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Influence of Different Rates of Phosphorus and Zinc Application to Micronutrients Uptake and DTPA Extractable Fe, Mn, Zn and Cu Status after Wheat (*Triticum aestivum* L.) Harvesting

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present study aimed to determine the influence of Different Rates of Phosphorus and Zinc Application to Micronutrients uptake and DTPA Extractable Fe, Mn, Zn and Cu status after wheat (*Triticum aestivum* L.) harvesting. Organic source of plant nutrients helps in increasing soil organic

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matter and improving soil environments as well as meeting a part of the nutrients need of crops. Organic matter like FYM also helped in improving the micronutrient status of soil. Zn, Fe and Mn play very important role in photosynthesis and growth of plants. A field trial was conducted at Agronomy Instructional Farm, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar, during *Rabi* season of 2020-21. The experiment encompassed of two aspects each having four levels of phosphorus (P_0–0 kg P_2O_5 ha^{-1}, P_1–30 kg P_2O_5 ha^{-1}, P_2–60 kg P_2O_5 ha^{-1} and P_3–90 kg P_2O_5 ha^{-1}) and zinc (Zn_0–0 kg Zn ha^{-1}, Zn_1–2.5 kg Zn ha^{-1}, Zn_2–5.0 kg Zn ha^{-1} and Zn_3–7.5 kg Zn ha^{-1}). A total of sixteen treatment combinations were laid out in randomized block design with factorial concept and replicated three times. Results revealed that different levels of phosphorus were found to be non-significant with respect to iron, manganese, zinc and copper content in grain and straw of wheat. But, significantly the highest Zn content in grain and straw was observed with the application of Zn @ 7.5 kg ha^{-1}. Whereas, significantly the highest Fe, Mn, Zn and Cu uptake by grain and straw was observed with the application of 90 kg P_2O_5 ha^{-1} and Zn @ 7.5 kg ha^{-1}; which remained at par with 60 kg P_2O_5 ha^{-1} and 5.0 kg Zn ha^{-1}. Hence, significantly the highest DTPA-extractable Zn content in soil after harvest was recorded with the application of 7.5 kg Zn ha^{-1}; which remained at par with 5.0 kg Zn ha^{-1}. It is concluded that application of 90 kg P_2O_5 ha^{-1} and Zn @ 7.5 kg ha^{-1} significantly increased the iron, zinc, manganese and copper uptake as well as DTPA-extractable Zn status after harvest of wheat.

Keywords: Phosphorus; zinc; wheat; micronutrient; uptake; soil.

1. INTRODUCTION

"Wheat is the prevailing grain crop of world commerce. It is a significant ingredient in the daily diet of millions of people. It plays an imperative role in the human diet and also provides a strong monetary support to the country" (Singh et al*.,* 2018). "Wheat is an exhaustive crop which requires the major and micronutrients in adequate amounts for higher production. Wheat is quite responsive to phosphorus and zinc, which plays an important role in growth and development of this crop. Zinc is essential for promoting certain metabolic reactions. It is necessary for the production of chlorophyll and carbohydrates. Zinc is directly or indirectly required by several enzyme systems, auxin and protein synthesis" (Singh et al., 2020; Yousaf et al., 2019). "In high-input agriculture, deficiency of micronutrients has become a major constraint to the productivity, stability and sustainability of soils. These deficiencies appeared much faster primarily due to the fast adoption of new agricultural technology, including cultivation of high-yielding crop varieties, increase in cropping intensity, expansion of irrigation facilities, more use of high-analysis fertilizers and poor-quality irrigation water. Among micronutrients, Zn is now regarded as the third most limiting nutrient element in crop production after N and P. The extent of Fe deficiency in India is next to the Zn. About 11% of Indian soils are deficient in iron and recently Mn has become critical. Cereal crops are inherently very low in grain Zn and Fe concentrations and growing them on potentially Zn and Fe-deficient soils further reduces Fe and Zn concentrations in grain (Cakmak et al*.,* 2010). Organic source of plant nutrients helps in increasing soil organic matter and improving soil environments as well as meeting a part of nutrient needs of crops. Organic matter like FYM also helped in improving the micronutrient status of soil. Zn, Fe and Mn play very important roles in the photosynthesis and growth of plants. To obtain high yields without deterioration of soil fertility, it is important to workout optimal combination of fertilizers and manures in the cropping system" (Pullicinoa et al*.,* 2009).

