase was more at higher rates of phosphorus application to soybean. Saha *et al*. (2014) studied the fate of different sources of applied P into its nutrition to wheat in pearl millet-wheat cropping system in a 40 years long term fertility experiment at Hisar, Haryana and found that the available P, saloid -P and Al-P were positively and significantly correlated with grain yield, straw yield, P concentration in grain, and total P uptake. They reported that Saloid-P and Al-P were the important forms of inorganic P and contributed mainly towards biological yield and total phosphorus uptake.

Devra *et al*. (2014) conducted a laboratory investigation at College of Agriculture, Bikaner to study the distribution of different phosphorus fractions and their relationship with soil properties in western plain of Rajasthan. They collected two hundred and nine surface soil samples (0-15 cm depth) from different locations of three districts of western plain of Rajasthan having texture sandy to loam and found that Ca-P was the dominant P fraction among all the soils of the study because of calcareous nature of the soils. The result also suggested that all the P fractions except Red-P and Ca-P gave significant positive correlation with OC, EC, CEC and silt plus clay but Total-P, Ca-P and Olsen-P had significant positive correlation with calcium carbonate except Saloid-P, Fe-P, Red-P and Org-P. Singh *et al.* (2016) investigated the status of various form of P in rice-wheat growing soils and found that saloid-P, Al-P, Fe-P, Ca-P, reductable soluble phosphate, occluded-P and organic-P ranged from 29.4 to 36.4, 12.3 to 16.1, 7.5 to 9.7, 89.0 to 98.1, 15.2 to 22.1, 16.9 to 22.5 and 116.8 to 165.7 mg kg^{-1}, respectively. They also concluded that among various fractions, major contributor to the availability of P was Ca-P and the soil was fairly rich in total-P reserve but the available P status was medium.

Chandarkala *et al.*(2017) carried an experiment by creating five phosphorus fertility gradients strips (very low, Low , medium, high and very high) in finger millet-maize cropping system and concluded that there was an increase in total-P , organic-P, reductant soluble P, occluded-P, and calcium-P fractions with the increased gradient strips from very low to very high applied with levels of P. Whereas, saloid-P, Al-P and Fe-P are the slowly and plant available labile-P forms which were decreased as the fertility gradients and dose of phosphorus increased. There was direct relationship with addition, fixation and distribution of P fractions. Hence, continuous P fertilization can be restricted in soils of high and very high initial P status as the phosphorus use efficiency was only 20-40 per cent which leads to build-up and transformations of phosphorus into non-labile phosphorus forms. Patle *et al*. (2019) studied various P fractions in four soil orders *viz.* Vertisols, Inceptisols, Alfisols and Aridisols and their results revealed that under different rates of P application the correlation studies of different fractions of P showed positive correlation with Ca-P in Vertisols and Aridisols whereas Fe-P, Al-P showed highly significant correlation with Inceptisols and Alfisols. This might be due to that the applied P fixed as Ca-P in Vertisols while as Fe-P and Al-P in Inceptisols and Alfisols. However, saloid-P did not show much response to different fraction of P except in Vertisols.

2.2.2 Zn fractions

Neelam and Verma(2001) concluded from their long term integrated nutrient management experiment that among various Zn fractions three Zn fractions namely specifically adsorbed exchangeable, non-specifically adsorbed exchangeable and organically bound are the most important Zn fractions contributing to Zn nutrition in rice-wheat cropping system. Chahal *et al.* (2005) reported from four different semi-arid tract of Punjab that size fractions and organic matter content in soil had a strong influence on the distribution of different forms of Zn fractions. Based upon the linear coefficient of correlation, the soil solution plus exchangeable Zn, adsorbed on inorganic sites, and DTPA Zn increased with increase in organic carbon but decreased with increase in pH and calcium carbonate content. Total Zn increased with increase in clay and silt content. Among the different forms, Zn bound by organic sites, water soluble plus exchangeable Zn and Zn adsorb on oxides were all correlated with DTPA extractable Zn.

Adhikari and Rattan (2007) conducted a greenhouse experiment at IARI, New Delhi to study the distribution of Zn fractions with respect to the Zn availability of Zn species for uptake by rice plant in five soils of different agro-ecological zones (*viz.*, Bhuna, Delhi, Gurgaon, Cooch-Behar and Pabra) having different physico-chemical properties and concluded that more than 90% of the total Zn content occurred in the residual form and a small fraction was present in the WS, EX, OM, AFe-OX and CFe-OX bound form. They also found that among the soils there was wide variation in the magnitude of the Zn fractions and the study also revealed that Zn in WS, OM, EX and AFe-OX were the fraction of Zn that played a significant role in uptake of Zn by rice crop.

Behera *et al*. (2008) concluded from a long term experiment in Inceptisol soil order that the DTPA-Zn concentration was higher in soil where Zn had been applied and declined with increase in soil depth. The distribution of different fractions of Zn under various treatments was inconsistent. Residual Zn was the dominant portion of total Zn at all soil depths. Zinc associated with easily reducible manganese, carbonate and iron and aluminium oxides contributed directly towards DTPA-extractable Zn. Sorbed Zn and Zn associated with organic matter contributed significantly towards Zn uptake. Highest uptake of Zn occurred in Zn treated plots during both the crops. Kumar and Qureshi (2012) conducted a greenhouse experiment and the results of the greenhouse study showed that the application of different sources of zinc *viz.* $ZnSO_4.7H_2O$, Zn-DTPA, Zn-EDTA and Zn-CH (Zinc chelated with a mixture of DTPA and EDTA) applied at various zinc levels (5, 10 and 20 mg kg^{-1}) increased wheat and succeeding maize dry matter yield. Positive, significant correlations were obtained between the zinc concentration in plant and the available zinc as well as the first two sequentially extracted Zn fractions (water soluble plus exchangeable and organically complexed). The zinc fractions in the soil after harvest of both crops were positively and significantly correlated with each other.

Norouzi *et al.* (2014) conducted a field studyin calcareous soil of Iran to investigate the changes in Zn chemical forms in soil solid phase as affected by four preceding crops (Clover, Safflower, Sunflower and Sorghum). A control treatment with no preceding crop (fallow) was also used and found that the preceding crops increased zinc concentration in exchangeable fraction, the organically bound zinc form and zinc bound to iron and manganese oxides. While decreased the carbonates and residual bound zinc forms. However, the changes in zinc fractions were dependent on the preceding crop type. Among the preceding crops used in this experiment, clover had the highest effect on transforming carbonate zinc form to exchangeable zinc and carbonate zinc labile forms and thus resulted in the highest Zn in the soil solid phase complex phase. Their findings also showed that preceding crops significantly increased the concentration of Zn in exchangeable and organic matter pools and in turn resulted in higher uptake of Zn by the target wheat. Ramzan *et al.* (2014) studied fractionation of zinc in soils of Himalayas, Jammu and Kashmir. They reported that distribution of Zn fractions in the soils on the basis of average concentrations was in following order residual (64.31 mg kg^{-1}) > oxide bound (6.05 mg kg^{-1}) > organic bound (5.78 mg kg^{-1}) > carbonate bound (1.79 mg kg^{-1}) > exchangeable (1.59 mg kg^{-1}) > water soluble (1.08 mg kg^{-1}).

Spalbar *et al.* (2017) studied distribution of zinc fractions in some rice-wheat growing soils of Jammu Region and concluded that distribution of Zn in the soils on the basis of average concentrations was in following order Residual Zn (78%) > Organic carbon bound-Zn (11%) > 3.39 mg kg^{-1} Amorphous sesquioxide-Zn(8%) > Crystalline sesquioxide-Zn(2%) > WSEX (1%). Correlation analysis showed that all the fractions of Zn were significantly negatively correlated with pH except for organic carbon bound-Zn, while as a positive relation with electrical conductivity, organic carbon and clay content. Similar findings were also earlier reported by Ashraf *et al.* (2012).

Jangir *et al*. (2018) studied the distribution of different fractions of Zn and their relation to soil properties in paddy growing soils of Panchkula, Haryana and found the following orders of various Zn fractions on the basis of Zn concentration: Residual-Zn > Crystalline iron and manganese oxide bound Zn > Carbonate-Zn > Organic-Zn > Exchangeable-Zn. Nisab and Ghosh (2019) conducted a study to find distribution of different forms of Zn under red and lateritic soils of West Bengal and found that the distribution of Zn in the soils based on average concentrations was in the order of 25.49 mg kg^{-1} Residual Zn (64.5%) > 5.05 mg kg^{-1} Manganese bound-Zn (12.7%) > 4.96 mg kg^{-1} Crystalline Sesquioxide-Zn (12.5%) > 2.61 mg kg^{-1} Amorphous Sesquioxide-Zn (6.6%) > 1.04 mg kg^{-1} Organic bound-Zn (2.6%) > 0.48 mg kg^{-1} Water soluble and Exchangeable-Zn (1.2%).

2.3 Release behaviour or P and Zn fractions at different incubation period

Khankhane and Yadav (2000) carried an incubation study and reported that among 24 inorganic P fractions, saloid-P decreased while Al-P, Fe-P and Ca-P increased significantly with period of incubation. Murthy *et al.* (2002) studied the transformation of added phosphorus into distinct fraction under incubation of few Vertisol pedons having different percentage of grey shale, basalt, granite and limestone and reported that the applied phosphate transformed mostly into Ca-P followed by Fe, Al-P and carbonate sorbed P fraction. Among the pedon maximum Ca-P fraction (370 mg kg^{-1}) was observed in Ap horizon of pedon derived from granodiorite parent material.

Ochwoh *et al*. (2005) conducted an experiment to study the chemical changes of applied and native phosphorus during incubation and distribution into different soil P pools in two different soils of South Africa and concluded that solution and labile P decreased but adsorbed, occluded and residual P increased with increase in incubation period. The content of different P forms varied in between both the soils. Ghichangi *et al*. (2009) studied the effect of goat manure and inorganic phosphate addition on soil inorganic and microbial biomass phosphorus fractions under laboratory incubation conditions and found that resin P decreased gradually with time in all treatments and $NaOHCO_3$ Pi fraction changed little with time in the control and goat manure amended soil but increased rapidly with application of P either alone or in combination with goat manure. However, microbial biomass P increased with time in all treatments peaking on 28 DAI and decreased thereafter with later period of incubation. The order of abundance of inorganic P fraction was NaOH Pi > Resin P > $NaHCO_3$ Pi. The combined application of P and goat manure produced two fold more microbial biomass than their sole applications.

Pant *et al*. (2017) studied the sequential extraction of different pools of phosphorus in alluvial and acid soils of Uttarakhand and found that in case of inorganic P fractions under alluvial soil the dominating species were Ca-P > Fe-P > Al-P > Saloid-P while in acidic soil the order was Fe-P > Al-P > Ca-P > Saloid-P. They also concluded that availability of dominant P fractions in alluvial soil received the maximum Ca-P up to 30 days and Fe-P up to 60 days in acidic soil. Talukder *et al.* (2011) observed that in many cases, the exchangeable-Zn found higher only at 15 days after incubation but sharply reduced at 30 days after incubation. The higher rate of release was obtained at early stage of incubation and it gradually reduced as the incubation period proceeded to 90 days.

Singh *et al*. (2006) conducted an investigation to study the effect of concentration and length of contact period on Zn sorption- desorption in four soils of different locations and the results from the study suggested that the amount and pattern of Zn sorbed, native and added Zn desorbed varied between the soils which revealed that soils of different location had different capacities for Zn supply to the soil solution. They concluded that Zn sorption depends on texture and CEC of the soils. The soils having high clay content and high CEC sorbed more Zn. The Zn desorption increased with increase in concentration of applied Zn to the soil and decreased with longer contact period with Zn in the soil.

Kamali *et al*. (2011) conducted an experiment to study the Zn transformations as affected by applied Zn and organic materials in soils of south Iran. The results from the incubation study revealed that residual Zn was the domination form of Zn in the untreated soil. The different fractions of Zn increased with increasing rates of Zn application but there was more pronounced for carbonate and residual fraction. Similarly, application of organic materials also increased all forms of Zn except Mn-oxide fraction

Ghasemi-Fasaei *et al.* (2012) conducted an experiment in southern Iran to investigate the zinc release patterns in different soil orders and concluded that Zn release rate from the studied soils was initially fast and followed by slower rate trend and further reported that clay and organic matter are most likely the main sites of zinc release in the studied soils. Saviour and Stalin (2014) conducted a laboratory incubation study at Coimbatore, Tamil Nadu to assess the distribution of different forms of soil Zn in sandy loam zinc deficit soils of two different locations from Pudukkottai district with graded level of Zn fertilizer application (0, 1.25, 2.50, 5.0, 7.5, 10.0 Zn as $ZnSO_4$ kg ha^{-1}). The soils were incubated at field capacity for 30 days period and destructive sampling was done at intervals *viz*., 0, 7, 15, 21 and 30 days after incubation and found that among various fraction studied, the amount of MNOX-Zn recorded an increased content (4.40, 5.28, 5.82, 5.01, 4.44 mg kg^{-1} and 4.23, 5.11, 5.65, 4.84, 4.27 mg kg^{-1} respectively in both the locations) in soils during incubation and gradually increased in both the soils which ranged from 3.61-5.82 and 3.44-5.65 mg kg^{-1}. The release trend attained a peak value (5.82 and 5.65 mg kg^{-1}) at 15 days of incubation due to application of Zn at the rate of 10 kg ha^{-1} and contributed 1.29 and 1.28% of total zinc in both the soils.

Preetha and Stalin (2014) carried the incubation study at Coimbatore, Tamil Nadu to study the distribution of Zn fractions in four soils having different available soil Zn status of different locations of Erode district, Tamil Nadu and concluded that various Zn fractions under incubation condition treated with successive levels of Zn fertilizer showed significant variation in almost all the locations and similar trend was observed for all the soils of the study. They also found that higher release of Zn was obtained with the highest dose of applied Zn than the lower doses. Among various Zn fractions the release of WSEX-Zn, OM-Zn and CFeOX-Zn noticed up to 15 DAI and thereafter get reduced after the end of the experiment up to 30DAI whereas release of MnOX-Zn, AFeOX-Zn, RES-Zn and Total-Zn consistent up to 30 DAI. The order of their abundance in all locations was WSEX < OM < AFe-OX < CFe-OX < Mn-OX < RES. The result of the study also suggested that the content of different Zn fractions varied between soils of all four locations and more than 95% of total Zn was present in RES-Zn fraction whereas a relatively small amount of TOTAL Zn occurred in WSEX, OM AFe-OX and CFe-OX.

CHAPTER- III

MATERIALS AND METHODS

The present investigation entitled "Influence of phosphorus and zinc on wheat yield and release behaviour of P and Zn in soils" was conducted in the screen house of Department of Soil Science, CCS HAU, Hisar during *rabi* season of 2018-19. For this two different experiments were conducted. First one was a pot experiment and the second was incubation study. For these experiments, two different soils, one was low in available P (from village Sadalpur) and another was high in available P (from village Saniyana) were brought from farmer's field. These soils were air dried, ground and passed through 2 mm aperture stainless sieve and stored in polythene bags for subsequent analysis. The details of materials used and procedures followed at various stages of the experiments are described in this chapter under following heads:

3.1 Experiment No. 1:

Effect of phosphorus and zinc on wheat yield and nutrient uptake (Pot study)

This experiment was conducted in the screen house of the department of Soil Science, CCS HAU, Hisar with following treatments:

Experimental details:

Soils	:	2
Test crop	:	Wheat (WH 1105)
Levels of P	:	5 (0, 30, 60, 120 and 180 mg P kg^{-1} soil)
Levels of Zn	:	4 (0, 2.5, 5 and 10 mg Zn kg^{-1} soil)
Replications	:	3
Design	:	Completely randomized design

For this experiment 120 pots (each pot having four kg soil) were filled and placed in the screen house. Five different levels of phosphorus (0, 30, 60, 120 and 180 mg P kg^{-1} soil) was applied through KH_2PO_4 and four level of zinc (0, 2.5, 5 and 10 mg Zn kg^{-1}) were applied through $ZnSO_4.7H_2O$ to both soils. The treatments of P and Zn were applied at the time of sowing along with recommended basal dose of nitrogen (through urea). The soil of the pots was moistened with water and mixed thoroughly. Ten wheat seeds were sown in each pot during second fortnight of November. Initially, water to the wheat plants was applied as per requirement of the crop while later on with the increase in temperature; water was applied on daily basis. After few days of germination, thinning of wheat plants was done and four healthy plants were left in each pot. The plants were allowed to grow up to maturity and the crop was harvested in first week of April. After the harvest of the crop, soil samples were collected from each pot. These soils samples were air dried ground and sieved through a two mm sieve and stored in cloth bags for further analysis of phosphorus and zinc fractions.

3.1.1 Wheat yield

After harvesting of the crop, threshing was done manually and separately for each pot. Grain yield of each pot was recorded and computed as g pot^{-1}. Straw yield from each pot was worked out by subtracting the grain yield from the biological yield of individual pot and computed as g pot^{-1}.

