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Content and uptake of nutrients in Wheat (*Triticum aestivum* L.) as influenced by phosphorus and zinc application in alluvial soil

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Abstract

A field experiment was conducted during the *rabi* season of 2018-19 on a sandy loam alluvial soil at R.B.S. College, Bichpuri, Agra (U.P.), to study the effect of four levels of phosphorus (0, 30, 60, 90 kg P₂O₅ ha⁻¹) and four levels of zinc (0, 2.5, 5.0, 7.5 kg Zn ha⁻¹) on the content and uptake of N, P, K, S and Zn by wheat (cv. Raj 3765) in a randomised block design with three replications. Increasing phosphorus significantly enhanced the content and uptake of N, P, K and S in grain and straw, phosphorus uptake nearly doubling (12.2 to 20.1 kg ha⁻¹), but slightly depressed grain zinc content (27.0 to 26.3 mg kg⁻¹), reflecting P-Zn antagonism. Zinc increased the content and uptake of N, P, K and S up to 5.0 kg Zn ha⁻¹, whereas zinc content and uptake increased up to the highest level (grain zinc 24.1 to 30.0 mg kg⁻¹). The P × Zn interaction was non-significant. Application of 60-90 kg P₂O₅ ha⁻¹ with 5.0 kg Zn ha⁻¹ is optimum for balanced nutrient uptake by wheat while minimising P-Zn antagonism.

Keywords: Phosphorus, zinc, wheat, nutrient content, nutrient uptake, P-Zn antagonism, alluvial soil

Introduction

Phosphorus (P) and zinc (Zn) are essential plant nutrients that play a significant role in regulating nutrient acquisition, physiological processes, and overall nutrient utilization efficiency in wheat (*Triticum aestivum* L.). Phosphorus is a vital component of nucleic acids, phospholipids, and adenosine triphosphate (ATP), and is actively involved in energy transfer, root development, photosynthesis, respiration, and various metabolic activities (Marschner, 2012) [7]. Zinc, although required in small quantities, is an important micronutrient that acts as a structural and catalytic component of several enzymes involved in protein synthesis, carbohydrate metabolism, chlorophyll synthesis, and auxin production. Adequate availability of phosphorus and zinc promotes better root growth, enhances nutrient absorption, and improves the physiological efficiency of plants. However, maintaining an appropriate balance between these nutrients is crucial, as excessive phosphorus application may reduce zinc availability and uptake through phosphorus-induced zinc deficiency, particularly in alkaline and calcareous soils (Cakmak, 2008; Zhang *et al.*, 2021) [1, 17].

The alluvial soils of the Indo-Gangetic plains are among the most productive agricultural soils and support intensive wheat cultivation. However, continuous cropping, intensive fertilizer use, and inadequate replenishment of micronutrients have resulted in nutrient imbalances, particularly deficiencies of available phosphorus and zinc (Singh *et al.*, 2015) [14]. In these soils, phosphorus fixation and reduced zinc availability often limit nutrient acquisition by crops, affecting the uptake and accumulation of essential nutrients. Such nutrient constraints may influence the concentration and uptake of nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and zinc (Zn) in wheat plants, ultimately affecting crop productivity and grain nutritional quality. Therefore, balanced application of phosphorus and zinc is essential for improving nutrient availability, enhancing fertilizer use efficiency, and sustaining wheat production under alluvial soil conditions (Rehman *et al.*, 2018) [10].

Nutrient content and uptake are important indicators for evaluating the nutritional status of crops and the effectiveness of fertilizer management practices. The nutrient content in plant tissues reflects the availability and absorption of nutrients, whereas nutrient uptake represents the total accumulation of nutrients by the crop and is influenced by both nutrient concentration and biomass production. Improved nutrient uptake contributes to better plant growth, efficient nutrient utilization, higher yield potential, and enhanced grain quality. Understanding the influence of phosphorus and zinc interaction on nutrient content and uptake is therefore essential for developing suitable nutrient management strategies for wheat cultivation (Hafeez *et al.*, 2013) ^[4].