"Phosphorus (P) is also an essential nutrient required by plants for normal growth and development. It plays a vital role in virtually every plant process like photosynthesis, energy storage and transfer, stimulating root development and growth, giving plants rapid and vigorous start leading to better tillering in wheat and encouraging earlier maturity and seed formation. Phosphorus is a component of DNA and RNA, which carries genetic information used to synthesize proteins. It also has a significant role in sustaining and building up soil fertility, particularly under the intensive system of agriculture. But phosphorus is one of the most immobile, inaccessible and unavailable nutrients present in the soil. Deficiency of soil phosphorus is one of the important chemical factors restricting plant growth in soil. Therefore, a sufficient quantity of soluble form of phosphorus fertilizers is applied to achieve maximum plant productivity. However, the applied soluble forms of phosphatic fertilizers rapidly become unavailable to plants by conversion into inorganic P fractions that are fixed by chemical adsorption and precipitation. Similarly, organic P fractions are immobilized in soil organic matter" (Cakmak, 2008).

"Zinc and iron deficiencies are well-documented public health issues affecting nearly half of the world population especially in developing countries like India. Zinc and iron deficiencies are the common micronutrient deficiencies in light textured soils of North Gujarat limiting both crop production and nutritional quality. Further, very low concentrations and poor bioavailability of Zn and Fe in the commonly used cereals aggravated the micronutrient deficiencies". (Malav et al. 2019) "The structural elements of growth, hormones and chlorophyll both depend on zinc as it participates in a variety of enzymatic processes. Zinc is essential for the healthy growth and reproduction of plants, animals and people. Zinc plays a crucial role in significant biochemical pathways, serving as a structural component or regulatory cofactor for various enzymes and proteins involved in protein metabolism, auxin metabolism (growth regulation), membrane integrity, and pathogen resistance" (Nawaz et al., 2024). "Breeding new cereal genotypes with high genetic capacity for grain accumulation of micronutrients is a widely accepted and sustainable solution to the problem. However, the breeding approach is a long-term process and may be affected by very low chemical solubility of Zn and Fe in soils due to high pH and low organic matter" (Cakmak, 2008). "Therefore, agronomy-related approaches offer short-term and complementary solutions to the Zn and Fe deficiency in crop production and human health. Soil amendments contributing to the solubility of Zn and Fe in soil solution, cereal-legume intercropping systems, and soil and foliar application of micronutrient-containing fertilizers are well-documented agronomic tools which contribute to root uptake, shoot and grain accumulation of Fe and Zn. Addition of organic material had a beneficial effect on crop growth, and productivity by sustaining soil health". (Malav et al. 2019)

2. MATERIALS AND METHODS

A field experiment was carried out during *Rabi*, season 2020-21. The experiment was carried out at Agronomy Instructional Farm, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Banaskantha (Gujarat) during *Rabi*, season 2020-21. Geographically, this place is located at 72°19' East longitude and 24°19' North latitude at 154.52 meters above the mean sea level and situated in North Gujarat agro-climatic zone of Gujarat state. The soil of the experimental field had a uniform topography with a gentle slope with good drainage. In order to know the physico-chemical properties of the soil before sowing a composite soil sample was taken from the experimental field to know the initial status of nutrients in soil as well as physico-chemical properties of soil. The soil of the experimental field was loamy sand in texture with neutral in reaction (pH 7.01) and electrical conductivity within the safe limit (0.19 dSm^{-1}). The soil was low in organic carbon content (0.39 %), DTPA-extractable Fe (2.59 mg kg^{-1}), DTPA-extractable Mn (4.51 mg kg^{-1}); medium in available P_2O_5 (41.26 kg ha^{-1}), K_2O (162.65 kg ha^{-1}), DTPA– extractable Zn (0.71 mg kg^{-1}) and DTPA– extractable Cu.