3.1.2 Nutrient content (N, P, K and Zn) in grain and straw

For estimation of total nitrogen (N), phosphorus (P) and potassium (K) content in grain and straw, grain and straw samples were dried at room temperature then grounded and digested in a diacid mixture of sulphuric acid (H_2SO_4) and perchloric acid ($HClO_4$) in ratio of 4:1. For estimation of zinc (Zn) plant samples were digested in diacid mixture of nitric acid (HNO_3) and perchloric acid in 4:1 ratio. After digestion, the digested mixture was filtered and 50 ml final volume was made and stored for further analysis. Nitrogen in digested plant material was determined by colorimetric method using Nessler's reagent given by Lindner, 1944. Phosphorus in plant samples was determined by Vanadomolybdate yellow colour method and K was determined using flame photometer by following Jackson (1958) method. Zinc (mg kg^{-1}) was determined by using atomic absorption spectrophotometer. The methods followed for plant analysis is given in Table 3.1.

3.1.3 Nutrient uptake by grain and straw

The uptake of N, P, K and Zn was computed from the data of N, P, K (%) and Zn (mg kg^{-1}) concentrations and grain and straw yield (g pot^{-1}), using the following formula:

Nutrient uptake = Nutrient concentration in grain/straw (% or mg kg^{-1}) x grain/straw yield (g pot^{-1})

3.1.4 Protein content

The protein content (%) in grain was calculated by multiplying the nitrogen content in grain by factor of 6.25.

Protein (%) = N (%) in grain x 6.25

Table 3.1: Methods followed for plant analysis

Nutrient	Method used	References
Nitrogen	Colorimetric method	Lindner (1944)
Phosphorus	Vanadomolybdophosphoric acid yellow color method	Koenig and Johnson (1942)
Potassium	Flame photometer method	Jackson (1958)
Zinc	Atomic absorption spectrophotometer	Model: Varian AA240z

3.2 Initial soil analysis

The processed samples of both the soils were used for the determination of selected physico-chemical properties of the soil *i.e*. texture, pH, electrical conductivity (EC), organic carbon, cation exchange capacity and available N, P and K; Diethylene Triamine Pentaacetic Acid (DTPA) extractable Zn, Fe, Mn and Cu. The analytical methods used for various soil parameters are given in Table 3.2.

Table 3.2: Methods used for various soil parameters

Soil properties	Method used
Soil texture	International pipette method (Piper, 1966)
pH (1:2)	Glass electrode pH meter (Jackson, 1973)
EC (dS m^{-1})	Conductivity bridge meter (Richard, 1954)
Organic carbon	Wet digestion method (Walkley and Black, 1934)
Cation exchange capacity [(cmol (p^+) kg^{-1})]	Hesse (1971)
Available nutrients (kg ha^{-1})	
Nitrogen	Subbiah and Asija (1956)
Phosphorus	Olsen *et al*. (1954)
Potassium	Flame photometry method (Jackson, 1958)
DTPA extractable micronutrient (mg kg^{-1})	
Zn, Fe, Mn and Cu	Lindsay and Norvell (1978)

3.3 Post harvest soil analysis for phosphorus fractions

The processed soil samples taken from each pot after the harvest of the crop were used for phosphorus fractions (Saloid-P, aluminium-P, iron-P, reductant soluble-P, calcium-P and organic-P). A sequential fractionation for soil inorganic phosphorus was performed by following a method outlined by (Chang and Jackson, 1957) and modified by (Peterson and Corey, 1966). Different fractions of soil P were extracted by using different extractants and the detail of the methods followed for sequential fractionation scheme of P is given below:

3.3.1 Saloid-P

The easily soluble and loosely bound-P was extracted by shaking soil sample. One g of soil and 50 ml 1N NH_4Cl was shaken in a 100 ml centrifuge tube for 30 minutes and centrifuge at 2000 rpm for 10 minutes. The supernatant was filtered and then 5 ml of aliquot was pipette out into 25 ml volumetric flask and 5 ml of ammonium molybdate was added. Then, 1 ml of chlorostannous reductant ($SnCl_2 .2H_2O$) solution was added and final volume was made with distilled water. Absorbance of the blue color solution was read at 660 nm wavelength after 10 minutes adding stannous chloride.

3.3.2 Aluminium-P

This form was extracted by adding 50 ml of 0.5 N, NH_4F (pH 8.2) to the soil residue of saloid-P. The suspension was shaken for an hour and centrifuged for 10 minutes (2000 rpm).The supernatant was decanted in volumetric flask and used for Al-P analysis. 3 ml of aliquot was taken with pipette and dispensed into the volumetric flask. Chloromolybdic boric acid solution was (3 ml) was added and mixed. Then chlorostannous reductant was added, mixed and absorbance was measured at 660 nm of the blue color solution within 15 to 45 minutes after adding chlorostannous reductant.

3.3.3 Iron-P

The residual soil from Al-P was washed twice with 25 ml portions of saturated NaCl by centrifugation at 2000 rpm for 5 minutes and decanted. The soil residue was shaken for 17 hours after addition of 50 ml 0.1 N NaOH and then centrifuged at 2000 rpm for 5 minutes. The supernatant was decanted in volumetric flask and analysis of Fe-P was preceded same as for Al-P.

3.3.4 Reductant soluble-P

The residual soil from Fe-P was washed twice with 25 ml of saturated NaCl. The soil residue was suspended in 25 ml of 0.3 M $Na_3C_6H_5O_7.2H_2O$ and 1g of solid $Na_2S_2O_4$ was added and shaken for 5 minutes. The suspension was heated in a water bath (75-80^o C) then diluted for 50 ml and shaken for 5 minutes. The supernatant was decantanted in volumetric flask and used for analysis of reductant soluble-P. The extract (3 ml) was taken in extraction tubes, 0.25 M $KMnO_4$ (1.5 ml) was added and allowed to stand for about 2 minutes. Then 3 ml of ammonium molybdate-sulphuric acid reagent was added followed by addition of 10 ml of isobutyl alcohol. The tubes were fixed by stopper and inverted to thoroughly disperse the alcohol through the aqueous phase and allowed to separate the alcohol from the aqueous phase. Five ml alcohol was taken from alcohol phase and dispensed into another set of extraction tubes, 3 ml of stannous chloride reductant was added and shaken as before. Again the alcohol phase was allowed.

A known volume of the alcohol layer (3 ml aliquot of extract) was dispensed into volumetric flask, 3 ml of absolute ethyl alcohol was added, mixed thoroughly and absorbance of the blue colour solution was read at 660 nm after 45 minutes.

3.3.5 Calcium bound-P

The residual soil from reductant soluble-P was washed twice with 25 ml of saturated NaCl and the supernatant solution was discarded. This form was extracted by adding 50 ml of 0.5 N H_2SO_4 to the soil residue and was shaken for an hour, centrifuged for 10 minutes (2000 rpm) and then the supernatant liquid was analysed for Ca-P same as for Al-P and Fe-P.

3.3.6 Organic-P

This fraction was calculated by subtracting inorganic P fractions from total P.

3.3.7 Total-P

Total-P was determined using the perchloric acid digestion method as outlined by Jackson (1973). One gram soil was digested in diacid mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$) and determined using vandomolybdate phosphoric yellow colour method of Koenig and Johnson (1942).

3.4 Post harvest soil analysis for zinc fractions

Different fractions of Zn were estimated by following the method of Tessier *et al*. (1979) and modified by Jeng and Singh (1993). The detail of different Zn fractions (water soluble plus exchangeable, carbonates bound, Fe/Mn oxides bound, organically bound and residual-Zn) is given below:

3.4.1 Water soluble plus exchangeable fraction

To extract this form of Zn- fraction 20 ml of 0.5 M $Ca(NO_3)_2$ solution was added in 1 g processed soil in centrifuge tubes (50 ml capacity) and shaken for 16 hours, centrifuged for 30 minutes at 5000-10,000 rpm and soil residue was taken out for next fraction. After that supernatant was filtered in plastic bottles and then from the aliquot this fraction was estimated by using Atomic Absorption Spectrophotometer (AAS).

3.4.2 Carbonate bound fraction

Eight ml of 1M NaOAc (pH 5) was added to the residual soil, shaken for 6 hours and centrifuged for 30 minutes (5000-10,000 rpm). The supernatant was filtered and this fraction was estimated same as water soluble plus exchangeable fraction.

3.4.3 Fe/Mn oxides bound fraction

For the extraction of this fraction 20 ml of 0.04 M $NH_2OH.HCl$ in 25% acetic acid was added to the soil residue of carbonate found fraction and was heated on water bath (96^oC) for 6 hours with occasional shaking, centrifuged and supernatant was filtered and the soil residue was taken for next fraction. The fraction was estimated by using AAS.

3.4.4 Organically bound fraction

Three ml of 0.02 M HNO_3, 5 ml of 30% H_2O_2 (pH 2) was added to the soil residue and was heated on water bath (85^oC) for 2 hours with occasional shaking after that 5 ml of 3.2 M NH_4OAc in 20% HNO_3 was added, shaken for 30 minutes and diluted to 20 ml with double distilled water (DDW). Then centrifuged, filtered and estimated by using AAS.

3.4.5 Residual fraction

The soil residue was digested with conc. H_2SO_4 (4-5 drops), 5 ml of 48% HF and 1 ml of 60% $HClO_4$. After that final volume was made to 100 ml with DDW, filtered and estimated.

3.4.6 Total Zn

To estimate total Zn in soil, 1 g processed soil was taken in conical flask (50 ml capacity) and digested with diacid mixture (HNO_3 and $HClO_4$ solution) and final volume was made with distilled water. Then, the solution was filtered and estimated for total Zn using AAS.

3.5 Experiment no.2: Release behavior of P and Zn in different soils (Incubation study)

The release behaviour of P and Zn in different soils was studied by conducting incubation experiment in laboratory. For this, 100 g processed soils were taken into wide mouth plastic bottles (in triplicates) and moisture content was maintained at field capacity and incubated at room temperature (25^{o}C). Sampling of both incubated soils was done at periodic intervals (1, 7, 14, 21, 28 and 35 days) and were analyzed for Olsen's P, DTPA-extractable Zn, P and Zn fractions using different methods as mentioned above.

3.6 Statistical analysis

The data generated through these experiments were analyzed using completely randomized design (CRD) and was subjected to statistical analysis for significance at 0.05 using OPSTAT software.

CHAPTER- IV

RESULTS

In order to study the influence of phosphorus and zinc on yield, nutrients content and their uptake by wheat crop**,** soils from two different villages were evaluated in a screen house experiment. The soil collected from village Sadalpur, district Hisar was low in available phosphorus and those collected from village Saniyana, district Fatehabad was high in available phosphorus. The release behaviour of P and Zn and their fractions in these soils were studied. The results obtained are presented in this chapter under the following heads:

4.1 Initial physico-chemical properties of soils

4.2 Wheat yield in low P and high P status soil

4.3 Plant analysis

- 4.3.1 Concentration of N, P, K and Zn in grain and straw
- 4.3.2 Uptake of N, P, K and Zn by grain and straw
- 4.3.3 Protein content

4.4 Post harvest soil analysis

- 4.4.1 Phosphorus fractions
- 4.4.2 Zinc fractions

4.5 Release behaviour and P and Zn fractions in different P status soils

- 4.5.1 Olsen's P
- 4.5.2 DTPA-extractable Zn
- 4.5.3 Phosphorus fractions
- 4.5.4 Zinc fractions

4.1 Initial physico-chemical properties of soils

The data pertaining to initial physico-chemical properties of low available P status soil and high available P status are presented in Table 4.1. The texture of the low available P status soil was sandy (92% sand, 4% silt and 4% clay). The pH of soil was 7.4, electrical conductivity (EC): 0.12 dS m^{-1}, organic carbon (OC): 0.15% and cation exchange capacity (CEC): 4.46 cmol (p^{+}) Kg^{-1}. The available N, P and K content of the soil was 28, 8 and 112 kg ha^{-1}, respectively. The DTPA-extractable Zn, Fe, Cu and Mn were found 0.3, 2.11, 1.94 and 2.48 mg kg^{-1}, respectively.

The texture of high available P status soil was sandy loam (60% sand, 24% silt and 16% clay). The pH of the soil was 7.1, EC: 1.0 dS m^{-1}, OC: 0.62% and CEC: 9.28 cmol (p^{+}) Kg^{-1}. The available N, P and K content of the soil was 182, 25 and 430 kg ha^{-1}, respectively. The DTPA-extractable Zn, Fe, Cu and Mn were found to be 0.72, 18.74, 3.08 and 10.26 mg kg^{-}

[1], respectively. In general, the content of all macro (N, P and K) and micronutrients (Zn, Fe, Cu and Mn) was found higher in high P status soil than low P status soil.

Table 4.1: Physico-chemical properties of soils

Initial soil parameters	Low Av. P status Soil	High Av. P status Soil
pH	7.4	7.1
EC (dS m^{-1})	0.12	1.0
Sand (%)	92	60
Silt (%)	4	24
Clay (%)	4	16
Texture	Sand	Sandy loam
CEC [(cmol (p^+) kg^{-1})]	4.46	9.28
Organic carbon (%)	0.15	0.62
Available Nitrogen (kg ha^{-1})	28	182
Available Phosphorus (kg ha^{-1})	8	25
Available Potassium (kg ha^{-1})	112	430
DTPA-extractable Zinc (mg kg^{-1})	0.30	0.72
DTPA-extractable Copper (mg kg^{-1})	1.94	3.08
DTPA-extractable Iron (mg kg^{-1})	2.11	18.74
DTPA-extractable Manganese (mg kg^{-1})	2.48	10.26

4.2 Wheat yield in low P and high P status soil

A perusal of data presented in Table 4.2 revealed that the average grain yield of wheat in low P status soil increased from 6.96 to 7.42 and 6.66 to 7.63 g pot^{-1} over control (4.36 and 5.50 g pot^{-1}) with the application of P and Zn, respectively. Whereas, the average straw yield of wheat increased from 9.53 to 10.01 and 8.98 to 9.88 g pot^{-1} over control (5.52 and 7.65 g pot^{-1}) with the application of P and Zn, respectively. In case of P treatments, the grain and straw yield recorded at 30 mg P kg^{-1} level was statistically at par with rest of the P levels. However, maximum average grain and straw yield (7.42 and 10.01 g pot^{-1}) was recorded at highest dose of P *i.e*. 180 mg kg^{-1}. But in case of Zn treatments, the grain yield (6.66 g pot^{-1}) recorded at 2.5 mg Zn kg^{-1} level was statistically at par with rest of the Zn levels. But the maximum grain and straw yield was recorded at 10 mg Zn kg^{-1}. The result indicated that P and Zn dosage rate synergistically affected grain and straw yield of wheat.

The interactive effect of graded level of P and Zn also found to be significant on grain and straw yield of wheat crop. Treatment combination 180 mg P kg^{-1} + 10 mg Zn kg^{-1} gave highest grain yield (7.87 g pot^{-1}). Whereas, maximum straw yield (10.41 g pot^{-1}) was observed at 120 mg P kg^{-1} + 10 mg Zn kg^{-1} level.

Table 4.2: Effect of P and Zn on grain and straw yield (g pot^{-1}) of wheat in low P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	0.50	4.50	6.20	6.70	4.36
30	6.57	6.64	6.80	7.84	6.96
60	6.80	7.37	7.52	7.86	7.39
120	6.80	7.38	7.55	7.86	7.40
180	6.82	7.42	7.56	7.87	7.42
Mean	5.50	6.66	7.04	7.63	
CD (p=0.05)	P-0.47 Zn-0.40 PxZn-0.90				
Straw					
0	0.66	5.93	7.26	8.22	5.52
30	9.26	9.36	9.40	10.11	9.53
60	9.36	9.53	9.99	10.33	9.80
120	9.38	10.02	10.04	10.41	9.96
180	9.57	10.05	10.10	10.31	10.01
Mean	7.65	8.98	9.36	9.88	
CD (p=0.05)	P-0.50 Zn-0.45 PxZn-1.00				

Perusal of the data given in Table 4.3 revealed that in high P status soil, application of Zn had significant effect on grain and straw yield of wheat crop, whereas application of graded level of P alone or in combination with different levels of Zn did not have any significant effect on grain and straw yield of wheat crop. The grain and straw yield of wheat increased from 6.55 to 8.23 g pot $^{-1}$ and 8.35 to 10.70 g pot^{-1} with the application of Zn over control (5.98 and 7.64 g pot^{-1}), respectively. In case of Zn treatments, the maximum mean grain yield (8.23 g pot^{-1}) and straw (10.70 g pot^{-1}) was obtained at highest dose of Zn *i.e.* 10 mg kg^{-1} level.

Table 4.3: Effect of P and Zn on grain and straw yield (g pot^{-1}) of wheat in high P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	5.40	6.36	7.26	8.20	6.81
30	6.10	6.40	7.26	8.22	6.99
60	6.12	6.62	7.30	8.23	7.07
120	6.13	6.68	7.31	8.24	7.09
180	6.14	6.70	7.31	8.24	7.10
Mean	5.98	6.55	7.29	8.23	
CD (p=0.05)	P- NS Zn-0.53 PxZn- NS				
Straw					
0	6.85	8.20	9.07	10.16	8.57
30	7.55	8.09	9.39	10.87	8.98
60	8.35	8.61	9.49	11.53	9.50
120	7.70	8.33	9.42	10.45	8.98
180	7.77	8.51	9.42	10.50	9.05
Mean	7.64	8.35	9.36	10.70	
CD (p=0.05)	P-NS Zn-0.68 PxZn-NS				

**NS- Non significant*

4.3 Plant analysis

After the harvest of wheat crop, grain and straw samples were collected and were analysed for their nutrient contents and uptake was calculated accordingly.