Despite the importance of phosphorus and zinc interaction in crop nutrition, limited information is available regarding their combined effect on the content and uptake of major nutrients in wheat grown under the alluvial soil conditions of the Agra region. Therefore, the present investigation was undertaken to assess the influence of different levels of phosphorus and zinc application on the content and uptake of nitrogen, phosphorus, potassium, sulfur, and zinc in wheat grain and straw, with the aim of developing an efficient nutrient management approach for improving wheat nutrition and productivity.

Materials and Methods

A field experiment was conducted during the *rabi* season of 2018-19 at the Research Farm of Raja Balwant Singh College, Bichpuri, Agra (U.P.), India (27.2° N, 77.91° E; 168 m above mean sea level), which has a semi-arid subtropical climate. A composite surface soil sample (0-23 cm) showed the soil to be sandy loam in texture, alkaline (pH 8.0), non-saline (EC 0.12 dS m⁻¹), low in organic carbon (3.1 g kg⁻¹), low in available N (165.0 kg ha⁻¹) and P (9.2 kg ha⁻¹), medium in available K (110.0 kg ha⁻¹) and deficient in DTPA-extractable zinc (0.54 mg kg⁻¹).

The experiment comprised four levels of phosphorus (0, 30, 60 and 90 kg P₂O₅ ha⁻¹) and four levels of zinc (0, 2.5, 5.0 and 7.5 kg Zn ha⁻¹), giving sixteen treatment combinations laid out in a randomised block design with three replications. Wheat variety

Raj 3765 was sown in the second week of November at 20 cm row spacing with a seed rate of 100 kg ha⁻¹. A uniform basal dose of 120 kg N ha⁻¹ (urea) and 40 kg K₂O ha⁻¹ (muriate of potash) was applied; phosphorus was applied as single super-phosphate and zinc as zinc oxide as per treatments at sowing. Five irrigations were given and recommended agronomic practices followed.

At harvest, plant height, tillers per plant, dry-matter accumulation, yield attributes (ear length, grains per ear, test weight) and grain and straw yields were recorded. Grain and straw samples were washed, oven-dried at 65–70 °C, ground and analysed. Nitrogen was determined colorimetrically after wet digestion (Snell and Snell, 1955) ^[16] and crude protein computed as N% × 6.25; phosphorus by the vanadomolybdate yellow-colour method (Chapman and Pratt, 1961) ^[2]; potassium by flame photometry; sulphur turbidimetrically; and zinc by atomic absorption spectrophotometry. Nutrient uptake was computed as content × yield. Data were analysed by ANOVA for a randomised block design and means compared using the critical difference (CD) at 5% (Fisher's test).

Results and Discussion

Nutrient content in grain and straw

Increasing phosphorus significantly enhanced the content of N, P, K and S in both grain and straw (Tables 1 and 2). Grain nitrogen increased from 1.91 to 1.97%, phosphorus from 0.18 to 0.25%, potassium from 0.47 to 0.53% and sulphur from 0.19 to 0.23% as phosphorus increased to 90 kg P₂O₅ ha⁻¹, reflecting improved availability and a synergistic effect on absorption (Singh *et al.*, 1998; Dewal and Pareek, 2004) ^[13, 3].

In contrast, grain zinc content declined slightly with phosphorus (27.0 to 26.3 mg kg⁻¹), demonstrating P-Zn antagonism, whereas zinc application increased grain zinc from 24.1 to 30.0 mg kg⁻¹ and straw zinc from 17.0 to 22.4 mg kg⁻¹ (Fig. 1a). The reciprocal antagonism was also evident, grain phosphorus content peaking at 5.0 kg Zn ha⁻¹ and declining at the highest zinc level (Fig. 1b). These results confirm the mutual P-Zn antagonism reported for wheat (Zhang *et al.*, 2021; Mishra *et al.*, 2017) ^[17, 8]. All P × Zn interactions for nutrient content were non-significant.