The experiment consisted of two factors each having four levels of phosphorus (P_0 - 0 kg P_2O_5 ha^{-1}, P_1 – 30 kg P_2O_5 ha^{-1}, P_2 – 60 kg P_2O_5 ha^{-1} and P_3 - 90 kg P_2O_5 ha^{-1}) and zinc (0 kg Zn ha^{-1}, 2.5 kg Zn ha^{-1}, 5.0 kg Zn ha^{-1} and 7.5 kg Zn ha^{-1}. A total of sixteen treatment combinations were laid out in randomized block design with factorial concept and replicated three times. Wheat variety GW- 451 was sown at a row distance of 22.5 cm. The weather conditions were almost favorable for the crop growth and there was no any severe attack of insect and disease during the course of investigation.

3. RESULTS AND DISCUSSION

Grain and Straw Yield: Data presented in Table 1 illustrated that the application of phosphorus had a significant effect on grain and straw yield of wheat. The treatment 90 kg P_2O_5 ha^{-1} gave significantly higher grain and straw yields over the control and 30 kg P_2O_5 ha^{-1}. However, it was at par with 60 kg P_2O_5 ha^{-1}. The maximum improvement over control was to the tune of 25.10 and 27.12 per cent higher by grain and straw yield. Application of phosphorus at 30, 60 and 90 kg ha^{-1} has resulted in the increase in mean grain by 12.43, 20.36 and 25.10 and straw by 13.76, 23.20 and 27.59 percent, respectively over control. The main reason for the increase in grain yield with different levels of phosphatic fertilizer might be due to the higher 1000-grain weight which might be due to a higher rate of photosynthesis and better crop health which ultimately increased the final grain and straw yield. Plants showed normal growth with the application of phosphorus and resulting in improved agronomic traits which lead to improved grain yield Vyas et al. (2012); Jat et al. (2016); Muhammad et al. (2016); Panotra et al. (2016) and Bairwa et al. (2018) also recorded "significant improvement in wheat grain yield with increase in phosphorus levels. Early tiller formation is vital to plant health and ultimately final yield potential. The initial tillers formed by the plant have higher yield potential than late tillers or delayed tillers. Tillers are just healthier and more productive when adequate phosphorus is available. The significant increase in straw yield due to the application of phosphorus could be attributed to the increased vegetative growth, possibly a result of the effective uptake and utilization of nutrients absorbed through its extensive root system developed under phosphorus fertilization".

The data given in Table 1 indicated that grain yield was significantly affected due to different doses of zinc. Significantly higher grain (3978 kg ha^{-1}) and straw (4850 kg ha^{-1}) yield was recorded with the application of Zn @ 7.5 kg ha^{-1}; which was at par with 5.0 kg Zn ha^{-1}. Application of Zn @ 7.5 kg ha^{-1} increased the grain yield by 19.55 and 11.64 per cent over control and 2.5 kg Zn ha^{-1}, respectively. Graded levels of Zn application at 2.5, 5.0 and 7.5 kg ha^{-1} increased mean straw yield by 8.70, 16.95 and 18.91 percent, respectively over control. The increase in the yield due to zinc application may be attributed to the fact that the initial status of available zinc in the experimental soil was low. Under such a situation an increase in the yield is quite natural. Further, increased grain yield is the manifestation of an increase in yield attributes i.e. number of effective tillers, number of grains per spike and spike length. Similar results were reported by Dwivedi et al. (2002); Khan et al. (2008) and Sharma et al. (2016). The interaction effect of phosphorus and zinc was found to be non-significant with respect to grain yield of wheat.

Fe Content: Different levels of phosphorus were found to be non-significant with respect to Fe content in grain and straw (Table 2). The maximum Fe content (51.62 and 297.78 mg kg^{-1}) in grain and straw was recorded with the application of 90 kg P_2O_5 ha^{-1} and minimum Fe content (47.85 and 287.92 mg kg^{-1}) in grain and straw was noted under control. The data given in Table 2 indicated that the effect of Zn application on Fe content in grain and straw was found non-significant. The maximum Fe content (51.51 and 294.37 mg kg^{-1}) in grain and straw was noted under Zn_3 level (7.5 kg Zn ha^{-1}) and minimum Fe content (48.03 and 292.14 mg kg^{-1}) in grain and straw was noted under Zn_0 (0 kg Zn ha^{-1}). The results obtained in the present investigation are in close conformity with those of Tabassum et al. (2014); Shivran (2016); Sipai et al. (2017) and Jat et al. (2018). The interaction effect of phosphorus and zinc on Fe content in grain was found to be non-significant.