4.3.1 Concentration of N, P, K and Zn in grain and straw

The data pertaining to N content in grain and straw of low P and high P status soils are presented in Table 4.4 and Table 4.5, respectively. It is evident from the results that N content in grain and straw was not significantly influenced by the application of different levels of P and Zn either alone or with their combinations in both types of soils. However, the higher N content in both grain and straw was recorded in high P status soil as compared to low P status soil.

Table 4.4: Effect of P and Zn on the nitrogen content (%) in wheat grain and straw in low P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	1.09	1.14	1.11	1.10	1.11
30	1.11	1.14	1.10	1.12	1.12
60	1.10	1.04	1.10	1.24	1.12
120	1.20	1.04	1.12	1.20	1.14
180	1.15	1.10	1.20	1.15	1.15
Mean	1.13	1.09	1.13	1.16	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				
Straw					
0	0.41	0.39	0.40	0.43	0.41
30	0.42	0.43	0.41	0.42	0.42
60	0.39	0.41	0.44	0.41	0.41
120	0.40	0.43	0.40	0.41	0.41
180	0.40	0.44	0.42	0.44	0.42
Mean	0.40	0.42	0.41	0.42	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				

Table 4.5: Effect of P and Zn on the nitrogen content (%) in wheat grain and straw in high P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	1.49	1.56	1.60	1.55	1.55
30	1.69	1.65	1.52	1.70	1.64
60	1.63	1.60	1.59	1.65	1.62
120	1.64	1.72	1.59	1.72	1.67
180	1.63	1.65	1.62	1.43	1.58
Mean	1.62	1.64	1.59	1.61	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				
Straw					
0	0.49	0.49	0.50	0.50	0.49
30	0.49	0.47	0.49	0.50	0.49
60	0.48	0.47	0.51	0.51	0.49
120	0.49	0.51	0.50	0.50	0.50
180	0.48	0.50	0.48	0.51	0.49
Mean	0.49	0.49	0.50	0.50	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				

The P content in grain and straw of wheat in low P and high P status soils are shown in Table 4.6 and Table 4.7, respectively. The result revealed that in low P status soil, increasing level of P from 0 to 180 mg kg^{-1} significantly increased the mean P content from 0.25 to 0.32 % in grain and from 0.022 to 0.028% in straw.

Table 4.6: Effect of P and Zn on the phosphorus content (%) in wheat grain and straw in low P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	0.22	0.26	0.26	0.28	0.25
30	0.26	0.26	0.28	0.28	0.27
60	0.27	0.27	0.31	0.29	0.29
120	0.29	0.30	0.31	0.30	0.30
180	0.34	0.32	0.31	0.31	0.32
Mean	0.28	0.28	0.29	0.29	
CD (p=0.05)	P-0.02 Zn-NS PxZn-NS				
Straw					
0	0.019	0.023	0.022	0.023	0.022
30	0.022	0.024	0.023	0.023	0.023
60	0.024	0.027	0.028	0.025	0.026
120	0.026	0.027	0.027	0.026	0.027
180	0.03	0.028	0.026	0.026	0.028
Mean	0.024	0.026	0.025	0.025	
CD (p=0.05)	P-0.002 Zn-NS PxZn-NS				

Table 4.7: Effect of P and Zn on the phosphorus content (%) in wheat grain and straw in high P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	0.25	0.29	0.29	0.31	0.29
30	0.29	0.29	0.31	0.31	0.30
60	0.30	0.32	0.34	0.33	0.32
120	0.33	0.35	0.35	0.34	0.34
180	0.40	0.36	0.35	0.35	0.37
Mean	0.31	0.32	0.33	0.33	
CD (p=0.05)	P-0.02 Zn-NS PxZn-NS				
Straw					
0	0.023	0.027	0.026	0.027	0.026
30	0.026	0.028	0.027	0.027	0.027
60	0.028	0.031	0.032	0.029	0.030
120	0.030	0.031	0.031	0.030	0.030
180	0.034	0.032	0.030	0.030	0.032
Mean	0.028	0.030	0.029	0.029	
CD (p=0.05)	P-0.002 Zn-NS PxZn-NS				

In low P status soil, the maximum mean content of P in grain (0.32%) was recorded at highest level of P *i.e.* 180 mg kg^{-1} which was statistically at par to 120 mg P kg^{-1} level. Similarly in straw also, maximum mean content (0.028%) was recorded at 180 mg P kg^{-1} level which was proved statistically par with 60 and 120 mg P kg^{-1} level. Application of Zn either alone or in combination with different levels of P did not have any significant effect on P content in grain and straw in both types of soils.

In high P status soil, the mean P content of grain and straw increased significantly from 0.29 to 0.37% and 0.026 to 0.032%, respectively with the increasing level of P from 0 to 180 mg kg^{-1}. The maximum mean P content in grain (0.37%) and straw (0.032%) was also recorded at highest dose of P *i.e.* 180 mg P kg^{-1}.

Perusal of the data given in Table 4.8 and Table 4.9 shows that application of different level of P and Zn either alone or in combination did not have significant effect on the K content in both grain and straw in both types of soil. However, higher value of K content in both grain and straw was recorded in high P status soil as compared to low P status soil.

Table 4.8: Effect of P and Zn on the potassium content (%) in wheat grain and straw in low P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	**2.5**	**5**	**10**	
Grain					
0	0.56	0.53	0.56	0.55	0.55
30	0.60	0.58	0.53	0.57	0.57
60	0.59	0.57	0.58	0.62	0.59
120	0.58	0.57	0.54	0.59	0.57
180	0.61	0.61	0.59	0.56	0.59
Mean	0.59	0.57	0.56	0.58	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				
Straw					
0	0.89	0.91	0.96	0.96	0.93
30	0.92	0.95	0.94	0.98	0.95
60	0.95	0.94	0.92	0.98	0.95
120	0.90	0.98	0.93	0.96	0.94
180	0.98	0.95	0.97	0.98	0.97
Mean	0.93	0.95	0.94	0.97	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				

Table 4.9: Effect of P and Zn on the potassium content (%) in wheat grain and straw in high P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	0.59	0.57	0.60	0.58	0.59
30	0.55	0.58	0.54	0.55	0.56
60	0.54	0.57	0.55	0.57	0.56
120	0.53	0.62	0.58	0.58	0.58
180	0.55	0.60	0.54	0.53	0.56
Mean	0.55	0.59	0.56	0.56	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				
Straw					
0	1.00	1.01	1.02	1.06	1.02
30	1.00	1.09	1.06	1.06	1.05
60	1.05	1.04	1.06	1.04	1.05
120	1.02	1.17	1.01	1.08	1.07
180	1.03	1.02	1.04	1.03	1.03
Mean	1.02	1.07	1.04	1.05	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				

It is evident from data presented in Table 4.10 that in low P status soil, increasing level of Zn form 0 to 10 mg kg^{-1} increased the average Zn content from 19.56 to 24.16 mg kg^{-1} in grain and from 9.77 to 12.76 mg kg^{-1} in straw. The maximum mean content of Zn in grain and straw was recorded in treatment receiving highest dose of Zn. However, application of different level of P either alone or in combination with Zn did not have any significant effect on Zn content of grain and straw.

Similarly, in high P status soil, the mean Zn content in grain and straw also increased from 23.22 to 28.03 mg kg^{-1} and 11.02 to 14.01 mg kg^{-1} with increasing level of Zn from 0 to 10 mg kg^{-1} (Table 4.11). The maximum mean content of Zn in grain (28.03 mg kg^{-1}) and straw (14.01 mg kg^{-1}) was recorded at highest level of Zn. However, the Zn content in both grain and straw was not influenced by the application of P either alone or in combination with different level of Zn.

Table 4.10: Effect of P and Zn on the zinc content (mg kg^{-1}) in wheat grain and straw in low P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	20.40	21.78	22.31	25.07	22.39
30	19.56	21.42	22.28	23.59	21.71
60	19.59	20.24	22.87	23.21	21.48
120	19.18	20.74	22.31	24.81	21.76
180	19.05	20.00	22.95	24.11	21.53
Mean	19.56	20.84	22.54	24.16	
CD (p=0.05)	P-NS Zn-1.31 PxZn-NS				
Straw					
0	9.98	11.97	12.19	14.09	12.06
30	9.67	11.69	12.05	12.62	11.51
60	9.78	11.11	12.08	12.51	11.37
120	9.70	11.01	12.00	12.33	11.26
180	9.73	11.18	11.95	12.24	11.28
Mean	9.77	11.39	12.06	12.76	
CD (p=0.05)	P-NS Zn-0.53 PxZn-NS				

Table 4.11: Effect of P and Zn on the zinc content (mg kg^{-1}) in wheat grain and straw in high P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	23.78	25.16	26.12	28.88	25.99
30	23.07	24.93	26.39	27.70	25.52
60	23.40	24.05	26.68	27.02	25.29
120	22.99	24.55	26.12	28.62	25.57
180	22.86	23.81	26.76	27.92	25.34
Mean	23.22	24.50	26.41	28.03	
CD (p=0.05)	P-NS Zn-1.74 PxZn-NS				
Straw					
0	11.23	13.22	13.44	15.34	13.31
30	10.92	12.94	13.30	13.87	12.76
60	11.03	12.36	13.33	13.76	12.62
120	10.95	12.26	13.25	13.58	12.51
180	10.98	12.43	13.20	13.49	12.53
Mean	11.02	12.64	13.30	14.01	
CD (p=0.05)	P-NS Zn-0.77 PxZn-NS				

4.2.3 Uptake of N, P, K and Zn by grain and straw

The results of uptake of macro as well as micronutrients are summarized under following heads:

4.2.3.1 Nitrogen uptake by grain and straw in low and high P status soil

The data pertaining to nitrogen uptake as influenced by different level of P and Zn in low P status soil are presented in Table 4.12 and it is quite clear from the given data that N uptake by grain and straw in low P status soil was affected significantly at different level of P and Zn. In P treatment, the highest N uptake by grain (8.54 mg pot^{-1}) and straw (4.25 mg pot^{-1}) was recorded with application of 180 mg P kg^{-1}. In case of Zn treatment, maximum N uptake by grain (8.86 mg pot^{-1}) and straw (4.16 mg pot^{-1}) was recorded at 10 mg Zn kg^{-1} level.

The interactive effect of P and Zn also had significant effect on N uptake by both grain and straw. Maximum N uptake (9.70 mg pot^{-1}) by grain was achieved when 60 mg P kg^{-1} was applied in combination with 10 mg Zn kg^{-1}, however, it was found statistically at par with 30 mg P kg^{-1} + 10 mg Zn kg^{-1} whereas in straw the highest N uptake (4.54 mg pot^{-1}) was recorded in treatment combination of 180 mg P kg^{-1} + 10 mg Zn kg^{-1} and was found at par with treatment combination of 30 mg P kg^{-1} + 10 mg Zn kg^{-1}.

Table 4.12: Effect of P and Zn on the nitrogen uptake (mg pot^{-1}) by wheat grain and straw in low P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	0.55	5.14	6.38	7.37	4.86
30	7.29	7.60	7.48	8.82	7.80
60	7.46	7.67	8.27	9.70	8.27
120	8.14	7.63	8.47	9.39	8.41
180	7.87	8.20	9.06	9.04	8.54
Mean	6.26	7.25	7.93	8.86	
CD (p=0.05)	P-0.45 Zn-0.40 PxZn-0.90				
Straw					
0	0.27	2.31	2.88	3.51	2.24
30	3.86	4.02	3.89	4.25	4.01
60	3.68	3.91	4.43	4.24	4.07
120	3.75	4.26	3.98	4.27	4.07
180	3.83	4.38	4.25	4.54	4.25
Mean	3.08	3.78	3.89	4.16	
CD (p=0.05)	P-0.25 Zn-0.22 PxZn-0.49				

In high P status soil, different levels of P and Zn had additive effect on the N uptake by wheat grain and straw (Table 4.13). In P treatment, the highest content of nitrogen uptake (11.84 mg pot^{-1}) by grain was recorded at 120 mg P kg^{-1} level, which was found statistically at par with the N uptake content at rest of the P levels. Whereas in case of straw, highest content of nitrogen uptake (4.69 mg pot^{-1}) was obtained with application of 60 mg P kg^{-1} which was found statistically at par with uptake at rest of the P levels (except 30 mg P kg^{-1} level). In Zn treatment, N uptake by both grain and straw significantly increased with each successive level of Zn. The maximum mean content of nitrogen uptake by grain (13.25 mg pot^{-1}) and straw (5.39 mg pot^{-1}) was recorded at highest level of applied Zn (10 mg kg^{-1}).

The combined applications of P and Zn also had additive effect on N uptake by grain and straw. The highest N uptake (14.16 mg pot^{-1}) by grain was recorded when P was applied @ 120 mg kg^{-1} along with 10 mg Zn kg^{-1} and was at par with uptake in 30 mg P kg^{-1} + 10 mg Zn kg^{-1} treatment. However, in straw the interactive effect of different level of P and Zn was found non-significant.

Table 4.13: Effect of P and Zn on the nitrogen uptake (mg pot^{-1}) by wheat grain and straw in high P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	8.04	9.90	11.61	12.72	10.57
30	10.33	10.59	11.07	13.98	11.49
60	9.95	10.58	11.63	13.61	11.44
120	10.06	11.47	11.65	14.16	11.84
180	10.02	11.03	11.81	11.76	11.16
Mean	9.68	10.72	11.55	13.25	
CD (p=0.05)	P-0.68 Zn-0.60 PxZn-1.35				
Straw					
0	3.36	4.00	4.50	5.08	4.24
30	3.70	3.82	4.64	5.47	4.41
60	4.04	4.06	4.84	5.84	4.69
120	3.75	4.25	4.75	5.21	4.49
180	3.70	4.22	4.53	5.37	4.45
Mean	3.71	4.07	4.65	5.39	
CD (p=0.05)	P-0.24 Zn-0.22 PxZn-NS				

4.2.3.2 Phosphorus uptake by grain and straw in low and high P status soil

Perusal of the data given in Table 4.14 revealed that mean content of P uptake by both grain and straw increased with increasing level of P and Zn. In response to P application, maximum P uptake *i.e.* 2.36 mg pot^{-1} in grain and 0.28 mg pot^{-1} in straw was recorded at highest level of P (180 mg P kg^{-1}). In response to Zn application, maximum content of P uptake by grain (2.23 mg pot^{-1}) and straw (0.24 mg pot^{-1}) was recorded at 10 mg Zn kg^{-1} level.

The interactive effect of P and Zn was also found significant on P uptake by both grain and straw. However, maximum P uptake by grain (2.44 mg pot^{-1}) was obtained with application 180 mg P kg^{-1} along with 10 mg Zn kg^{-1}. But in case of straw, maximum P uptake (0.29 mg pot^{-1}) was observed at 180 mg P kg^{-1} level.

Table 4.14: Effect of P and Zn on the phosphorus uptake (mg pot^{-1}) by wheat grain and straw in low P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	0.11	1.17	1.50	1.88	1.16
30	1.69	1.72	1.90	2.20	1.88
60	1.83	1.99	2.33	2.28	2.11
120	1.98	2.21	2.34	2.36	2.22
180	2.30	2.35	2.34	2.44	2.36
Mean	1.58	1.89	2.08	2.23	
CD (p=0.05)	P-0.13 Zn-0.12 PxZn-0.27				
Straw					
0	0.01	0.14	0.16	0.19	0.12
30	0.20	0.22	0.22	0.23	0.22
60	0.22	0.26	0.28	0.26	0.26
120	0.24	0.27	0.27	0.27	0.26
180	0.29	0.28	0.26	0.27	0.28
Mean	0.19	0.23	0.24	0.24	
CD (p=0.05)	P- 0.02 Zn-0.02 PxZn-0.03				

Each successive level of P and Zn had additive effect on the P uptake by both grain and straw in high P status soil (Table 4.15). In P treatment, the maximum P uptake by grain (2.58 mg pot^{-1}) was observed at 180 mg P kg^{-1} level while in straw highest P uptake (0.28 mg pot^{-1}) was recorded at 60 and 180 mg P kg^{-1} level. In case of Zn treatments, maximum mean P uptake by both grain (2.70 mg pot^{-1}) and straw (0.30 mg pot^{-1}) was observed at highest dose of Zn (10 mg Zn kg^{-1}). The interaction effect of P and Zn on P uptake was found to be non-significant.

Table 4.15: Effect of P and Zn on the phosphorus uptake (mg pot^{-1}) by wheat grain and straw in high P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	1.35	1.84	2.11	2.54	1.96
30	1.77	1.86	2.25	2.55	2.11
60	1.84	2.12	2.48	2.72	2.29
120	2.02	2.34	2.56	2.80	2.43
180	2.46	2.41	2.56	2.88	2.58
Mean	1.89	2.11	2.39	2.70	
CD (p=0.05)	P-0.14 Zn-0.13 PxZn-NS				
Straw					
0	0.16	0.22	0.24	0.27	0.22
30	0.20	0.23	0.25	0.29	0.24
60	0.23	0.27	0.30	0.33	0.28
120	0.23	0.26	0.29	0.31	0.27
180	0.26	0.27	0.28	0.32	0.28
Mean	0.22	0.25	0.27	0.30	
CD (p=0.05)	P-0.02 Zn-0.02 PxZn-NS				

4.2.3.3 Potassium uptake by grain and straw in low and high P status soil

Perusal of the data given in Table 4.16 indicates that in low P status soil the mean content of K uptake by grain and straw was influenced by different levels of applied P and Zn. In P treatments, the maximum K uptake by grain and straw *i.e.* 4.38 and 9.71 mg pot^{-1}, respectively was recorded at highest dose of applied P. Whereas in Zn treatments, the maximum K uptake by grain and straw *i.e.* 4.41 and 9.60 mg pot^{-1}, respectively was recorded at highest dose of applied Zn (10 mg Zn kg^{-1}).

