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Research Article

Phosphorus and Zinc Levels Influence the Growth Characteristics and Yield of Cotton (*Gossypium hirsutum* L.) in Loamy Sand Soils of Punjab

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ABSTRACT

Both phosphorus (P) and zinc (Zn) are crucial for the optimal cotton yield. To maximize cotton yield, the P and Zn applications must be optimized. The results exhibited that maximum plant growth characteristics were obtained with 30 kg P ha^{-1}. Significant effects of P and Zn, and a non-significant effect of the P × Zn interaction, on boll weight and cotton yield were recorded. Maximum boll weight (7.91 g) and seed cotton yield (37.8 q ha^{-1}) at location A, 37.2 q ha^{-1} at location B were observed with 20 kg P ha^{-1} and 5 kg Zn ha^{-1}. However, maximum boll weight (7.57 g) was recorded with P @ 30 kg ha^{-1} and Zn @ 5 kg ha^{-1} at location B. Correlation values for plant height (0.883, 0.824), sympodial branches (0.825, 0.809), boll plant^{-1}(0.820, 0.884), boll weight (0.295, 0.837), cotton seed yield (0.295, 0.473) and stalk yield (0.823, 0.884) suggested that yield traits and seed cotton yield were positively depends on phosphorus. Similarly, yield traits such as plant height (-0.121, -0.147), sympodial branches (-0.987, 0.102), boll plant-1 (-0.984, -0.148), and stalk yield (-0.122, -0.129) showed significant ($p < 0.05$) negative correlations with Zn. whereas, significantly ($p<0.05$) positive correlations were recorded with boll weight (0.532, 0.817) and cotton seed yield (0.524, 0.548).

Key words: Cotton, Phosphorus, Zinc, Plant growth, Seed cotton yield, Stalk yield

Introduction

One of the most important natural fibre crops, cotton (*Gossypium hirsutum* L.) is also used as organic matter to improve soil, to make textiles, vegetable oil, medicines, animal feed, energy, and industrial lubricants. In 2022–2023, China was the world's top cotton producer with 59.80 lakh tonnes, followed by India (52 lakh tonnes), the United States (31.96 lakh tonnes), and Brazil (29.46 lakh tonnes). India produced 337.23 lakh bales of 170 kg cotton from 130.49 lakh hectares in 2022–2023, yielding 439 kg lint ha^{-1}. Although India owns 40% of the world's cotton-growing area, it leads the world in cotton production, accounting for only 21% of the crop. After the dominant rice-wheat cropping system, the cotton-wheat cropping system is the second-largest cropping system in south-west Punjab. This system is mostly used on light-textured, low-fertility soils, largely due to poor-quality groundwater (Brar and Singh, 2021; Singh *et al.,* 2023). Chemical fertilizers play a significant role in boosting cotton yield, and any nutritional deficiency or toxicity causes a decline in yield and plant development.

Phosphorus is essential for the growth, size, and maturity of cotton bolls (Din *et al.,* 2014). It is well recognized to affect lipid, protein, nucleic acid, and photosynthesis, and other significant chemical production processes. Additionally, its deficiency

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tends to decrease the amount of nodes, fruiting branches, leaves, amino acid and protein production per plant (Ahmad *et al.,* 2009). A considerable percentage of soils in the nation (~41%) have P deficiency, which is a foreseeable result of both high and low pH (Das *et al.,* 2022). In Punjab, intensively cultivated soils, 36.4% of the state's total area has less than 12 kg P ha^{-1} (mean 5.11 kg P ha^{-1}), 17.8% of state's total area is in the medium range between 12 and 22 kg P ha^{-1} (average 16.47 kg P ha^{-1}), 19.6% of the state's total area is in the high range between 22 and 50 kg P ha^{-1} (mean 32.58 kg P ha^{-1}), 26.2% area is very high range greater than 50% with an average of 108.89 kg P ha^{-1} (Mandal *et al.,* 2018).

Besides phosphorus (P), cotton requires zinc (Zn), a micronutrient element, to live a healthy life. Zinc affects protein and carbohydrate metabolism and chlorophyll production, and is responsible for enhanced yield and yield attributes. Also, many enzymes require Zn ions as cofactors to function. Zinc may also be necessary for plants to produce chlorophyll, which increases crop output (Pruthvi and Chandrashekara, 2021). Use of Zn increased cotton seed output, seed index, boll weight and boll bearing, leaf chlorophyll, seed protein, oil quantity and quality, membrane permeability and fibre quality. Zinc concentration in the leaves was positively associated with fibre attributes, total unsaturated fatty acids, protein content, and boll weight (Ahmed *et al.,* 2010). In Indian soils, about 36.5, 12.8, 7.1 and 4.2% soils were deficient in available Zn, Fe, Mn and Cu (Behera *et al.,* 2025), however, in Punjab soils, Zn deficiency varied from 0-36.2% with an average value of 12.1% (Dhaliwal *et al.,* 2020).