Table 1. Effect of phosphorus and zinc application on yield and nutrients content in grain and straw of wheat

Treatments	Yield (kg ha^{-1})	
	Grain	**Straw**
Phosphorus levels (kg ha^{-1})		
P_0: 0 kg P_2O_5 ha^{-1}	3229	3903
P_1: 30 kg P_2O_5 ha^{-1}	3630	4440
P_2: 60 kg P_2O_5 ha^{-1}	3886	4809
P_3: 90 kg P_2O_5 ha^{-1}	4040	4980
S.Em. ±	77	124
C.D. *(P = 0.05)*	222	359
Zinc levels (kg ha^{-1})		
Zn_0: 0 kg Zn ha^{-1}	3327	4079
Zn_1: 2.5 kg Zn ha^{-1}	3563	4433
Zn_2: 5.0 kg Zn ha^{-1}	3917	4770
Zn_3: 7.5 kg Zn ha^{-1}	3978	4850
S.Em. ±	77	124
C.D. *(P = 0.05)*	222	359
Interaction		
P x Zn	NS	NS
C.V. (%)	7.20	9.50

Table 2. Effect of phosphorus and zinc application on iron, manganese, zinc and copper content in grain and straw of wheat

Treatments	Micronutrients content (mg kg^{-1})							
	Fe		Mn		Zn		Cu	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Phosphorus levels (kg ha^{-1})								
P_0: 0 kg P_2O_5 ha^{-1}	47.85	290.63	35.28	54.81	23.84	44.07	3.79	6.18
P_1: 30 kg P_2O_5 ha^{-1}	48.76	287.92	36.33	55.60	25.78	47.81	3.90	6.24
P_2: 60 kg P_2O_5 ha^{-1}	50.03	297.78	38.11	56.38	25.49	49.25	4.11	6.37
P_3: 90 kg P_2O_5 ha^{-1}	51.62	295.39	39.25	57.89	25.65	49.16	4.28	6.48
S.Em. ±	1.46	10.35	1.18	1.51	0.96	1.44	0.13	0.21
C.D. *(P = 0.05)*	NS	NS	NS	NS	NS	NS	NS	NS
Zinc levels (kg ha^{-1})								
Zn_0: 0 kg Zn ha^{-1}	48.03	292.37	35.75	55.27	20.16	42.83	3.94	6.21
Zn_1: 2.5 kg Zn ha^{-1}	48.10	292.14	37.13	55.94	24.69	44.08	4.02	6.29
Zn_2: 5.0 kg Zn ha^{-1}	50.63	294.37	37.81	56.59	27.41	49.46	4.03	6.32
Zn_3: 7.5 kg Zn ha^{-1}	51.51	292.85	38.29	56.87	28.50	53.93	4.10	6.45
S.Em. ±	1.46	10.35	1.18	1.51	0.96	1.44	0.13	0.21
C.D. *(P = 0.05)*	NS	NS	NS	NS	2.78	4.15	NS	NS
Interaction								
P x Zn	NS	NS	NS	NS	NS	NS	NS	NS
C.V. (%)	10.21	12.24	11.02	9.34	13.26	10.46	11.36	11.71

Mn Content: The effect of different levels of phosphorus on Mn content in grain and straw was found non-significant (Table 2). The maximum Mn content (39.25 and 57.89 mg kg^{-1}) in grain and straw was noted under P_3 level (90 kg P_2O_5 ha^{-1}); whereas minimum Mn content (35.28 and 54.81 mg kg^{-1}) in grain and straw was noted under P_0 (0 kg P_2O_5 ha^{-1}). Among different levels of zinc application of 7.5 kg Zn ha^{-1} (Zn_3) recorded the maximum Mn content (38.29 and 56.87 mg kg^{-1}) in grain and straw; whereas, minimum Mn content (35.75 and 55.27 mg kg^{-1}) in grain and straw was noted under control. The interaction effect of phosphorus and zinc on Mn content in grain was found to be non-significant (Table 2).