The interactive effect of P and Zn on K uptake by grain and straw was also found significant. The maximum K uptake by grain (4.87 mg pot^{-1}) was recorded at 60 mg P kg^{-1} + 10 mg Zn kg^{-1} level. While in case of straw, highest K uptake by straw (10.10 mg pot^{-1}) was recorded with 180 mg kg^{-1} of P applied in combination with 10 mg Zn kg^{-1}.

Table 4.16: Effect of P and Zn on the potassium uptake (mg pot^{-1}) by wheat grain and straw in low P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	0.28	2.38	3.23	3.70	2.40
30	3.94	3.89	3.59	4.47	3.97
60	4.01	4.23	4.36	4.87	4.37
120	3.97	4.23	4.05	4.64	4.22
180	4.17	4.52	4.45	4.38	4.38
Mean	3.27	3.85	3.94	4.41	
CD (p=0.05)	P-0.21 Zn-0.19 PxZn-0.42				
Straw					
0	0.59	5.41	6.97	7.92	5.22
30	8.51	8.88	8.86	9.91	9.04
60	8.89	8.99	9.16	10.09	9.28
120	8.47	9.82	9.30	9.99	9.40
180	9.39	9.56	9.80	10.10	9.71
Mean	7.17	8.53	8.82	9.60	
CD (p=0.05)	P-0.49 Zn-0.44 PxZn-0.99				

Data presented in Table 4.17 shows that K uptake by grain in high P status soil was not significantly affected with different levels of P. In case of straw, K uptake was significantly increased over control under all level of P. The maximum uptake of K uptake by straw (9.94 mg pot^{-1}) was recorded at 60 mg P kg^{-1} level.

Graded dose of applied Zn significantly increased the K uptake by both grain and straw. The highest mean content of K uptake *i.e.* 4.63 mg pot^{-1} in grain and 11.28 mg pot^{-1} in straw was recorded at 10 mg Zn kg^{-1} level. The application of P in combination with Zn did not significantly influence the K uptake by both grain and straw.

Table 4.17: Effect of P and Zn on the potassium uptake (mg pot^{-1}) by wheat grain and straw in high P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	3.19	3.59	4.38	4.77	3.98
30	3.38	3.68	3.96	4.52	3.89
60	3.30	3.80	3.99	4.69	3.95
120	3.25	4.12	4.22	4.78	4.09
180	3.38	4.02	3.95	4.38	3.93
Mean	3.30	3.84	4.10	4.63	
CD (p=0.05)	P-NS Zn-0.19 PxZn-NS				
Straw					
0	6.86	8.25	9.29	10.74	8.79
30	7.56	8.79	9.93	11.52	9.45
60	8.76	8.92	10.06	12.03	9.94
120	7.86	9.75	9.49	11.29	9.60
180	8.00	8.65	9.77	10.82	9.31
Mean	7.81	8.87	9.71	11.28	
CD (p=0.05)	P- 0.64 Zn-0.58 PxZn-NS				

4.2.3.4 Zinc uptake by grain and straw in low and high P status soil

The data given in Table 4.18 revealed that average content of Zn uptake significantly increased over control with application of P. The significant increased was observed only up to 30 mg P kg^{-1} level, after that the treatments did not differ significantly. However the maximum mean content of Zn uptake by grain and straw *i.e.*161.74 and 113.10 µg pot^{-1} was recorded at 120 mg P kg^{-1} and 180 mg kg^{-1} level, respectively. The average content of Zn uptake significantly increased from 106.51 to 184.00 µg pot^{-1} in grain and 74.34 to 125.45 µg pot^{-1} in straw with increasing levels of Zn from 0 to10 mg kg^{-1}. The highest Zn uptake by both grain and straw was recorded at 10 mg Zn kg^{-1} level.

The application of Zn in combination with P also had additive effect on Zn uptake by both grain and straw. The maximum content of Zn uptake by grain (195.03 µg pot^{-1}) was recorded in 120 mg P kg^{-1} + 10 mg Zn kg^{-1} treatment combination. It was proved at par with the treatment combination of 30 mg P kg^{-1} + 10 mg Zn kg^{-1} whereas in case of straw it was recorded highest (129.32 µg pot^{-1}) under treatment combination of 60 mg P kg^{-1} with 10 mg Zn kg^{-1} and was found at par with treatment application of P @ 30 mg kg^{-1} in combination with 10 mg Zn kg^{-1}.

Table 4.18: Effect of P and Zn on the zinc uptake (µg pot^{-1}) by wheat grain and straw in low P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	10.20	98.00	128.26	167.95	101.10
30	128.53	142.21	151.50	184.97	151.80
60	133.30	149.26	172.06	182.35	159.24
120	130.45	153.06	168.44	195.03	161.74
180	130.06	148.31	173.52	189.72	160.40
Mean	106.51	138.17	158.76	184.00	
CD (p=0.05)	P-9.47 Zn-8.47 PxZn-18.94				
Straw					
0	6.59	70.98	88.48	115.85	70.48
30	89.54	109.45	113.27	127.59	109.96
60	91.51	105.88	120.71	129.32	111.86
120	90.99	110.32	120.51	128.32	112.54
180	93.08	112.39	120.73	126.19	113.10
Mean	74.34	101.81	112.74	125.45	
CD (p=0.05)	P-5.90 Zn-5.27 PxZn-11.79				

Perusal of the data (Table 4.19) revealed that mean content of Zn uptake increased significantly from 160.02 to 230.55 µg pot^{-1} and 108.40 to 149.77 µg pot^{-1} in grain and straw over control *i.e.*128.41 and 76.93 µg pot^{-1}, respectively with the each successive addition of Zn level. The maximum Zn uptake in both grain (230.55 µg pot^{-1}) and straw (149.77 µg pot^{-1}) was observed at 10 mg Zn kg^{-1}. However, Zn uptake by grain and straw did not significantly influenced by application of P either alone or in combination with Zn.

Table 4.19: Effect of P and Zn on the zinc uptake (µg pot^{-1}) by wheat grain and straw in high P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	128.41	160.02	189.63	236.82	178.72
30	140.73	159.55	191.59	227.69	179.89
60	143.21	159.21	194.76	222.37	179.89
120	140.93	163.99	190.94	235.83	182.92
180	140.36	159.53	195.62	230.06	181.39
Mean	138.73	160.46	192.51	230.55	
CD (p=0.05)	P-NS Zn-10.29 PxZn-NS				
Straw					
0	76.93	108.40	121.90	155.85	115.77
30	82.45	104.68	124.89	150.77	115.70
60	92.10	106.42	126.50	158.65	120.92
120	84.42	102.13	124.82	141.91	113.32
180	85.31	105.78	124.34	141.65	114.27
Mean	84.24	105.48	124.49	149.77	
CD (p=0.05)	P-NS Zn-7.29 PxZn-NS				

4.2.4 Protein content

The application of P and Zn either alone or in combination had no significant influence on protein content of grain and straw in both low P and high P status soils (Table 4.20 and Table 4.21). However, comparatively high content of protein was observed in grain than straw in both types of soil.

Table 4.20: Effect of P and Zn on the protein content (%) in wheat grain and straw in low P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	6.81	7.14	6.93	6.88	6.94
30	6.94	7.15	6.88	7.03	7.00
60	6.85	6.50	6.87	7.72	6.98
120	7.48	6.46	7.02	7.47	7.11
180	7.21	6.91	7.49	7.18	7.20
Mean	7.06	6.83	7.04	7.26	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				
Straw					
0	2.56	2.44	2.48	2.67	2.54
30	2.60	2.69	2.58	2.63	2.62
60	2.46	2.56	2.77	2.56	2.59
120	2.50	2.66	2.48	2.56	2.55
180	2.50	2.72	2.63	2.75	2.65
Mean	2.52	2.61	2.59	2.63	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				

Table 4.21: Effect of P and Zn on the protein content (%) in wheat grain and straw in high P status soil

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Grain					
0	9.31	9.73	10.00	9.69	9.68
30	10.59	10.34	9.53	10.63	10.27
60	10.16	9.99	9.96	10.34	10.11
120	10.26	10.73	9.96	10.74	10.42
180	10.20	10.29	10.09	8.92	9.88
Mean	10.11	10.22	9.91	10.06	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				
Straw					
0	3.06	3.05	3.10	3.13	3.09
30	3.06	2.95	3.09	3.15	3.06
60	3.02	2.95	3.19	3.17	3.08
120	3.04	3.19	3.15	3.12	3.13
180	2.98	3.10	3.01	3.19	3.07
Mean	3.03	3.05	3.11	3.15	
CD (p=0.05)	P-NS Zn-NS PxZn-NS				

4.3 Post harvest soil analysis

After the harvest of wheat crop, soil samples were collected separately from each pot from both types of soil. These soil samples were processed, analysed for various P and Zn fractions and results obtained are summarized under following heads:

4.3.1 Phosphorus fractions in low P status and high P status soils

The data related with different forms of P fractions as influenced by different levels of applied P and Zn is given below in concerned subheads:

4.3.1.1 Saloid-P

Data pertaining to the saloid bound phosphorus content in low P and high P status soils are presented in Table 4.22. The data revealed that application of P in both types of soil had significant effect on Saloid-P content. The Saloid-P content of soils significantly increased from 2.88 to 17.75 mg kg^{-1} and 4.23 to 19.66 mg kg^{-1} in low P status and high P status soil, respectively with increasing level of P from 0 to 180 mg P kg^{-1}. However, maximum average content of Saloid-P *i.e.*17.75 mg kg^{-1} in low P status soil and 19.66 mg kg^{-1} in high P status soil was obtained when P was applied @ 180 mg kg^{-1}. In both types of soil, application of different levels of Zn either alone or in combination with P did not have any significant effect on Saloid-P content. However, at each successive level of applied P, the mean content of Saloid-P was higher in high P status soil as compared to low P status soil.

Table 4.22: Effect of different levels of P and Zn on Saloid-P content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Low P status soil					
0	2.92	3.00	2.82	2.76	2.88
30	5.08	5.20	5.00	5.10	5.10
60	6.10	6.25	6.34	6.42	6.28
120	14.00	13.90	13.40	13.20	13.63
180	18.04	17.64	18.00	17.32	17.75
Mean	9.23	9.20	9.11	8.96	
CD (p-0.05)	P- 0.72	Zn- NS	PxZn- NS		
High P status soil					
0	4.17	4.25	4.07	4.43	4.23
30	6.75	6.90	6.71	6.59	6.74
60	7.60	7.75	7.84	8.01	7.80
120	15.60	15.39	14.83	15.02	15.21
180	20.30	19.50	19.76	19.08	19.66
Mean	10.89	10.76	10.64	10.63	
CD (p-0.05)	P- 0.77	Zn- NS	PxZn- NS		

4.3.1.2 Aluminium-P (Al-P)

The data given in Table 4.23 revealed that with increasing level of P from 0 to 180 mg P kg^{-1}, the mean Al-P content significantly increased from 25.59 to 74.42 mg kg^{-1} in low P status soil and 72.31 to 137.33 mg kg^{-1} in high P status soil. The maximum mean content of Al-P in low P status soil (74.42 mg kg^{-1}) and high P status soil (137.33 mg kg^{-1}) was recorded with application of 180 mg kg^{-1} of P. The application of different levels of Zn either alone or in combination with effect of different levels of P did not significantly influenced the Al bound P content in both types of soil. The mean content of Al-P was found higher in high P status soil as compared to low P status soil.

Table 4.23: Effect of different levels P and Zn on Al-P content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	**2.5**	**5**	**10**	
Low P status soil					
0	25.20	26.54	25.62	24.98	25.59
30	31.35	32.60	32.90	33.25	32.53
60	36.58	37.20	38.20	38.50	37.62
120	60.50	58.52	57.59	54.54	57.79
180	79.24	74.65	72.54	71.25	74.42
Mean	46.57	45.90	45.37	44.51	
CD (p-0.05)	P- 2.58	Zn- NS	PxZn- NS		
High P status soil					
0	70.40	72.57	70.34	75.92	72.31
30	107.86	110.58	106.77	107.19	108.10
60	114.46	116.28	112.70	110.48	113.48
120	125.30	134.20	118.24	124.63	125.59
180	142.64	138.26	136.34	132.10	137.33
Mean	112.13	114.38	108.88	110.06	
CD (p-0.05)	P- 6.30	Zn- NS	PxZn- NS		

4.3.1.3 Iron-P (Fe-P)

Perusal of the data (Table 4.24)showed that the average content of Fe-P content increased from 35.24 to 82.42 mg kg^{-1} in low P status soil and 39.81 to 95.67 mg kg^{-1} in high P status soil with the application of each successive level of P over their respective control (23.52 and 39.81 mg kg^{-1}). The maximum mean content of Fe-P was recorded at highest level of applied P in both types of soils. It was also observed that Fe-P content was not significantly influenced with application of graded levels of Zn either alone or in combination with P in both the soils. The mean content of Fe-P at each successive level of P application was found higher in high P status soil as compared to low P status soil.

Table 4.24: Effect of different levels of P and Zn on Fe-P content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Low P status soil					
0	24.59	23.09	23.91	22.47	23.52
30	36.24	34.05	34.69	35.99	35.24
60	41.59	39.50	40.18	38.12	39.85
120	65.35	62.19	63.63	61.33	63.12
180	83.96	83.43	82.23	80.05	82.42
Mean	50.35	48.45	48.93	47.59	
CD (p-0.05)	P- 3.34 Zn- NS PxZn- NS				
High P status soil					
0	41.40	37.91	42.85	37.10	39.81
30	53.55	56.87	56.81	53.96	55.30
60	68.72	70.67	65.67	64.07	67.28
120	92.80	88.76	88.04	86.24	88.96
180	100.10	95.30	94.22	93.06	95.67
Mean	71.31	69.90	69.52	66.89	
CD (p-0.05)	P- 4.11 Zn-NS PxZn- NS				

4.3.1.4 Reductable-P (Red-P)

The data given in Table 4.25 indicates that the application of graded dose of P significantly influenced the Red-P content in both the soils. It is clear from the data that the mean content of Red-P content increased from 22.21 to 81.19 mg kg^{-1} in low P status soil and 34.74 to 88.41 mg kg^{-1} in high P status soil with increasing level of P from 0 to 180 mg kg^{-1}.

Table 4.25: Effect of different levels of P and Zn on Red-P content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Low P status soil					
0	23.29	21.79	22.61	21.17	22.21
30	34.94	32.75	33.39	34.69	33.94
60	40.29	38.20	38.88	36.82	38.55
120	64.12	60.96	62.40	60.10	61.90
180	82.73	82.20	81.00	78.82	81.19
Mean	49.07	47.18	47.66	46.32	
CD (p-0.05)	P- 3.18 Zn- NS PxZn- NS				
High P status soil					
0	36.32	32.83	37.77	32.02	34.74
30	48.47	51.79	51.73	48.88	50.22
60	63.64	65.59	60.59	58.99	62.20
120	87.72	83.68	82.96	81.16	83.88
180	89.01	88.71	88.54	87.38	88.41
Mean	65.03	64.52	64.32	61.69	
CD (p-0.05)	P- 4.23 Zn-NS PxZn- NS				

Maximum average content of Red-P in low P status soil (81.19 mg kg^{-1}) as well as in high P status soil (88.41 mg kg^{-1}) was recorded at highest dose of P application (180 mg Pkg^{-1}). However, application of different levels of Zn either alone or in combination with different levels of P did not significantly influenced the Red-P content in both types of soil. Comparatively higher mean content of Red-P was noticed in high P status soil than low P status soil.

4.3.1.5 Calcium-P (Ca-P)

Perusal of the data given in Table 4.26 showed that application of different levels of P had significant effect on Ca-P content in both low P status and high P status soils. With increasing level of P from 0 to 180 mg kg^{-1}, the mean content of Ca-P increased significantly from 101.14 to 145.25 mg kg^{-1} in low P status soil and from 153.95 to 244.77 mg kg^{-1} in high P status soil. In both the soils, highest Ca-P content was obtained at 180 mg P kg^{-1} level. Whereas in both soils, application of different levels of Zn either alone or in combination with different levels of P did not have any significant effect on Ca-P content. However, at each successive level of applied P, the amount of Ca-P was found higher in high P status soil as compared to low P status soil.