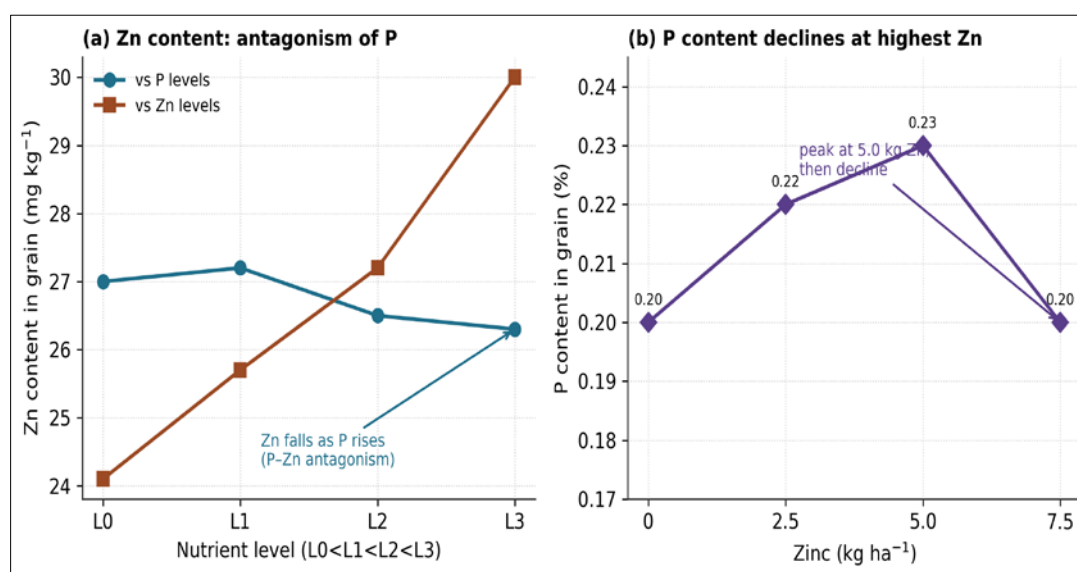


Fig 1: Phosphorus–zinc antagonism in wheat grain: (a) grain zinc content falls as phosphorus rises but increases with zinc; (b) grain phosphorus content peaks at 5.0 kg Zn ha⁻¹ and declines thereafter.

Table 1: Effect of phosphorus and zinc levels on nutrient content in wheat grain

Treatment	N (%)	P (%)	K (%)	S (%)	Zn (mg kg ⁻¹)
Phosphorus (kg P₂O₅ ha⁻¹)					
0	1.91	0.18	0.47	0.19	27.0
30	1.94	0.20	0.49	0.20	27.2
60	1.96	0.22	0.51	0.22	26.5
90	1.97	0.25	0.53	0.23	26.3
Zinc (kg ha⁻¹)					
0	1.92	0.20	0.49	0.20	24.1
2.5	1.93	0.22	0.50	0.21	25.7
5.0	1.96	0.23	0.51	0.22	27.2
7.5	1.97	0.20	0.50	0.21	30.0
SEm ±	0.09	0.005	0.007	0.003	0.09
CD (P=0.05)	0.26	0.014	0.020	0.008	0.26

Table 2: Effect of phosphorus and zinc levels on nutrient content in wheat straw

Treatment	N (%)	P (%)	K (%)	S (%)	Zn (mg kg ⁻¹)
Phosphorus (kg P₂O₅ ha⁻¹)					
0	0.51	0.09	1.79	0.08	19.7
30	0.52	0.10	1.81	0.10	19.9
60	0.54	0.11	1.83	0.11	19.6
90	0.56	0.12	1.84	0.12	19.9
Zinc (kg ha⁻¹)					
0	0.52	0.09	1.80	0.09	17.0
2.5	0.53	0.10	1.82	0.10	18.2
5.0	0.54	0.12	1.83	0.12	20.8
7.5	0.55	0.11	1.82	0.10	22.4
SEm ±	0.04	0.003	0.008	0.004	0.008
CD (P=0.05)	0.11	0.008	0.023	0.011	0.023