Zn Content: Zinc content in grain and straw was not significantly influenced due to different levels of phosphorus (Table 2). The maximum Zn content (25.65 and 49.25 mg kg^{-1}) in grain and straw was noted under P_3 level (90 kg P_2O_5 ha^{-1}); whereas, the minimum Zn content (23.84 and 44.07 mg kg^{-1}) in grain and straw was noted under control. A decrease in the Zn content at an increased P level may be due to either decrease in the available Zn content as a result of the reaction of zinc with phosphorus in the soil or due to retarded absorption of Zn by the roots. Phosphate in the roots may also inhibit the translocation of Zn to the above-ground parts. Dilution effect due to an increase in the yield may also be responsible for decreased Zn content in the grain and straw. All these factors may also operate simultaneously resulting in decreased Zn concentration in plants at the elevated P level The results obtained in the present investigation are in close conformity with those of Reddy and Yadav (1994) and Sharma and Bapat (2000). A perusal of the data given in Table 2 revealed that Zn content in grain and straw was significantly influenced due to different levels of zinc application. Application of 7.5 kg Zn ha^{-1} (Zn_3) recorded the highest Zn content in grain and straw; it remained at par with Zn_2 level (5.0 kg Zn ha^{-1}). Application of Zn @ 7.5 kg ha^{-1} significantly increased Zn content in grain and straw by 41.6% and 25.91 per cent over control. The results obtained in the present investigation are in close conformity with those of Gupta and Kalra (2006); Patel et al. (2010) and Yassen et al. (2010). The interaction effect of phosphorus and zinc was found to be non-significant with respect to Zn content in grain (Table 2).

“The beneficial role of zinc in increasing the cation exchange capacity of roots helped in increased absorption of nutrients from the soil. Further, the beneficial role of zinc in chlorophyll formation, regulating the auxin concentration and its stimulatory effect on most of the physiological and metabolic processes of the plant, might have helped the paints in the absorption of greater amounts of nutrients from soil. Thus, the favorable influence of zinc on photosynthesis and metabolic processes augmented the production of photosynthates and their translocation to different plant parts including grain which ultimately increased the concentration of nutrients in grain and straw" which in cognizance of the findings of Dwivedi et al. (2002); Gupta and Kalra (2006); Patel et al. (2010) and Yassen et al. (2010).

Cu Content: A different level of phosphorus was found to be non-significant with respect to Cu content in grain and straw (Table 2). The maximum Cu content (4.28 and 6.48 mg kg^{-1}) in grain and straw was noted under P_3 level (90 kg P_2O_5 ha^{-1}); whereas, minimum Cu content (3.79 and 6.18 mg kg^{-1}) in grain and straw was noted under control. An application of 7.5 kg Zn ha^{-1} (Zn_3) recorded the maximum Cu content (4.10 and 6.45mg kg^{-1}) in grain and straw; while minimum Cu content in grain (3.94 and 6.21 mg kg^{-1}) was noted under control. The interaction effect of phosphorus and zinc on Cu content in grain was found to be non-significant (Table 2).

Table 3. Effect of phosphorus and zinc on micronutrients uptake by grain and straw of wheat

Treatments	Micronutrients uptake (g ha^{-1})							
	Fe		Mn		Zn		Cu	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Phosphorus levels (kg ha^{-1})								
P_0: 0 kg P_2O_5 ha^{-1}	155	1135	114	214	77	172	12	24
P_1: 30 kg P_2O_5 ha^{-1}	177	1279	132	247	94	214	14	28
P_2: 60 kg P_2O_5 ha^{-1}	195	1431	149	271	101	239	16	31
P_3: 90 kg P_2O_5 ha^{-1}	210	1469	159	288	104	248	17	32
S.Em. ±	7	59	5	10	4	9	1	1
C.D. *(P = 0.05)*	20	172	15	28	11	27	2	4
Zinc levels (kg ha^{-1})								
Zn_0: 0 kg Zn ha^{-1}	160	1189	119	226	67	175	13	25
Zn_1: 2.5 kg Zn ha^{-1}	172	1303	132	248	88	198	14	28
Zn_2: 5.0 kg Zn ha^{-1}	199	1407	149	271	107	236	16	30
Zn_3: 7.5 kg Zn ha^{-1}	206	1415	153	276	114	263	16	31
S.Em. ±	7	59	5	10	4	9	1	1
C.D. *(P = 0.05)*	20	172	15	28	11	27	2	4
Interaction								
P x Zn	NS	NS	NS	NS	NS	NS	NS	NS
C.V. (%)	12.97	15.49	14.56	14.84	12.65	13.39	14.97	16.70