Table 4.26: Effect of different levels of P and Zn on Ca-P content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Low P status soil					
0	100.45	101.66	100.28	102.15	101.14
30	116.40	118.80	118.80	116.88	117.72
60	128.00	126.80	124.00	123.00	125.45
120	135.00	135.00	134.00	138.00	135.50
180	149.00	148.00	144.00	140.00	145.25
Mean	125.77	126.05	124.22	124.01	
CD (p-0.05)	P- 7.37	Zn- NS	PxZn- NS		
High P status soil					
0	158.80	145.90	158.80	152.30	153.95
30	190.20	188.00	186.30	181.20	186.43
60	220.10	237.30	230.60	228.47	229.12
120	240.40	236.20	232.73	230.10	234.86
180	251.60	248.20	243.40	235.89	244.77
Mean	212.22	211.12	210.37	205.59	
CD (p-0.05)	P- 15.77	Zn- NS	PxZn- NS		

4.3.1.6 Organic-P (Org-P)

Data pertaining to the Org-P content in low P and high P status soils are presented in Table 4.27. It is evident from the obtained data that graded dose of P had significant effect on Org-P content in different P status soils. The average content of Org-P increased significantly from 53.14 to 135.15 mg kg^{-1} and 71.33 to 240.68 mg kg^{-1} in low P and high P status soil, respectively with increasing levels of applied P from 0 to 180 mg kg^{-1}. The maximum mean content of Org-P in low P status soil (135.15 mg kg^{-1}) and high P status soil (240.68 mg kg^{-1}) was obtained at 180 mg P kg^{-1}. However, application of different levels of Zn either alone or in combination with different levels of P had not found significant effect on Org-P content in both the soils whereas the mean content of Org-P at each successive level of applied P found higher in high P status soil compared to low P status soil.

Table 4.27: Effect of different levels of P and Zn on Org-P content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	**Zn levels (mg kg^{-1})**				**Mean**
	0	**2.5**	**5**	**10**	
Low P status soil					
0	57.74	52.51	55.07	47.24	53.14
30	67.93	71.85	62.10	65.43	66.83
60	93.43	84.21	89.58	79.01	86.56
120	108.88	110.52	117.17	125.59	115.54
180	145.21	135.21	130.96	129.21	135.15
Mean	94.64	90.86	90.98	89.30	
CD (p-0.05)	P- 6.73 Zn- NS PxZn- NS				
High P status soil					
0	73.91	79.75	70.65	61.01	71.33
30	98.87	92.17	86.13	89.72	91.72
60	120.41	115.23	118.90	110.63	116.29
120	187.56	176.52	194.15	203.43	190.42
180	248.17	245.48	233.23	235.82	240.68
Mean	145.79	141.83	140.61	140.12	
CD (p-0.05)	P- 10.83 Zn- NS PxZn- NS				

4.3.1.7 Total-P

It is apparent from the data given in Table 4.28 that application of P had significant effect on Total-P content in both low P status and high P status soil. It was noticed that increasing level of P from 0 to 180 mg kg^{-1} significantly increased the Total-P from 228.47 to 536.17 mg kg^{-1} and 376.37 to 826.52 mg kg^{-1} in low P and high P status soil, respectively. However, maximum mean content of Total-P *i.e.* 536.17 mg kg^{-1} in low P status soil and 826.52 mg kg^{-1} in high P status soil was recorded at 180 mg P kg^{-1}. In both type of soils, application of Zn either alone or in combination with graded dose of P did not found any significant effect on Total-P content. At each successive levels of P application, the mean content of Total-P content was higher in high P status soil.

Table 4.28: Effect of different levels of P and Zn on Total-P content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Low P status soil					
0	234.19	228.59	230.31	220.77	228.47
30	291.94	295.25	286.89	291.34	291.36
60	345.99	332.16	337.18	321.87	334.30
120	447.85	441.09	448.19	452.76	447.47
180	558.18	541.13	528.73	516.65	536.17
Mean	375.63	367.65	366.26	360.68	
CD (p-0.05)	P- 26.25	Zn- NS	PxZn- NS		
High P status soil					
0	385.00	373.21	384.48	362.78	376.37
30	505.70	506.31	494.45	487.54	498.50
60	594.93	612.82	596.30	580.65	596.18
120	749.38	734.75	730.95	740.58	738.91
180	851.82	835.45	815.49	803.33	826.52
Mean	617.36	612.51	604.34	594.98	
CD (p-0.05)	P- 42.14	Zn- NS	PxZn- NS		

4.3.2 Zinc fractions

The data related with different forms of Zn fractions influenced by graded levels of applied P and Zn is given under following heads:

4.3.2.1 Water soluble plus exchangeable-Zn (WSEX-Zn)

The data given in Table 4.29 revealed that application of graded level of P and Zn had significant effect on WSEX-Zn content in both type of soils. It was found that increasing level of Zn from 0 to 10 mg kg^{-1} significantly increased the mean content of WSEX-Zn content from 0.12 to 0.43 mg kg^{-1} and 0.29 to 0.51 mg kg^{-1} in low P and high P status soils, respectively. The maximum mean content of WSEX-Zn *i.e.* 0.43 mg kg^{-1} in low and 0.51 mg kg^{-1} in high P status soil was recorded at 10 mg Zn kg^{-1} level. Application of graded dose of P adversely affected the WSEX-Zn content in both soils. Increasing levels of P from 0 to 180 mg kg^{-1} significantly decreased the mean content of WSEX-Zn content from 0.43 to 0.16 mg kg^{-1} in low P status soil and 0.54 to 0.28 mg kg^{-1}in high P status soil.

The application of different level of Zn in combination with different level of P also had significant effect on WSEX-Zn in both types of soils. However, maximum WSEX-Zn content 0.69 and 0.72 mg kg^{-1}in low P and high P status soils respectively, was obtained in 10 mg Zn kg^{-1} treatment. The higher mean content of WSEX-Zn content was recorded in high P status soil as compared to low P status soil.

Table 4.29: Effect of different levels of P and Zn on WSEX-Zn content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	**2.5**	**5**	**10**	
Low P status soil					
0	0.16	0.34	0.53	0.69	0.43
30	0.15	0.31	0.46	0.62	0.39
60	0.12	0.22	0.30	0.38	0.26
120	0.10	0.18	0.23	0.27	0.20
180	0.09	0.15	0.18	0.21	0.16
Mean	0.12	0.24	0.34	0.43	
CD (p-0.05)	P- 0.02 Zn- 0.02 PxZn- 0.04				
High P status soil					
0	0.37	0.48	0.58	0.72	0.54
30	0.34	0.40	0.49	0.59	0.46
60	0.30	0.34	0.42	0.48	0.38
120	0.26	0.29	0.32	0.38	0.31
180	0.20	0.22	0.34	0.38	0.28
Mean	0.29	0.35	0.43	0.51	
CD (p-0.05)	P- 0.03 Zn- 0.03 PxZn- 0.06				

4.3.2.2 Carbonate bound-Zn (CAR-Zn)

Perusal of the data (Table 4.30) showed that the mean content of CAR-Zn significantly increased from 0.98 to 1.22 mg kg^{-1} in low P status soil over control (0.90 mg kg^{-1}) with increasing level of Zn from 2.5 to 10 mg kg^{-1}.

Table 4.30: Effect of different levels of P and Zn on CAR-Zn content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	**2.5**	**5**	**10**	
Low P status soil					
0	1.02	1.19	1.38	1.64	1.31
30	1.01	1.12	1.20	1.38	1.18
60	0.90	0.95	1.04	1.14	1.01
120	0.79	0.84	0.92	0.99	0.89
180	0.77	0.82	0.89	0.94	0.86
Mean	0.90	0.98	1.09	1.22	
CD (p-0.05)	P- 0.07 Zn- 0.06 PxZn- 0.14				
High P status soil					
0	1.69	1.79	1.98	2.26	1.93
30	1.55	1.65	1.70	1.79	1.67
60	1.26	1.20	1.28	1.32	1.27
120	1.11	1.01	1.12	1.27	1.13
180	1.00	1.05	1.10	1.19	1.09
Mean	1.32	1.34	1.44	1.57	
CD (p-0.05)	P- 0.09 Zn- 0.08 PxZn- NS				

Whereas, in case of high P status soil, significant increase in mean content over control was observed only at 5 and 10 mg Zn kg^{-1}. Increasing levels of P from 0 to 180 mg kg^{-1}

significantly decreased the CAR-Zn from 1.31 to 0.86 in low P status soil and from 1.93 to 1.09 mg kg^{-1} in high P status soil.

The application of different levels of Zn in combination with different levels of P also had significant effect on CAR-Zn in low P status soil and non-significant effect in high P status soil. The maximum content of CAR-Zn (1.64 mg kg^{-1}) in low P status soil was recorded when Zn was applied alone @ 10 mg kg^{-1}. Comparatively higher mean content of CAR-Zn content was recorded in high P status soil than low P status soil.

4.3.2.3 Fe/Mn oxide bound-Zn (Fe/MnOX-Zn)

The results given in Table 4.31 revealed that application of different levels of P and Zn significantly influenced Fe/MnOX-Zn content in both soils. The mean content of Fe/MnOX-Zn increased from 4.13 to 5.64 mg kg^{-1} and 5.83 to 7.34 mg kg^{-1} in low P status and high P status soils, respectively with increasing level of Zn from 0 to 10 mg kg^{-1}. The maximum mean content of Fe/MnOX-Zn *i.e.* 5.64 mg kg^{-1} in low P status soil and 7.34 mg kg^{-1} in high P status soil was recorded at 10 mg Zn kg^{-1} level. Application of increasing level of P significantly reduced the mean content of Fe/MnOX-Zn from 6.29 to 3.66 mg kg^{-1} in low P and from 7.99 to 5.36 mg kg^{-1} in high P status soils, respectively.

The combined effect of different doses of P and Zn was found to be significant in low P status soil. The maximum Fe/MnOX-Zn content (7.86 mg kg^{-1}) was obtained when Zn was applied @10 mg kg^{-1}. The higher mean content of Fe/MnOX-Zn content was recorded in high P status soil as compared to low P status soil

Table 4.31: Effect of different levels of P and Zn on Fe/MnOX-Zn content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Low P status soil					
0	5.32	5.45	6.54	7.86	6.29
30	4.51	4.61	5.10	6.12	5.08
60	4.05	4.10	4.36	5.16	4.42
120	3.76	3.75	4.01	4.66	4.05
180	3.00	3.18	4.05	4.40	3.66
Mean	4.13	4.22	4.81	5.64	
CD (p-0.05)	P- 0.28 Zn- 0.25 PxZn- 0.57				
High P status soil					
0	7.02	7.15	8.24	9.56	7.99
30	6.21	6.31	6.80	7.82	6.79
60	5.75	5.80	6.06	6.86	6.12
120	5.46	5.45	5.71	6.36	5.75
180	4.70	4.88	5.75	6.10	5.36
Mean	5.83	5.92	6.51	7.34	
CD (p-0.05)	P- 0.44 Zn- 0.39 PxZn- NS				

4.3.3.4 Organic bound-Zn (ORG-Zn)

Data pertaining to ORG-Zn content in low P and high P status soils are shown in Table 4.32. The mean content of ORG-Zn in both soils was significantly influenced with P and Zn application. In Zn treatment, the maximum mean content of ORG-Zn in low P status soil (1.96 mg kg^{-1}) and high P status soil (3.88 mg kg^{-1}) was recorded when Zn was applied @10 mg kg^{-1}. However, mean content of ORG-Zn showed decreasing trend in response to different levels of P in both the soils and it decreased from 2.34 to 1.34 mg kg^{-1} and 4.25 to 1.64 mg kg^{-1} in low P and high P status soils, respectively with increasing levels of P from 0 to 180 mg kg^{-1}.

The interaction of P and Zn had significant effect on ORG-Zn content in both soils. The ORG- Zn content varied from 1.29 to 2.80 mg kg^{-1} in low P status soil whereas in high P status soil it ranged from 1.47 to 6.20 mg kg^{-1}. The highest content of ORG-Zn in both soils was obtained at when only Zn was applied @10 mg kg^{-1} while the lowest content of ORG-Zn was recorded when 180 mg kg^{-1} of P was applied in combination 10 mg Zn kg^{-1}.

Table 4.32: Effect of different levels of P and Zn on ORG-Zn content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Low P status soil					
0	2.04	2.15	2.38	2.80	2.34
30	2.00	2.10	2.28	2.66	2.26
60	1.82	1.80	1.75	1.72	1.77
120	1.50	1.38	1.30	1.30	1.37
180	1.42	1.34	1.30	1.29	1.34
Mean	1.76	1.76	1.80	1.96	
CD (p-0.05)	P- 0.12 Zn- 0.11 PxZn- 0.24				
High P status soil					
0	3.10	3.60	4.10	6.20	4.25
30	2.71	2.96	3.50	4.88	3.51
60	2.40	2.50	2.60	3.60	2.78
120	2.14	2.34	2.44	3.27	2.55
180	1.88	1.60	1.62	1.47	1.64
Mean	2.45	2.60	2.85	3.88	
CD (p-0.05)	P- 0.17 Zn- 0.16 PxZn- 0.35				

4.3.2.5 Residual-Zn (RES-Zn)

The content of RES-Zn in low P status and high P status soils are presented in Table 4.33. It indicated that application of P and Zn in both soils had significant effect on residual-Zn content. The mean content of RES-Zn content in both soils increased from 25.22 to 28.68 mg kg^{-1} and 35.80 to 39.46 mg kg^{-1} with increasing levels of Zn from 0 to 10 mg kg^{-1}. The maximum mean content of RES-Zn *i.e.* 28.68 mg kg^{-1} in low P status soil and 39.46 mg kg^{-1}

in high P status soil soils was recorded at 10 mg Zn kg^{-1} level. In both soils, application of different levels of P adversely affected the mean content of RES-Zn and it decreased from 29.82 to 24.22 and 45.20 to 29.78 mg kg^{-1} with increasing level of P (0 to 180 mg kg^{-1}). The interactive effect of graded doses of P and Zn on RES-Zn content in both soils was found to be non-significant. The content of RES-Zn was found higher in high P status soil compared with low P status soil.

Table 4.33: Effect of different levels of P and Zn on RES-Zn content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	**2.5**	**5**	**10**	
Low P status soil					
0	27.35	28.62	30.37	32.93	29.82
30	26.88	27.71	28.90	30.52	28.50
60	25.12	25.68	26.80	28.12	26.43
120	23.87	24.52	25.41	26.37	25.04
180	22.88	23.86	24.68	25.45	24.22
Mean	25.22	26.08	27.23	28.68	
CD (p-0.05)	P- 1.54 Zn- 1.38 PxZn- NS				
High P status soil					
0	42.85	44.22	45.40	48.33	45.20
30	40.07	41.88	42.87	44.96	42.44
60	36.99	37.84	38.81	40.42	38.51
120	30.37	30.07	31.08	32.66	31.05
180	28.71	29.26	30.21	30.93	29.78
Mean	35.80	36.65	37.67	39.46	
CD (p-0.05)	P- 2.04 Zn- 1.82 PxZn- NS				

4.3.2.6 Total-Zn

The data given in Table 4.34 revealed that total-Zn content in both soils was significantly influenced with increasing level of P and Zn application. In both low P and high P status soils, total-Zn content increased from 35.92 to 40.67 mg kg^{-1} and 55.85 to 63.30 mg kg^{-1}, with increasing levels of Zn from 0 to 10 mg kg^{-1}. The maximum mean content of total-Zn in low P status soil and high P status soil *i.e.* 40.67 and 63.30 mg kg^{-1}, respectively was recorded at highest level of Zn (10 mg Zn kg^{-1}). However, the mean content of total-Zn decreased from 43.52 to 33.32 mg kg^{-1} in both low P status soil and from 69.88 to 42.12 mg kg^{-1} in high P status soil with increasing levels of P from 0 to 180 mg kg^{-1}. The applications of different levels of P in combination with different levels of P did not have any significant effect on total-Zn content in both the soils.

Table 4.34: Effect of different levels of P and Zn on total-Zn content (mg kg^{-1}) in low P and high P status soils

P levels (mg kg^{-1})	Zn levels (mg kg^{-1})				Mean
	0	2.5	5	10	
Low P status soil					
0	40.22	42.09	44.18	47.61	43.52
30	38.77	40.86	42.52	44.64	41.70
60	35.02	36.83	38.20	39.90	37.49
120	33.15	33.78	34.88	36.52	34.58
180	32.42	32.72	33.45	34.68	33.32
Mean	35.92	37.26	38.65	40.67	
CD (p-0.05)	P- 2.67 Zn- 2.39 PxZn- NS				
High P status soil					
0	62.08	66.35	71.78	79.69	69.98
30	60.46	63.33	66.12	71.54	65.36
60	56.12	57.03	58.69	61.12	58.24
120	52.92	53.41	54.14	55.25	53.93
180	47.65	47.85	48.06	48.90	48.12
Mean	55.85	57.59	59.76	63.30	
CD (p-0.05)	P- 3.61 Zn- 3.23 PxZn- NS				

4.4 Release behaviour of P and Zn fractions in different P status soils

To study the release behaviour of P and Zn and their fractions at different days of incubation, samples from two different soils (low in available P and high in available P) were incubated for 1, 7, 14, 21, 28 and 35 days. After completion of incubation period, these samples were analysed. The content of available P (Olsen's P) and Zn along with the status of different P and Zn fractions at each incubation period is given below under following subheadings:

4.4.1 Olsen's P

Perusal of the data given in Figure 4.1 revealed that in low P status soil, Olsen's P content increased from 7.91 to 17.4 kg ha^{-1} with increase in incubation period from 1 to 21 days, thereafter, it decreased to 9.1 kg ha^{-1} at 35 days of incubation. In case of high P status soil, the increase in Olsen's P content was observed up to 28 days after incubation (DAI) and after that it decreased. The content of Olsen's P increased from 24.87 to 98.01 kg ha^{-1} with increase in incubation period from 1 to 28 days, thereafter, it decreased to 87.93 kg ha^{-1} at 35 days of incubation. However, in both the soils, the content of available P decreased at 1 DAI as compared to their respective initial P values (8.00 and 25 kg ha^{-1}). The content of Olsen's P was comparatively higher in high P status soil than low P status soil.