Nutrient uptake by grain and straw

Nutrient uptake increased significantly with phosphorus, being the outcome of improved content and yield (Tables 3 and 4, Fig. 2a). Total nitrogen uptake rose from 107.2 to 136.3 kg ha⁻¹ and phosphorus uptake nearly doubled (12.2 to 20.1 kg ha⁻¹) as phosphorus increased to 90 kg P₂O₅ ha⁻¹; potassium, sulphur and zinc uptake also increased steadily. These results corroborate Sepat and Rai (2013) ^[12], Kumar *et al.* (2014) ^[5] and Malav *et al.* (2025) ^[6].

Zinc increased N, P, K and S uptake up to 5.0 kg Zn ha⁻¹, with a reduction at 7.5 kg ha⁻¹, whereas zinc uptake increased consistently up to the highest level, from 197.0 to 271.3 g ha⁻¹ (Fig. 2b). The antagonistic effect of higher phosphorus on zinc, and of higher zinc on phosphorus uptake, was again evident. All P × Zn interactions were non-significant. Similar behaviour has been reported by Sahay *et al.* (2009) ^[11], Pandey and Rana (2016) ^[9] and Singh and Singh (2017) ^[15].

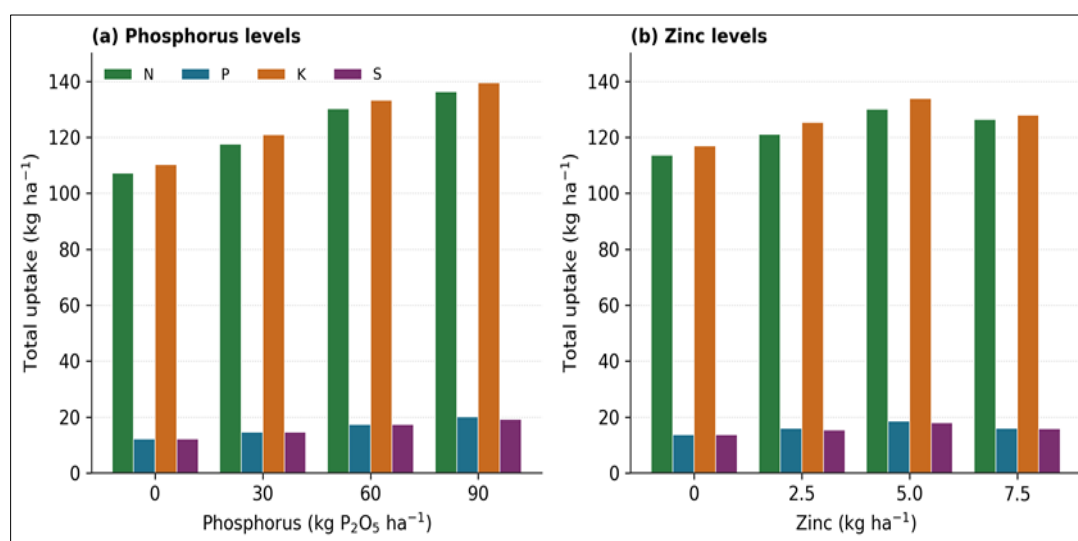
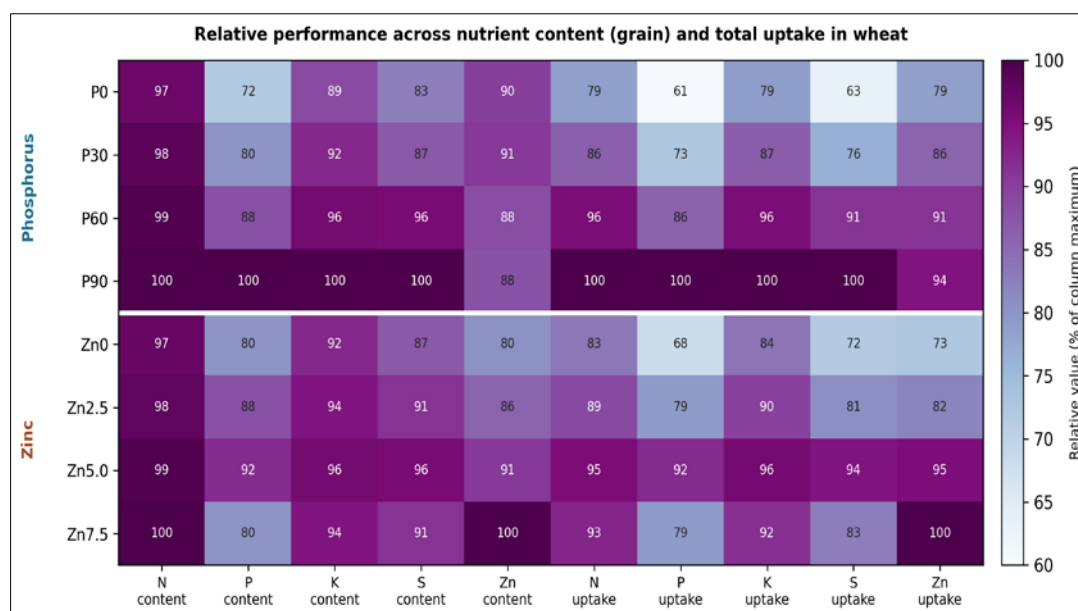
**Fig 2:** Total (grain + straw) uptake of N, P, K and S by wheat as influenced by (a) phosphorus and (b) zinc levels.