Table 4. Effect of phosphorus and zinc application on DTPA-extractable micronutrients content in soil after harvest of wheat

Treatment	DTPA-extractable micronutrients (mg kg^{-1})			
	Fe	Mn	Zn	Cu
Phosphorus levels (kg ha^{-1})				
P_0: 0 kg P_2O_5 ha^{-1}	2.38	4.37	0.68	0.31
P_1: 30 kg P_2O_5 ha^{-1}	2.42	4.44	0.74	0.31
P_2: 60 kg P_2O_5 ha^{-1}	2.46	4.53	0.74	0.32
P_3: 90 kg P_2O_5 ha^{-1}	2.53	4.60	0.76	0.32
S.Em. ±	0.08	0.16	0.02	0.01
C.D. *(P = 0.05)*	NS	NS	NS	NS
Zinc levels (kg ha^{-1})				
Zn_0: 0 kg Zn ha^{-1}	2.42	4.36	0.68	0.30
Zn_1: 2.5 kg Zn ha^{-1}	2.44	4.47	0.74	0.31
Zn_2: 5.0 kg Zn ha^{-1}	2.46	4.53	0.75	0.32
Zn_3: 7.5 kg Zn ha^{-1}	2.46	4.58	0.77	0.32
S.Em. ±	0.08	0.16	0.02	0.01
C.D. *(P = 0.05)*	NS	NS	0.06	NS
Interaction				
P x Zn	NS	NS	NS	NS
C.V. (%)	10.98	12.75	10.08	8.70

Fe Uptake: A perusal of data given in Table 3 revealed that Fe uptake by grain and straw of wheat was significantly influenced due to different doses of phosphorus. Application of 90 kg P_2O_5 ha^{-1} recorded the highest Fe uptake (209.50 and 1469.30 g ha^{-1}) by grain and straw; but it remained at par with 60 kg P_2O_5 ha^{-1}. The magnitude of increase in Fe uptake by grain due to P_2O_5 @ 90 kg ha^{-1} was 35.50 and 18.15 percent over control and 30 kg P ha^{-1}, respectively. This result is in accordance with those reported by Mehta et al*.* 2005. A perusal of data given in Table 3 revealed that Fe uptake by grain of wheat was significantly influenced due to different levels of zinc. Among different levels of zinc application of 7.5 kg Zn ha^{-1} recorded the highest Fe uptake by grain and straw; but it remained at par with 5.0 kg Zn ha^{-1}. Significantly highest Fe uptake (1414.70 g ha^{-1}) by straw was noted under the application of 7.5 kg Zn ha^{-1}; which was at par with 2.5 and 5.0 kg Zn ha^{-1}. The magnitude of increase in Fe uptake by grain due to Zn @ 7.5 kg ha^{-1} was 28.25 and 19.91 percent over control and 2.5 kg P ha^{-1}, respectively. The results obtained in present investigation are in close conformity with those of Rathod et al. (2012); Kuniya (2014); Tabassum et al*.* (2014); Abbas et al*.* (2010); Shivran (2016) and Jat et al*.* (2018). The interaction effect of levels of phosphorus and zinc was found to be non-significant with respect to Fe uptake by grain (Table 4).

Mn Uptake: The significant effect of different levels of phosphorus was noticed on Mn uptake by grain and straw (Table 3). Application of 90 kg P_2O_5 ha^{-1} recorded the highest Mn uptake (158.74 and 288.45 g ha^{-1}) by grain; but it remained at par with 60 kg P_2O_5 ha^{-1}. Minimum Mn uptake (113.92 and 214.36 g ha^{-1}) by grain and straw was noted under control. The magnitude of increase in Mn uptake by grain due to P_2O_5 @ 90 kg ha^{-1} was 39.34 and 20.51 percent over control and 30 kg P_2O_5 ha^{-1}, respectively. While, the magnitude of the increase in Mn uptake by straw due to P_2O_5 @ 90 kg ha^{-1} was 34.56 and 16.76 percent over control and 30 kg P ha^{-1}, respectively.