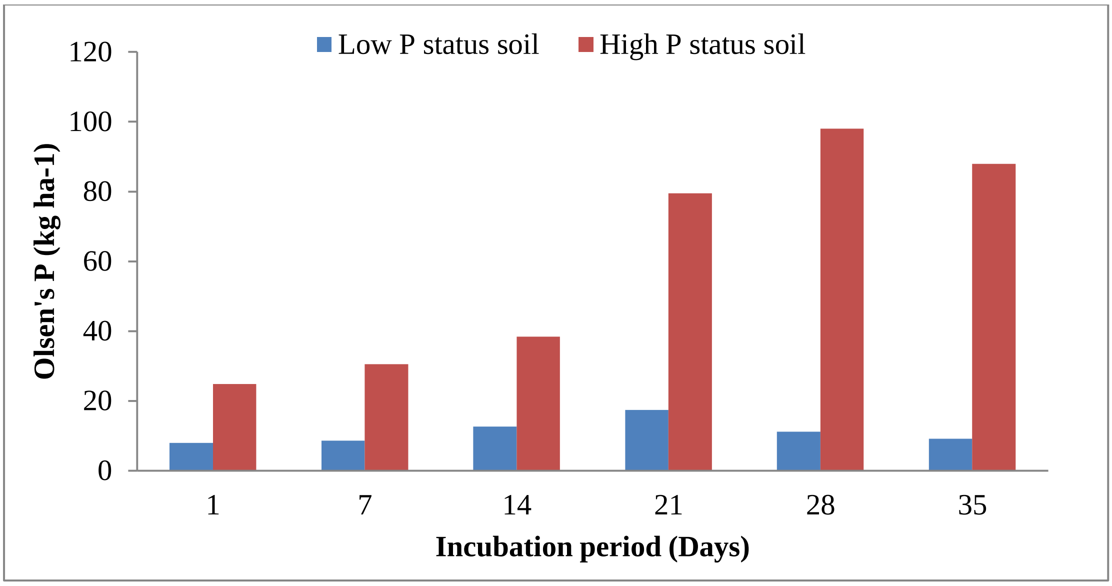

Fig. 4.1: Release behaviour of Olsen's P in low P and high P status soils at different days of incubation

4.4.2 DTPA-extractable Zn

It is evident from the trend shown in Figure 4.2 that the DTPA-extractable Zn content in both soils decreased gradually, as the incubation period increases. The DTPA-extractable Zn content decreased from 0.34 to 0.21 mg kg^{-1} and 0.76 to 0.60 mg kg^{-1} in low P status and high P status soils, respectively from 1 to 35 DAI. The content of DTPA-extractable Zn was found higher at 1 DAI in both soils as compared to their respective initial values (0.30 and 0.72 mg kg^{-1}) and then decreased with later period of incubation. The high P status soil was also high in DTPA-extractable Zn content as compared to low P status soil.

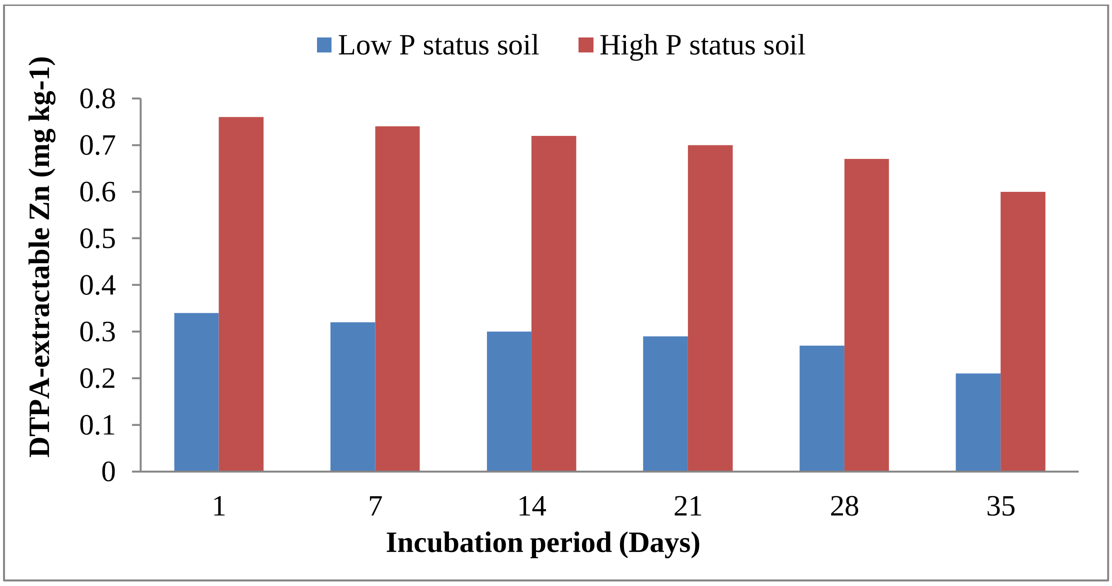

Fig. 4.2: Release behaviour of DTPA-extractable Zn in low P and high P status soils at different days of incubation

4.4.3 Phosphorus fractions

The Fig 4.3 and 4.4 shows the P fractions at different incubation period in low and high P status soils. It indicate that in both the soils, the content of all P fractions *i.e.* Saloid-P, Al-P, Fe-P, Red-P, Ca-P and Total-P (except Org-P fraction) increased up to 28 DAI and thereafter showed declining trend in the content. Distribution of various P fractions in both soils followed the sequence: Ca-P > Org-P > Al-P > Fe-P > Red-P >Saloid-P. In both the soils Ca-P was found the most dominant fraction while Saloid-P was the least available P fraction. It was noticed that the content of different P fractions was higher in high P status soil compared to low P status soil.

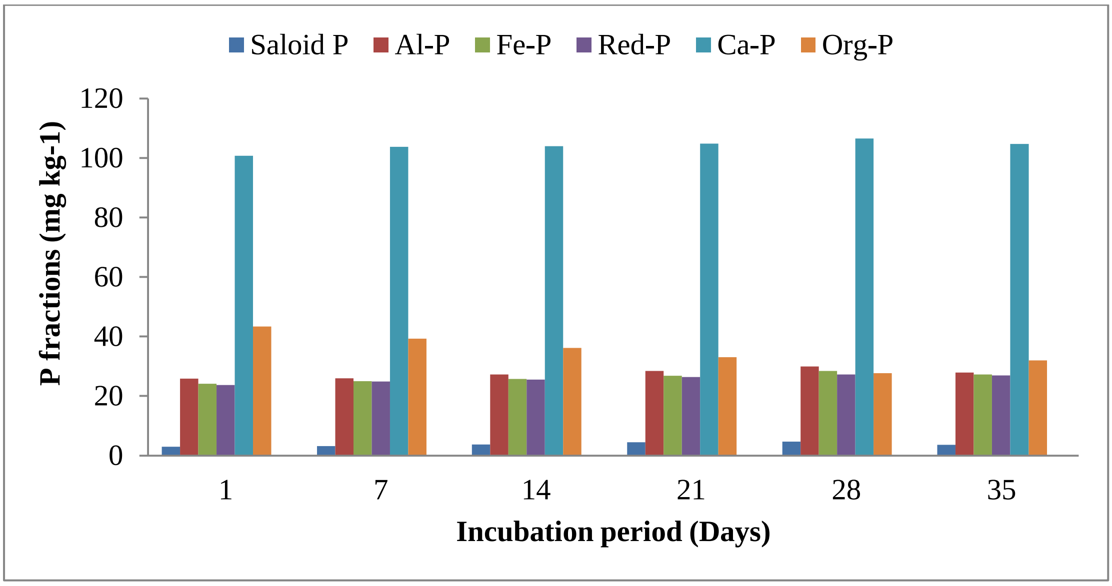

Fig. 4.3: Distribution of P fractions in low P status soil at different days of incubation

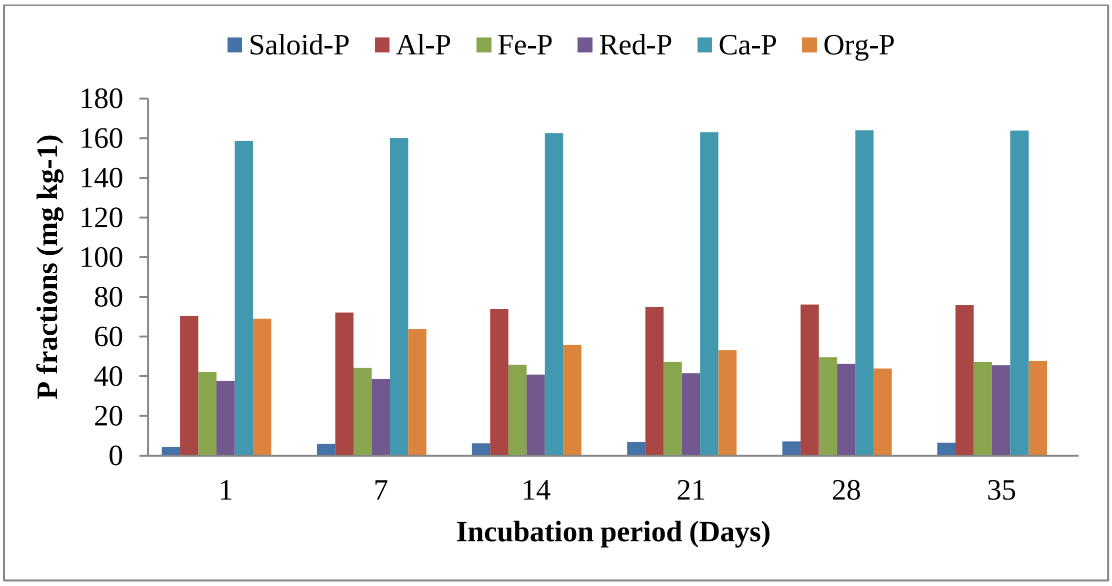

Fig. 4.4: Distribution of P fractions in high P status soil at different days of incubation

4.4.4 Zinc fractions

The Fig 4.5 and 4.6 shows the distribution of various fraction of Zn in low and high P status soil at different days of incubation period. It indicates that the content of various forms of Zn at different days of incubation period was found higher in high P status soil compared to low P status soil. In both the soils, the content of different forms of Zn fractions *i.e.* water soluble exchangeable- Zn (WSEX-Zn), carbonate-Zn (CAR-Zn), iron and manganese-Zn (Fe/MnOX-Zn), organic-Zn (ORG-Zn) and residual-Zn (RES-Zn) content decreased gradually with increase in incubation period *i.e.* from 1 to 35 days. The order of preponderance of different Zn fractions in both soils: RES-Zn > Fe/MnOX-Zn > CAR-Zn > ORG-Zn> WSEX-Zn. Among different Zn fractions, WSEX-Zn was the least form of Zn fraction while residual form of Zn was the most dominant fraction.

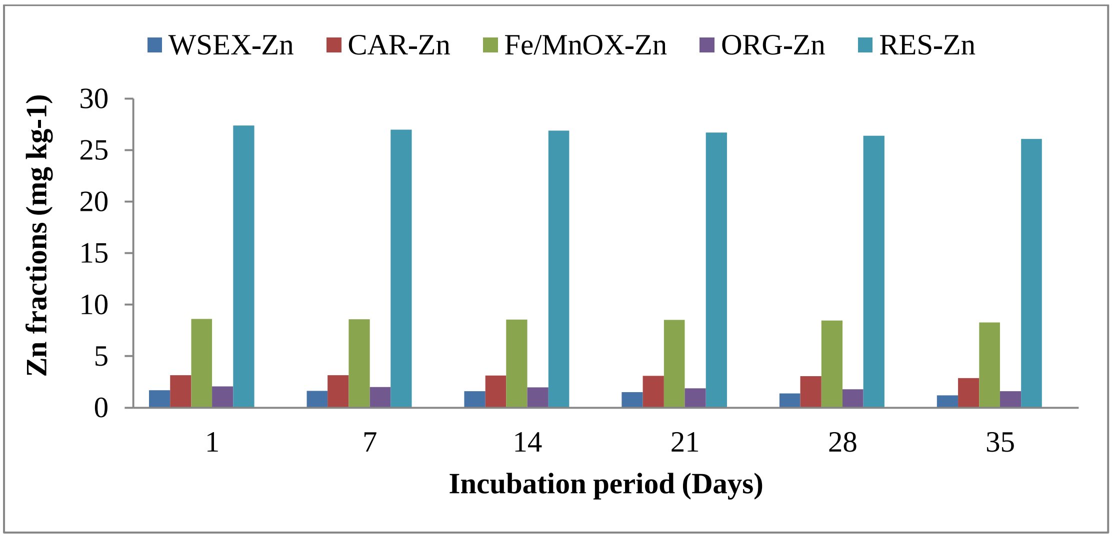

Fig. 4.5: Distribution of various forms of Zn in low P status soil at different days of incubation

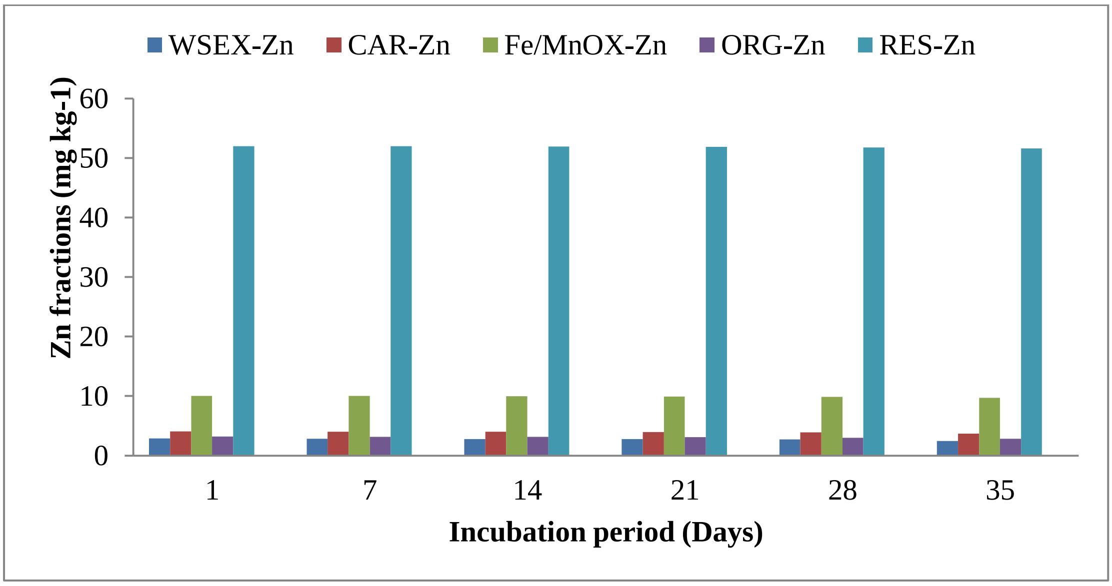

Fig. 4.6: Distribution of various forms of Zn in high P status soil at different days of incubation

CHAPTER- V

DISCUSSION

The results of the experimental study entitled **"Influence of phosphorus and zinc on wheat yield and release behaviour of P and Zn in soils"** presented in the previous chapter are discussed and interpreted in this chapter in light of the scientific evidence to establish cause and effect relationship.

5.1 Initial physico-chemical properties of soils

5.1.1 Soil reaction (pH)

Soil pH is an important measure for determining the acidity and alkalinity of a soil and it influences the crop growth and development by affecting the solubility of ions. From the data given in Table 4.1 it is evident that both of the soils are neutral in reaction.

5.1.2 Electrical conductivity

Electrical conductivity of a soil is the measurement of soluble salts in soil-water system, which also affects the availability of nutrients to the crops. The EC of low P status soil was 0.12 dS m^{-1} and high P status soils 1.0 dS m^{-1} (Table 4.1). It indicates that both the soils are non- saline.

5.1.3 Soil texture

The parent material from which the soil is developed, governs the texture of the soil and it significantly influences the productivity of the soil by altering several soil physical properties. Perusal of the data (Table 4.1) revealed that texture of the low P and high P status soil was sandy and sandy loam, respectively.

5.1.4 Cation exchange capacity

The data in Table 4.1 shows that cation exchange capacity of the low P status and high P status was 4.46 and 9.28 cmol (p^+) kg^{-1}, respectively. The CEC of high P status was higher as compared to the low P status soil.

5.1.5 Organic carbon content

It is revealed from the data given in Table 4.1 that low P status soil was found low in organic carbon content (0.15%) which may be due to rapid organic carbon decomposition in bare exposed soil during summers, excessive nutrient mining in soil, no green manuring and inadequate fertilizer use. The organic carbon content of high P status soil was medium in range *i.e.* 0.62%.

5.1.6 Available N, P, and K

The content of available N, P and K was 28, 8 and 112 kg ha^{-1} in low P status soil and 182, 25 and 430 kg ha^{-1} in high P status soil, respectively (Table 4.1). The content of available N, P and K was low in low P status as compared to high P status soil. The low available nutrient contents in the former soil may be due to sandy soil more prone to erosion, have low organic carbon content and nutrient holding capacity.