Table 3: Effect of phosphorus and zinc levels on uptake of N, P and K by wheat grain and straw (kg ha⁻¹)

Treatment	N grain	N straw	P grain	P straw	K grain	K straw
Phosphorus (kg P ₂ O ₅ ha ⁻¹)						
0	81.4	25.8	7.6	4.6	19.8	90.4
30	89.4	28.2	9.1	5.5	22.4	98.5
60	98.2	32.0	10.9	6.4	25.3	108.0
90	102.1	34.2	12.8	7.3	27.2	112.3
Zinc (kg ha ⁻¹)						
0	86.2	27.4	8.9	4.8	21.8	95.1
2.5	91.3	29.7	10.3	5.6	23.4	102.0
5.0	98.1	32.0	11.4	7.1	25.3	108.6
7.5	95.0	31.4	9.6	6.3	23.9	104.0
S.Em ±	1.59	0.59	0.35	0.19	0.44	1.01
CD (P=0.05)	4.61	1.72	1.01	0.55	1.27	2.89

Table 4: Effect of phosphorus and zinc levels on uptake of S (kg ha⁻¹) and Zn (g ha⁻¹) by wheat grain and straw

Treatment	S grain	S straw	Zn grain	Zn straw
Phosphorus (kg P ₂ O ₅ ha ⁻¹)				
0	8.0	4.1	114.0	99.6
30	9.1	5.5	124.1	108.3
60	10.9	6.5	131.5	116.0
90	11.8	7.3	135.0	121.3
Zinc (kg ha ⁻¹)				
0	8.9	4.8	107.2	89.8
2.5	9.8	5.6	120.4	102.0
5.0	10.9	7.1	134.9	123.4
7.5	10.0	5.8	143.3	128.0
S.Em ±	0.59	0.44	1.92	2.11
CD (P=0.05)	1.71	1.28	5.57	6.12

**Fig 3:** Relative performance (% of column maximum) of phosphorus and zinc levels across nutrient content (grain) and total uptake in wheat

Conclusion

Application of phosphorus up to 90 kg P₂O₅ ha⁻¹ and zinc up to 5.0 kg Zn ha⁻¹ enhanced the content and uptake of N, P, K and S by wheat, while zinc uptake increased up to the highest zinc level. A clear mutual P-Zn antagonism was recorded. For balanced nutrient uptake and quality of wheat in alluvial soils of the Agra region while minimising the antagonism, 60-90 kg P₂O₅ ha⁻¹ together with 5.0 kg Zn ha⁻¹ is recommended.

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