The significant effect of different levels of zinc was noticed on Mn uptake by grain and straw (Table 3). Application of 7.5 kg Zn ha^{-1} recorded the highest Mn uptake (153.48 and 276.08 g ha^{-1}) by grain; but it remained at par with 5.0 kg Zn ha^{-1}. The magnitude of increase in Mn uptake by grain due to Zn @ 7.5 kg ha^{-1} was 28.86 and 16.16 percent over control and 2.5 kg Zn ha^{-1}, respectively. While, the extent of increase in Mn uptake by straw due to Zn @ 7.5 kg ha^{-1} was 22.00 and 11.35 percent over control and 2.5 kg Zn ha^{-1}, respectively. These results are in accordance with those reported by Abbas et al*.* (2010). The interaction effect of phosphorus and zinc was found to be non-significant with respect to Mn uptake by grain (Table 3).

Zn Uptake: The significant effect of phosphorus was noticed on Zn uptake by grain and straw (Table 3). Among different levels of phosphorus, an application of 90 kg P_2O_5 ha^{-1} recorded the highest Zn uptake (104.48 and 247.50 g ha^{-1}) by grain and straw; but it remained at par with 30 and 60 kg P_2O_5 ha^{-1}. The magnitude of increase in Zn uptake by grain due to P_2O_5 @ 90 kg ha^{-1} was 35.75 percent over control. While, the magnitude of increase in Zn uptake by straw due to P_2O_5 @ 90 kg ha^{-1} was 43.73 percent over control. It seen from data given in Table 3 revealed that the difference in Zn uptake by grain and straw was found to be significant due to different levels of zinc. Among different levels of zinc, an application of 7.5 kg Zn ha^{-1} recorded the highest Zn uptake by grain and straw; but it remained at par with 5.0 kg Zn ha^{-1}. The highest Zn uptake (114.17 and 263.21 g ha^{-1}) by grain was noted under 7.5 kg Zn ha^{-1}. The magnitude of increase in Zn uptake by grain due to Zn @ 7.5 kg ha^{-1} was 70.12 and 29.72 percent over control and 2.5 kg Zn ha^{-1}, respectively. While, the magnitude of the increase in Zn uptake by straw due to Zn @ 7.5 kg ha^{-1} was 50.20 and 33.21 percent over control and 2.5 kg Zn ha^{-1}, respectively. These results are in accordance with those reported by Dewal and Pareek (2004); Verma et al*.* (2005); Parihar et al*.* (2005) and Abbas et al*.* (2010). The interaction effect of phosphorus and zinc on Zn uptake by grain was found to be non-significant (Table 3).

Cu Uptake: The significant effect of different levels of phosphorus was noticed on Cu uptake by grain and straw (Table 3). Among different levels of phosphorus, an application of 90 kg P_2O_5 ha^{-1} recorded the highest Cu uptake (17.32 and 32.41 g ha^{-1}) by grain and straw; but it remained at par with 30 and 60 kg P_2O_5 ha^{-1}. The magnitude of increase in Cu uptake by grain due to P_2O_5 @ 90 kg ha^{-1} was 41.50 and 21.97 percent over control and

30 kg P_2O_5 ha^{-1}, respectively. It seen from data given in table 3 revealed that the differences in Cu uptake by grain and straw were found to be significant due to different levels of zinc. Among different levels of zinc, an application of 7.5 kg Zn ha^{-1} was recorded as the highest Cu uptake (16.42 and 31.47 g ha^{-1}) by grain and straw. The magnitude of increase in Cu uptake by grain due to Zn @ 7.5 kg ha^{-1} was 24.96 and 14.42 percent over control and 2.5 kg Zn ha^{-1}, respectively. The interaction effect of phosphorus and zinc on Cu uptake by grain was found to be non-significant (Table 3).