5.1.7 DTPA-extractable micronutrients (Zn, Fe, Mn and Cu)

The content of DTPA-extractable Zn, Cu, Fe and Mn was 0.3, 1.94, 2.11 and 2.48 mg kg^{-1} in low P status soil. The content of DTPA-extractable Zn, Cu, Fe and Mn in high P status soil was 0.72, 3.08, 10.26 and 18.74 mg kg^{-1}, respectively. The content of DTPA-extractable micronutrient was comparatively higher in high P status soil as compared to low P status soil which may be due to high cation exchange capacity *i.e.* 9.28 cmol (p^+) kg^{-1}) and high organic carbon content of former soil then later soil.

5.2 Plant analysis

After harvesting of wheat crop, the effect of various levels of P and Zn application on wheat grain and straw yield, nutrient concentrations was recorded and nutrient uptake was calculated. The results obtained were discussed under following heads:

5.2.1 Grain and straw yield of wheat

In low P status soil, the average grain yield of wheat under P and Zn treatments increased from 4.36 to 7.42 and 5.50 to 7.63 g pot^{-1}, respectively and that of average straw yield increased from 5.52 to 10.01 and 7.65 to 9.88 g pot^{-1}, respectively. While in high P status soil, under P and Zn treatment, the average grain yield of wheat increased from 6.81 to 7.10 and 5.98 to 8.23 g pot^{-1}, respectively and that of average straw yield increased from 8.57 to 9.05 and 7.64 to 10.70 g pot^{-1}, respectively (Table 2.2 and 4.3). Application of Zn significantly affected the grain and straw yield in both types of soils while application of P significantly affects the yield of wheat crop only in low P status soil. In low P status soil, in PxZn treatment, the optimum yield of grain (7.84 g pot^{-1}) was recorded at 30 mg P kg^{-1} + 10 mg Zn kg^{-1} level. This might be due to the addition of P along with Zn fertilizer to meet the required level of both the nutrients in low P status soil.

In high P status soil, application of P either alone or in combination with Zn did not have any significant effect on both grain and straw yield. However, application of Zn had significant effect on increasing grain as well as straw yield. This may due to the fact that the application of Zn may favorably influenced various growth processes, enzymatic reactions, hormone production and better translocation of photosynthates to the reproductive parts.

Comparatively higher grain and straw yield were recorded in high P status soil than low P status soil. This might be due to high organic carbon content and high CEC of high P status soil which leads to more nutrient availability and nutrient exchange in the soil. The findings of present study was in agreement with the findings of Jain and Dahama (2006), Arshad *et al*. (2016) and Mishra *et al*. (2017) who reported that grain and straw yields of wheat significantly enhanced with increasing doses of P and Zn and also interactive effect of P and Zn had significantly influenced the yield of wheat.

5.2.2 Concentration of N, P, K and Zn and their uptake by grain and straw

In both types of soils, the application of different levels of P either alone or in combination with different levels of Zn did not have significant effect on concentration of N and K in grain as well as straw (Table 4.4, 4.5, 4.9 and 4.10). In P treatment, increasing level of P increased the mean P content in grain as well as straw in both types of soil (Table 4.6 and 4.7). In low P status and high P status soil, the maximum mean P content in grain (0.32 and 0.37%) and straw (0.028 and 0.032 %) was recorded at 180 mg P kg^{-1} level. However, influence of Zn application either alone or in combination with P did not have any significant effect on P concentration in grain and straw in both the soils. In low and high P status soil, increasing level of Zn form 0 to 10 mg kg^{-1} increased the average Zn content from 19.56 to 24.16 and 23.22 to 28.03 mg kg^{-1} in grain and the corresponding increase in straw was 9.77 to 12.76 and 11.02 to 14.01 mg kg^{-1}, respectively (Table 4.11 and 4.12). However, application of different levels of P either alone or in combination with Zn did not have any significant effect on Zn content of grain and straw in both types of soil.

Application of different level of P alone and their combination with different level of Zn had additive effect on the uptake of N, P, K and Zn by grain and straw (Table 4.12 to 4.19). This may be due to better plant growth and hence more uptakes of nutrients. In low P status soil, highest N uptake by grain and straw *i.e*. 9.70 and 4.54 mg pot^{-1} was recorded with application of 60 mg P kg^{-1} in combination with 10 mg Zn kg^{-1} and 180 mg P kg^{-1} along with 10 mg Zn kg^{-1}, respectively. However, in case of high P status soils, highest N uptake by grain (14.16 mg pot^{-1}) and straw (5.84 mg pot^{-1}) was recorded in treatment combination of 120 mg P kg^{-1} + 10 mg Zn kg^{-1} and 60 mg P kg^{-1} + 10 mg Zn kg^{-1}, respectively. Similar findings were also reported by Singh *et al*. (2004) and Chauhan *et al*. (2014). In low P status soil, highest P uptake by grain (2.44 mg pot^{-1}) was obtained with application 180 mg P kg^{-1} along with 10 mg Zn kg^{-1}. In high P status soil, the effect of P× Zn on P uptake by grain and straw was found to be non-significant; however, highest P uptake by grain (2.88 mg pot^{-1}) was obtained with application 180 mg P kg^{-1} along with 10 mg Zn kg^{-1}. But in case of straw, maximum content of P uptake (0.33 mg pot^{-1}) was recorded at 60 mg P kg^{-1} + 10 mg Zn kg^{-1} level. Comparable findings were also reported by Singh *et al*. (2004), Yang *et al*. (2010), Singh and Singh, (2012) and Arshad *et al*. (2016). In low P status soil, highest K uptake by grain (4.87 mg pot^{-1}) was recorded at 60 mg P kg^{-1} + 10 mg Zn kg^{-1} level, while in case of straw, highest K uptake (10.10 mg pot^{-1}) was recorded with 180 mg kg^{-1} of P applied in combination with 10 mg Zn kg^{-1}. In high P status soil, the effect of PxZn on K uptake by grain and straw was found to be non-significant, however, maximum content of K uptake by grain (4.78 mg pot^{-1}) was recorded with the application of 120 mg P kg^{-1} + 10 mg Zn kg^{-1}. But in case of straw, highest K uptake (12.03 mg pot^{-1}) was recorded at 60 mg P kg^{-1} + 10 mg Zn kg^{-1} level. Similar findings related with concentration and uptake of K were also reported by

Maurya *et al*. (2015) and Mishra *et al*. (2017). In low P status soil, the highest Zn uptake by grain (195.03 µg pot^{-1}) was recorded under the treatment combination of 120 mg P kg^{-1} + 10 mg Zn kg^{-1} while in straw it was recorded maximum (129.32 µg pot^{-1}) when 60 mg P kg^{-1} was applied along with 10 mg Zn kg^{-1}. In high P status soil, the maximum Zn uptake by grain (235.83 µg pot^{-1}) was recorded at 120 mg P kg^{-1}+ 10 mg Zn kg^{-1} level and straw (158.65 µg pot^{-1}) was recorded at 60 mg P kg^{-1}+ 10 mg Zn kg^{-1} level. The present findings are in agreement to the findings of Zhu *et al*. (2001), Yang *et al*. (2010), Zhang *et al.* (2012), Arshad *et al*. (2016) and Mishra *et al*. (2017).

Comparatively higher uptake of N, P, and Zn was recorded in grain as compared to straw, while K uptake was found higher in straw than grain. This might be due to the higher accumulation of N, P and Zn in grains and K in straw. The higher uptake of N, P, K and Zn was recorded in high P status soil as compared to low P status soil. This can be as nutrient uptake is the product of yield (grain or straw) and nutrient concentration (N, P, K or Zn) which were also reported higher in high P status soil. Similar findings were also reported by Maurya *et al*. (2015) and Mishra *et al*. (2017), Mathpal *et al*. (2015) and Ghulam *et al*. (2009).

5.2.3 Protein content

The data related with protein content is given in Table 4.20 and 4.21 and it was reported that individual application of P and Zn and their interaction did not show any definite trend with respect to protein content of wheat in both low P and high P status soils and statistically found non-significant in this investigation. Similar findings were also observed by Xin-kai *et al*. (2012). But the results of present study are contradictory to the findings of Jat *et al.* (2018).

5.3 Post harvest soil analysis

5.3.1 Phosphorus fractions

Increasing level of P significantly influenced the Total-P, Org-P and various inorganic fractions (Saloid-P, Al-P, Fe-P, Red-P and Ca-P), whereas different level of Zn either alone or its application with different level of P did not have any significant effect on these P fractions (Tables 4.22 to 4.28) in both low P and high P status soils. In both soils, all these fractions consistently increased with increase in P application rate. In P treatments, the maximum content of all these fractions was recorded when P applied alone at its highest rate *i.e*. 180 mg P kg^{-1}. Similar finding of maximum P fractions content with highest dose of P was also reported by Kumar *et al*. (2013) and Chandrakala *et al.* (2017). This might be due to the transformation of added P into the different unavailable forms of P. The concentrations of these fractions were found high in high P status soil as compared to the low P status soil. Similar findings related with high values of P fractions in soils of high available P content was reported by Nayak and Patel (2016). This might be due to difference in initial level of available P, organic matter content of soils and texture of soil. Ojo *et al*. (2015) also reported that the differences in values of P fractions in soils are significantly influenced by soil types. Increase in rate of P fertilization increases the P fractions which are also found in agreement with the findings of Murthy *et al*. (2002), Sihag *et al*. (2005), Setia and Sharma (2007) and Kaur *et al*. (2015).

The saloid-P content in low P and high P status soil ranged from 2.82 to18.04 mg kg^{-1} and 4.07 to 20.30 mg kg^{-1}, respectively (Table 4.22). The higher amount of saloid-P in high P status soil may be due to the slow transformation of soluble forms of P applied into relatively less soluble forms with progress of time. The results were found in conformity with the findings of Singh and Sharma (2007) and Singh *et al*. (2016). The Al-P content ranges from 24.98 to 79.24 mg kg^{-1} in low P status soil and 70.34 to 142.64 mg kg^{-1} in high P status soil (Table 4.23). From the results of the data given in Table 4.24, it is clear that the higher values of Fe-P content was found in high P status (ranges from 37.10 to 100.10 mg kg^{-1}) as compared to its values in low P status soil (ranges from 22.47 to 83.96 mg kg^{-1}). Relatively higher content of Al-P and Fe-P in high P status soil might be due to presence of sesquioxides which might have transformed a portion of applied P into these forms. The Red-P content in soils of low P status and high P status varied from 21.17 to 82.73 mg kg^{-1} and 32.02 to 89.01 mg kg^{-1}, respectively (Table 4.25). The increase in biomass and biological activity might have suppressed the formation of this form and thereby causing increase in the content of Ca-P and Al-P (Kaur *et al*., 2015). The content of Ca-P in low P and high P status soils varied from 100.28 to 149.00 mg kg^{-1} and 152.30 to 251.60 mg kg^{-1}, respectively (Table 4.26). The highest content of Ca-P among different P fractions might be due to neutral pH and calcareous nature of the soil. The dominance of Ca-P fraction in these soils was also more or less correlated with the findings of Devra *et al*. (2014) who reported that Ca-P was the dominant inorganic P fraction in soils of Rajasthan having high $CaCO_3$ and pH range in between 7.04 to 9.98. The data given in Table 4.27 shows that the Org-P content in low P status soil varied from 47.24 to 145.21 mg kg^{-1} whereas in high P status soils it ranged from 61.01 to 248.17 mg kg^{-1}. The differences in values of both soils might be due to the difference in organic matter content, clay content and total-P content in both soils. The results are in agreement with the findings of Singh *et al*. (2016) and Lungmuana *et al*. (2012). The total-P content presented in Table 4.28 revealed that in low P status soil it ranges from 220.77 to 558.18 mg kg^{-1} whereas in high P status it varied from 362.78 to 851.82 mg kg^{-1}. The higher values of total-P in high P status soil may be due to the higher clay content of the soil as compared to the low P status soil. Mahmood *et al*. (2003) also reported high concentration of total-P in heavy soil in comparison to the light soil. Among these various P fractions, Ca-P was the dominant form whereas Saloid-P was present in the least amount in both soils. Kaur *et al*. (2015), Singh and Sharma, (2007) and Kalaivanan and Sudhir, (2012) also reported the similar results. The relative abundance of these fractions was same in both soils and in the following order Ca-P > Org-P > Al-P > Fe-P > Red-P > Saloid-P. Similar trend of abundance of different forms of P fractions were also reported by Chandrakala *et al*. (2017) and Patle *et al*. (2019).

5.3.2 Zinc fractions

In Zn treatment, application of different levels of Zn significantly enhanced the total-Zn and various Zn fractions (WSEX-Zn, CAR-Zn, Fe/MnOX-Zn, ORG-Zn and RES-Zn) content (Tables 4.29 to 4.34). However, graded levels of P adversely affected the different Zn fraction in low and high P status soil. Mandal and Mandal, (1986) also reported negative relation between addition of P on Zn fractions content. Total-Zn content is the sum of all forms of Zn fractions. The total-Zn content varied from 47.65 to 79.69 mg kg^{-1} and was considerably higher in high P status as compared to the low P status soil in which it ranges from 32.42 to 47.61 mg kg^{-1} (Table 4.34). The differences in values of total-Zn may be due to type and nature of parent materials or relative amount of clay content in the soil. Similar results were also reported by Chahal *et al*., 2005 and Sharma *et al*., 2004. The content of WSEX-Zn was slightly higher in high P status soil as compared to low P status soil. The content of WSEX-Zn, CAR-Zn, Fe/MnOX-Zn, ORG-Zn and RES-Zn in low P status soil was found in the range of 0.09 to 0.69, 0.77 to 1.64, 3.00 to 7.86, 1.29 to 2.80 and 22.88 to 32.93 mg kg^{-1}, respectively. Similarly, the corresponding values of these fractions for high P status soil were 0.20 to 0.72, 1.00 to 2.26, 4.70 to 9.56, 1.47 to 6.20 and 28.71 to 48.33 mg kg^{-1}, respectively. The contribution of various Zn fractions to total-Zn in relations to their contents in both the soils followed the order: RES-Zn > Fe/MnOX-Zn > ORG-Zn > CAR-Zn > WSEX-Zn. The results are in close proximity to the findings of Jangir *et al*. (2018). It was reported that RES-Zn fraction was the dominant fractions in both the soils. The large amount of this fraction may be due to sorption of Zn with minerals which might not be available for exchange with soil solution and considered as non labile fraction of Zn. The results are in agreement with the findings of Jangir *et al*. (2018), Spalbar *et al*. (2017), Suresh Kumar *et al*. (2004) and Singh *et al*., (2011). The Fe/MnOX-Zn was 2^{nd} dominant after RES-Zn among various Zn fractions. The higher content of this form may be due to the higher affinity of fixation sites with the oxides of iron and manganese having large surface area. Similar findings were also reported by Tehrani (2005), Bahera *et al*. (2008) and Nisab & Ghosh, (2019). The contribution of ORG-Zn was also considerable next to the oxides bound Zn. The highest range of this fraction was measured in high P status soil having relatively higher organic carbon content as compared to low P status soil. The results are in accordance with the findings of Chahal *et al*. (2005), Adhikari and Rattan, (2007) and Bahera *et al*. (2008). The results of CAR-Zn in this study are similar to the findings of Ramzan *et al*. (2014) and probably contribute to the availability of the soil Zn (Chirwa and Yerokun, 2012). The WSEX-Zn was the least dominant fraction. The reason for low concentration of WSEX-Zn might be due to the fixation of soluble Zn by oxides and carbonates in soil as reported by Saviour and Stalin, (2014) and Chatterjee *et al*. (1992). The results are in conformity with the findings of Nisab and Ghosh, (2019); Spalbar *et al*., (2017) or might be due to high buffering capacity of soils (Ramzan *et al*. 2014). The relative content of all these fractions was high in high P status soil as compared to the low P status soil. The variations in the concentrations of these forms of Zn in both soils may be due the texture, clay content, OC content or P and Zn fertilization. Similar findings were also reported by Nisab and Ghosh, 2019; Behera *et al*., 2008; Adhikari and Rattan, 2007; Chahal *et al*. 2005 and Mandal and Mandal, 1986.

5.4 Release behaviour and P and Zn fractions in different P status soils

5.4.1 Olsen's P

The periodical changes in Olsen's P content in low P status soil showed that with the progress of incubation period, available P gradually increased up to 21 DAI and after that it decreased as the incubation period further proceed to 35 DAI. Similarly, in high P status soil also, a consistent increase in available P was noticed but up to 28 DAI and it declined with further increase in incubation period (35 DAI), Fig. 4.1. The content of Olsen-P was higher in high P status soil as compared to the low P status soil. This may be due to the high initial P and higher OC content of high P status soil. The results of the study are in agreement with the findings of Kaloi *et al.* (2001) and Rajput *et al*. (2014) They reported that high organic matter content resulted in lesser P adsorption whereas high clay in combination with calcium carbonate contents increased the adsorption of P. Similar results regarding P release behaviour increased through incubation period was also reported by Dey *et al*. (2019) and McDowell and Sharpley, (2003).

5.4.2 DTPA-extractable Zn

The DTPA-extractable Zn gradually decreased with the increase in incubation period up to 35 days after incubation (DAI) in both low P and high P status soils. However, slightly higher amount of DTPA-extractable Zn was recorded at 1 DAI as compared to its initial values in both the soils. The content of DTPA-extractable Zn was higher in high P status soil as compared to the low P status soil. This might be due to difference in their initial amount of soil Zn, texture and presence of relatively higher amounts of sesquioxides. Singh *et al.* (2006), Talukder *et al*. (2011) and Ghasemi-Fasaei *et al*. (2012) also reported similar release behaviour of Zn and reported that longer the contact time of Zn with soils resulted in the lesser desorption of both native and added Zn.

5.4.3 Phosphorus fractions

The content of various P fractions varied with the progress of incubation period (1 to 35 DAI) in both low P and high P status soils (Fig 4.3 and 4.4). The content of various P fractions like saloid-P, Al-P, Fe-P and Red-P in both low P and high P status soils increased with increase in incubation period up to 28 DAI and then the content of these fractions declined with further increase in incubation period. Whereas, content of Org-P decreased initially up to 28 DAI and thereafter it increased with increase in incubation period. The content of various P fractions was found higher in high P status soil as compared to the low P status soil. It was also noticed that in both the soils, Ca-P was the most dominant fraction and saloid-P was the least. The order of relative abundance of these inorganic P fractions in both soils followed the order: Ca-P > Al-P > Fe-P > Red-P > Saloid-P. The obtained results of this study were in conformity with the findings of Kumar *et al.* (2015) and Pant *et al*. (2017) who also found the similar trend of P fractions and availability of Ca-P as dominant P fraction in alluvial soil.

5.4.4 Zinc fractions

The results of the periodical changes in different forms of Zn fractions (Fig 4.5 and 4.6) showed that the content of various Zn fractions (WSEX-Zn, CAR-Zn, Fe/MnOX-Zn, ORG-Zn and RES-Zn) consistently decreased with the increase in incubation period from 1 to 35 DAI in both low and high P status soils. However, the amount of different fractions was higher in high P status soil as compared to the low P status soil. Among different Zn fractions WSEX-Zn was the least form of Zn fraction while residual form of Zn was the most dominant fraction. It was recorded that order of contribution of different fractions towards total-Zn was RES-Zn > Fe/MnOX-Zn > CAR-Zn > ORG-Zn > WSEX-Zn which remained same in both the soils. Similar findings about order of Zn fractions and their release behaviour were also reported by Preetha and Stalin (2014) and Saviour and Stalin (2014).

CHAPTER- VI

SUMMARY AND CONCLUSION

An investigation entitled **"Influence of phosphorus and zinc on wheat yield and release behaviour of P and Zn in soils"** was conducted during *rabi* season of 2018-19 at Screen House, Department of Soil Science, CCS Haryana Agricultural University, Hisar, Haryana (India). The summary and conclusion of research findings is being presented here in this chapter. The salient findings of research problem and conclusion drawn are given here under following heads:

6.1 Initial physico-chemical properties of soils

The low P status soil was found to have pH 7.4, EC 0.12 dS m^{-1}, OC 0.15%, CEC 4.46 cmol (p^+) kg^{-1} and sandy in texture. The available N, P and K content 28, 8 and 112 kg ha^{-1} and DTPA extractable Zn, Cu, Fe and Mn 0.30, 1.94, 2.11 and 2.48 mg kg^{-1}, respectively. Whereas, high P status soil have pH 7.1, EC 1.0 dS m^{-1}, OC 0.62%, CEC 9.28 cmol (p^+) kg^{-1} and sandy loam in texture. The available N, P and K content 182, 25 and 430 kg ha^{-1} and DTPA extractable Zn, Cu, Fe and Mn 0.72, 3.08, 18.74 and 10.26 mg kg^{-1}, respectively.

6.2 Grain and straw yield of wheat in low P and high P status soil

In low P status soil, the average grain yield of wheat under P and Zn treatments increased from 4.36 to 7.42 and 5.50 to 7.63 g pot^{-1} and that of average straw yield increased from 5.52 to 10.01 and 7.65 to 9.88 g pot^{-1}, respectively. While in high P status soil, the average grain yield of wheat increased from 6.81 to 7.10 and 5.98 to 8.23 g pot^{-1} and that of average straw yield increased from 8.57 to 9.05 and 7.64 to 10.70 g pot^{-1} with the application of P and Zn, respectively. In low P status soil, in PxZn treatment, the optimum yield of grain (7.84 g pot^{-1}) was recorded at 30 mg P kg^{-1} + 10 mg Zn kg^{-1} level. In high P status soil, application of P either alone or in combination with Zn did not have any significant effect on both grain and straw yield.

6.2.1 Concentration, nutrient uptake and protein content

In both types of soil, different level of P and Zn did not have any significant effect on the N, K and protein content in grain and straw in both soils. In low P status and high P status soil, increasing level of P significantly affect the P content in grain and straw and the maximum P content in grain (0.32 and 0.37%) and straw (0.028 and 0.032 %) was recorded at 180 mg P kg^{-1} level. In both types of soil, in Zn treatment, application of Zn significantly affect the Zn content in grain and straw In low and high P status soil, increasing levels of Zn from 0 to 10 mg kg^{-1} increased the average Zn content from 19.56 to 24.16 and 23.22 to 28.03 mg kg^{-1} in grain and the corresponding increase in straw was 9.77 to 12.76 and 11.02 to 14.01

mg kg^{-1}, respectively. Application of different levels of P and Zn either alone or their combination had additive effect on the uptake of N, P, K and Zn by grain and straw. The application of P and Zn either alone or in combination did not had any significant influence on the protein content of grain and straw in both low P and high P status soils.

6.3 P fractions

In P treatment, application of increasing level of P from 0 to 180 mg kg^{-1} significantly increased the Saloid-P from 2.88 to 17.75 mg kg^{-1} and 4.23 to 19.66 mg kg^{-1}; Al-P from 25.59 to 74.42 mg kg^{-1} and 72.31 to 137.33 mg kg^{-1}; Fe-P from 23.52 to 82.42 mg $kg^{-1}$and 39.81 to 95.67 mg kg^{-1}; Red-P from 22.21 to 81.19 mg $kg^{-1}$and 34.74 to 88.4 mg kg^{-1}; Ca-P from 101.14 to 145.25 mg kg^{-1} and 153.95 to 244.77 mg kg^{-1} and Org-P from 53.14 to 135.15 mg kg^{-1} and 71.33 to 240.68 mg kg^{-1} and Total-P from 228.47 to 536.17 mg kg^{-1} and 376.37 to 826.52 mg kg^{-1} in low and high P status soil, respectively. The maximum content of these fractions was reported at highest dose of P in both types of soils. But the effect of different levels of Zn and PxZn on different forms of P fractions was found to be non-significant in both soils. The concentration of different forms of P fractions was higher in high P status soil as compared to low P status soil. Among various P fractions Ca-P was the most dominant form and Saloid-P was the least abundant form of P fraction in both soils. The relative order of abundance of different forms of P fractions was Ca-P > Org-P > Al-P > Fe-P > Red-P > Saloid-P which remained same in both soils.

6.5 Zn fractions

In low and high P status soils, in Zn treatment, application of different level of Zn significantly affect the WSEX-Zn, CAR-Zn, Fe/MnOX-Zn, ORG-Zn, RES-Zn and total-Zn content. In low and high P status soil, the content of WSEX-Zn increased from 0.12 to 0.43 mg kg^{-1} and 0.29 to 0.51 mg kg^{-1}; CAR-Zn from 0.90 to 1.22 mg kg^{-1} and 1.32 to 1.57 mg kg^{-1}; Fe/MnOX-Zn from 4.13 to 5.64 mg kg^{-1} and 5.83 to 7.34 mg kg^{-1}; ORG-Zn from 1.76 to 1.96 mg kg^{-1} and 2.45 to 3.88 mg kg^{-1}; RES-Zn from 25.22 to 28.68 mg kg^{-1} and 35.80 to 39.46 mg kg^{-1}, respectively. Whereas graded levels of P adversely affected the different Zn fraction. The residual Zn contributed the most of residual Zn while water soluble exchangeable-Zn contributed least to the Total-Zn content of both soils. The distribution of various Zn fraction in low P status soil as well as high P status soil was in the order RES-Zn > Fe/MnOX-Zn > ORG-Zn > CAR-Zn > WSEX-Zn.

6.6 Release behaviour of P and Zn fractions

The Olsen's P content increased with increase in incubation period up to 21 days in low P status soil and up to 28 days in high P status soil and then decreased thereafter in both soils with the progress of incubation period whereas the DTPA-extractable Zn content gradually decreased with progress of incubation time up to 35 DAI in both low P and high P status soil. The concentration of various P fractions like Saloid-P, Al-P, Fe-P and Red-P in both low P and high P status soils increased with increase in incubation period up to 28 DAI and then decreased with further increase in incubation period while the content of Org-P get reduced initially up to 28 DAI in both soils and increased thereafter as the incubation period further proceeded. However, the content of various fractions of Zn consistently decreased with increase in incubation period in both soils.

Conclusion

Combined application of 30 mg P kg^{-1} along with 10 mg Zn kg^{-1} was found to be the optimum fertilizer dose for higher yield of both grain and straw in low P status soil. Whereas in case of high P status soil highest crop yield of wheat can be achieved with application of 10 mg Zn kg^{-1} alone. In both types of soil, the relative abundance of different P fractions was in the order: Ca-P > Org-P > Al-P > Fe-P > Red-P > Saloid-P. The order of preponderance of various Zn fractions was RES-Zn > Fe/MnOX-Zn > ORG-Zn > CAR-Zn > WSEX-Zn in both the soils.

The release of Olsen's P was first increased up to 21 and 28 days in low and high P status soil, respectively. Release of different forms of P fractions in both soils increased up to 28 DAI and then decreased with further increase in incubation period. However, DTPA-extractable Zn and various Zn fractions decreased consistently with increase in incubation period (up to 35 DAI). The order of distribution of various P and Zn fractions in incubation study was found similar to the order of post-harvest analysis of P and Zn fractions.

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Appendix I: Release of Olsen's P and DTPA- extractable Zn at different days after incubation in low P and high P status soils

Incubation period (Days)	Olsen's P (kg ha^{-1})		DTPA-extractable Zn (mg kg^{-1})	
	Sadalpur soil	Saniyana soil	Sadalpur soil	Saniyana soil
1	7.91	24.87	0.34	0.76
7	8.63	30.50	0.32	0.74
14	12.60	38.40	0.30	0.72
21	17.40	79.49	0.29	0.70
28	11.20	98.01	0.27	0.67
35	9.10	87.93	0.21	0.60

Appendix II: Distribution of various phosphorus fractions at different days after incubation in low and high P status soil

Incubation period	Phosphorus fractions (mg kg^{-1})						
	Low P status soil						
	Saloid-P	Al-P	Fe-P	Red-P	Ca-P	Org-P	Total-P
1	2.98	25.83	24.1	23.69	100.73	43.36	220.69
7	3.12	25.95	24.94	24.9	103.72	39.25	221.88
14	3.72	27.22	25.75	25.5	103.96	36.19	222.34
21	4.5	28.41	26.8	26.4	104.86	33.01	223.98
28	4.65	29.96	28.4	27.21	106.59	27.64	224.45
35	3.6	27.84	27.25	26.88	104.7	31.97	222.24
High P status soil							
1	4.20	70.60	42.15	37.59	158.75	69.11	382.40
7	5.86	72.18	44.28	38.67	160.15	63.76	384.9
14	6.20	73.99	45.88	40.86	162.54	55.85	385.32
21	6.82	75.12	47.25	41.45	163.12	53.14	386.90
28	7.11	76.20	49.64	46.31	163.98	43.97	387.21
35	6.55	75.80	47.10	45.60	163.85	47.86	386.76

Appendix III: Distribution of various Zn fractions at different days after incubation in low and high P status soil

Incubation period	Zinc fractions (mg kg^{-1})					
	Low P status soil					
	WSEX-Zn	CAR-Zn	Fe/MnOX-Zn	ORG-Zn	RES-Zn	Total-Zn
1	1.70	3.16	8.60	2.06	27.4	42.92
7	1.64	3.14	8.57	2.00	27.00	42.35
14	1.59	3.11	8.54	1.97	26.88	42.09
21	1.50	3.09	8.51	1.88	26.70	41.68
28	1.39	3.05	8.47	1.78	26.39	41.08
35	1.21	2.87	8.26	1.61	26.10	40.05
High P status soil						
1	2.85	4.06	10.03	3.18	52.00	72.12
7	2.82	4.02	10.00	3.16	51.97	71.97
14	2.79	3.99	9.98	3.13	51.94	71.83
21	2.75	3.96	9.92	3.08	51.89	71.6
28	2.69	3.88	9.87	2.99	51.80	71.23
35	2.46	3.67	9.69	2.80	51.59	70.21

ABSTRACT

Title of thesis		Influence of phosphorus and zinc on wheat yield and release behaviour of P and Zn in soils
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Admission No.		2018A92M
Title of degree		M.Sc. (Soil Science)
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Degree awarding University		CCS Haryana Agricultural University,
		Hisar- 125 004 (Haryana), India.
Year of award of degree		2020
Major subject		Soil Science
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No. of words in the abstract		679

Keywords: Wheat crop, low P status soil, high P status soil, P fraction, Zn fraction, incubation study, nutrient concentration, and protein content

The present study entitled "Influence of phosphorus and zinc on wheat yield and release behaviour of P and Zn in soils" was carried out during *rabi* season 2018-19 in the Department of Soil Science, CCS HAU, Hisar (Haryana). A pot experiment was conducted using wheat (variety WH 1105) as test cop with five levels of P (0, 30, 60, 120 and 180 mg P kg^{-1}) and four level of Zn 0, 2.5, 5 and 10 mg Zn kg^{-1}) in two different P status soils.

Both the soils were neutral in reaction and non-saline. The OC of low P status soils was 0.15%, CEC 4.46 cmol (p^+) kg^{-1}available N, P and K content 28, 8 and 112 kg ha^{-1}, respectively. The OC content of high P status soils was 0.62%, CEC 9.28 cmol (p^+) kg^{-1}, available N, P and K content 182, 25 and 430 kg ha^{-1}, respectively. The DTPA extractable Zn, Cu, Fe and Mn content in soil was 0.30, 1.94, 2.11 and 2.48 mg kg^{-1} in low P status soil whereas corresponding value of these parameters in high P status soil was 0.72, 3.08, 18.74 and 10.26 mg kg^{-1}. The texture of low and high P status soil was sandy and sandy loam. In low P status soil, significantly higher yield of grain and straw (7.84 and 10.11g pot^{-1}, respectively) was recorded with the application of 30 mg P kg^{-1} + 10 mg Zn kg^{-1} over control. In high P status soil, in Zn treatment, maximum grain and straw yield (8.23 and 10.73 g pot^{-1}, respectively) was recorded at 10 mg Zn kg^{-1} level. In both types of soils, the application of different level of P and Zn did not have any significant effect on N, K and protein content of grain and straw. In P treatment, the highest content of P in grain and straw in both soils was recorded with application of highest level of P (180 mg kg^{-1}) and in Zn treatment, similar was true for Zn content. In low P status soil, the uptake of N and K by grain was maximum (9.70 and 4.87 mg pot^{-1}, respectively) in 60 mg P kg^{-1} + 10 mg Zn kg^{-1} treatment. In case of high P status soil, maximum N uptake by grain (14.16 mg pot^{-1}) was recorded in 120 mg P kg^{-1} + 10 mg Zn kg^{-1} treatment, while K uptake by grain was recorded highest (4.78 mg pot^{-1}) in 120 mg P kg^{-1} + 10 mg Zn kg^{-1}. In low and high P status soil, the maximum P uptake by grain (2.36 and 2.88 mg pot^{-1}) was recorded in 120 mg P kg^{-1} + 10 mg Zn kg^{-1} and 180 mg P kg^{-1} + 10 mg Zn kg^{-1} treatment, respectively. The maximum Zn uptake by grain (195.03 µg pot^{-1}) in low P status soil was recorded in 120 mg P kg^{-1} + 10 mg Zn kg^{-1}.But in high P status soil it was recorded maximum (236.82 µg pot^{-1}) in 10 mg Zn kg^{-1} treatment. Among the various P fractions Ca-P was the predominating fraction in both soils. The order of relative abundance of different P fractions in both soil was Ca-P > Org-P > Al-P > Fe-P > Red-P > Saloid-P. The distribution of various Zn fraction in low and high P status soil was in the order RES-Zn > Fe/MnOX-Zn > ORG-Zn > CAR-Zn > WSEX-Zn. In incubation study, the content of available P release from soil increased up to 21 and 28 days in low and high P status soil and then decreased with further increase in incubation period. Whereas, the content of DTPA-extractable Zn released from both types of soils decreased with increase in incubation period. In both soils, the content of various P fractions consistently increased with increasing incubation period up to 28 DAI and then decreased in the later period of incubation, whereas content of Zn fractions decreased consistently with increase in incubation period. In general, the content of different P and Zn fractions was found higher in high P status soil as compared to low P status soil.

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I, hereby, declare that all the information given in the resume are true to the best of my knowledge.

Date: July 28, 2020 **(Sunitha Fogat)**

Place: Bawal, Haryana

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I**, Sunitha Fogat,** Admn. No. **2018A92M** undertakes that I give copy right to the CCS HAU**,** Hisar of my thesis entitled **"Influence of phosphorus and zinc on wheat yield and release behaviour of P and Zn in soils".** I also undertake that patent, if any, arising out of the research work conducted during the programme shall be filed by me only with due permission of the competent authority of CCS HAU, Hisar.

(Sunitha Fogat)