DTPA-extractable Fe: A perusal of data presented in Table 4 revealed that DTPA-extractable Fe content in soil after the harvest of wheat did not differ significantly due to different levels of phosphorus. Numerically, higher value of DTPA-extractable Fe content (2.53 mg kg^{-1}) in soil was recorded with the application of 90 kg P_2O_5 ha^{-1}; while, minimum DTPA-extractable Fe content (2.38 mg kg^{-1}) in soil was noted under control. The data given in Table 4 indicated that different levels of zinc failed to show significant effect on DTPA-extractable Fe content in soil after the harvest of wheat. The maximum DTPA-extractable Fe content (2.46 mg kg^{-1}) in soil was recorded with the application of Zn @ 7.5 kg ha^{-1}; while, the minimum DTPA-extractable Fe content in soil (2.42 mg kg^{-1}) was recorded under control. The interaction effect of phosphorus and zinc on DTPA-extractable Fe content in soil after the harvest of wheat was found non-significant.

DTPA-extractable Mn: A perusal of data presented in Table 4 revealed that DTPA-extractable Mn content in the soil after harvest of crop was failed to reach the levels of significance due to different levels of phosphorus. The maximum value of DTPA-extractable Mn content (4.60 mg kg^{-1}) in soil was recorded with the application of 90 kg P_2O_5 ha^{-1}; while the minimum DTPA-extractable Mn content (4.37 mg kg^{-1}) in soil was noted under control.The data given in Table 4 indicated that different levels of zinc failed to show a significant effect on DTPA-extractable Mn content in soil after the harvest of crop. Maximum DTPA-extractable Mn content in soil (4.58 mg kg^{-1}) was noted with the application of Zn @ 7.5 kg ha^{-1}; while, minimum DTPA-extractable Mn content in soil (4.36 mg kg^{-1}) was noted under control. The interaction effect of P x Zn was found non-significant with respect to DTPA-extractable Mn content in soil after harvest of crop.

DTPA-extractable Zn: A perusal of data presented in Table 4 revealed that differences in DTPA-extractable Zn content in soil due to different levels of phosphorus were found to be non-significant. The maximum build-up of DTPA-extractable Zn content (0.76 mg kg^{-1}) in the soil after harvest was recorded with the application of 90 kg P_2O_5 ha^{-1} over rest of the treatments. The minimum DTPA-extractable Zn content (0.68 mg kg^{-1}) in soil at harvest was recorded under control.

The data regarding DTPA-extractable Zn content in soil as influenced by different levels of zinc are furnished in Table 4. The significantly higher build-up of DTPA-extractable Zn content (0.77 mg kg^{-1}) in the soil after the harvest of wheat was recorded with the application of Zn @ 7.5 kg ha^{-1}; which was at par with 2.5 kg Zn ha^{-1} and 5 kg Zn ha^{-1}. The minimum DTPA-extractable Zn content (0.68 mg kg^{-1}) in soil at harvest was recorded under control. The interaction effect of P x Zn failed to show its significant effect on DTPA-extractable Zn content in soil after harvest.

DTPA-extractable Cu: A perusal of data is presented in Table 4 and the result revealed that DTPA-extractable Cu content in soil after harvest did not differ significantly due to different levels of phosphorus. A numerically higher value of DTPA-extractable Cu content (0.32 mg kg^{-1}) in soil was recorded with the application of 90 kg P_2O_5 ha^{-1} and minimum DTPA-extractable Cu content (0.31 mg kg^{-1}) in soil was noted under control. The data given in Table 4 indicated that different levels of zinc failed to reach the levels of significance on DTPA-extractable Cu content in soil after the harvest of the crop. The maximum DTPA-extractable Cu content (0.32 mg kg^{-1}) in soil was recorded with the application of Zn @ 7.5 kg ha^{-1}; while minimum DTPA-extractable Cu content (0.30 mg kg^{-1}) in soil was noted under control. The interaction effect of P x Zn failed to show its significant effect on DTPA-extractable Cu content in soil after harvest.

4. CONCLUSION

It is concluded that application of 90 kg P2O5 ha-1 and Zn @ 7.5 kg ha-1 significantly increased the iron, zinc, manganese and copper uptake as well as DTPA-extractable Zn status after harverst of wheat. Sufficient quantity of soluble form of phosphorus fertilizers is applied to achieve maximum plant productivity. However, the applied soluble forms of phosphatic fertilizers rapidly become unavailable to plants by conversion into inorganic P fractions that are fixed by chemical adsorption and precipitation. Similarly, organic P fractions are immobilized in soil organic matter.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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