High P levels decrease Zn availability to the plants by the dilution effect, slower translocation of Zn in plants and cause an imbalance of nutrients at the cellular level. Therefore, the use of fertilizers at the optimal rate is essential. Use of P and Zn in cotton should be optimized since high P utilization reduces Zn absorption capacity in plants. The cotton production is restricted by a lack of Zn and P, particularly in areas where intensive farming has led to higher cotton yields (Santos *et al.,* 2018). To prevent P-Zn antagonism in the soil system, it's vital to use the right method, supply and rate of fertilizer. P and Zn have a positive interaction up to a certain limit, but after that, a negative interaction is observed. A practical strategy is to apply balanced fertilizer after conducting soil tests. Other crucial techniques to mitigate the antagonistic relationship between P and Zn include maintaining sufficient organic matter in the soil, seed coating with Zn, selecting crop species that are Zn-efficient, and enhancing plant root association with beneficial soil microorganisms (Saha *et al.,* 2022). This led to the hypothesis that cotton performance would be impacted by P and Zn interaction. Thus, studies were conducted to evaluate the application of P and Zn for enhancing agronomic characteristics and cotton yield in loamy sand soils of the southern part of Punjab, India, without a necessarily antagonistic effect.

Materials and Methods

Study area description

During *Kharif* 2022, the study was conducted at two different locations, namely site A: Research Farm, Regional Research Station (RRS), Bathinda and site B: Jewan Singh Wala Research Farm (JSWF), Bathinda, Punjab, India.

The initial physico-chemical properties of soils from both sites were determined according to standard methods (Jackson, 1973) and are presented in Table 1. The soils of the experimental sites were loamy sand. The soil calcium carbonate ($CaCO_3$), as

Table 1. Basic physical and chemical characteristics of the soils

Parameters	Location A	Location B
Sand (%)	77.6	76.2
Silt (%)	15.5	16.6
Clay (%)	6.9	7.2
Soil texture	Loamy sand	Loamy sand
$CaCO_3$ (%)	5.86	3.25
$pH_{1:2}$	8.43	8.95
$EC_{1:2}$ (dSm^{-1})	0.35	0.61
Soil OC (%)	0.42	0.36
N (kg ha^{-1})	243.5	224.3
P (kg ha^{-1})	22.5	13.5
K (kg ha^{-1})	348	320
DTPA- Fe (mg kg^{-1})	5.85	4.96
DTPA-Zn (mg kg^{-1})	0.96	0.85
DTPA-Cu (mg kg^{-1})	0.54	0.44
DTPA-Mn (mg kg^{-1})	4.67	4.15

well as macro and micro-nutrients, were slightly higher at location A as compared to location B; however, at location B, slightly higher soil pH and EC were recorded.

Experiment details

Using cotton crop (*Gossypium hirsutum* L.) variety RCH-776, four levels of zinc (0, 5, 7.5, and 10 kg Zn ha^{-1}) and phosphorus (0, 20, 30, and 40 kg P ha^{-1}) were used in the study. The experimental layout comprised 16 treatments, viz. T_1-P_0Zn_0, T_2-P_0Zn_5, T_3-$P_0Zn_{7.5}$, T_4-P_0Zn_{10}, T_5-$P_{20}Zn_0$, T_6-$P_{20}Zn_5$, T_7-$P_{20}Zn_{7.5}$, T_8-$P_{20}Zn_{10}$, T_9-$P_{30}Zn_0$, T_{10}-$P_{30}Zn_5$, T_{11}-$P3_0Zn_{7.5}$, T_{12}-$P_{30}Zn_{10}$, T_{13}-$P_{40}Zn_0$, and T_{14}-$P_{40}Zn_5$, T_{15}-$P_{40}Zn_{7.5}$ and T_{16}-$P_{40}Zn_{10}$were replicated thrice, in Factorial Randomized Block Design. Nitrogen@ @ 105 kg ha^{-1} and K @ 50 kg ha^{-1} were supplied through urea and MOP, respectively, in all treatments. Magnesium sulphate @ 62.5 kg ha^{-1}was also applied as a basal dose. All P, K, Zn, and magnesium sulphate were added to the soil during field preparation, while N was applied in two parts, half at the time of thinning and the other half during flower appearance.

Measurement and observations

In each experimental plot, ten representative plants were selected, excluding boundary rows from both sides, to record data on plant height, sympodial branches, and bolls. The average value was worked out and recorded for statistical analysis. The weight of 25 picked cotton bolls from each plot was measured using a digital weighing machine with a least count of 0.01 g, the average was calculated, and the result was recorded as the boll weight. Following the completion of all plot pickings, the total plot seed cotton and stalk yield was calculated in kg plot^{-1} and converted to q ha^{-1}.

Statistical analysis

All parameters were analyzed statistically by SPSS version 16.0 software. To assess significant differences at a 5% level between the outcomes attributable to different amounts of zinc (Zn) and phosphorus (P) in the crop, a two-way ANOVA was performed.

Results and Discussion

Plant height

The effect of different phosphate (P) and zinc (Zn) levels on plant height is shown in Fig. 1. The P effect was significant, while Zn and P × Zn interactions were not significant at both locations. The minimum plant height was reported for the control treatment (P0) at 104.6 cm and 130.0 cm, whereas the tallest plant height was obtained from

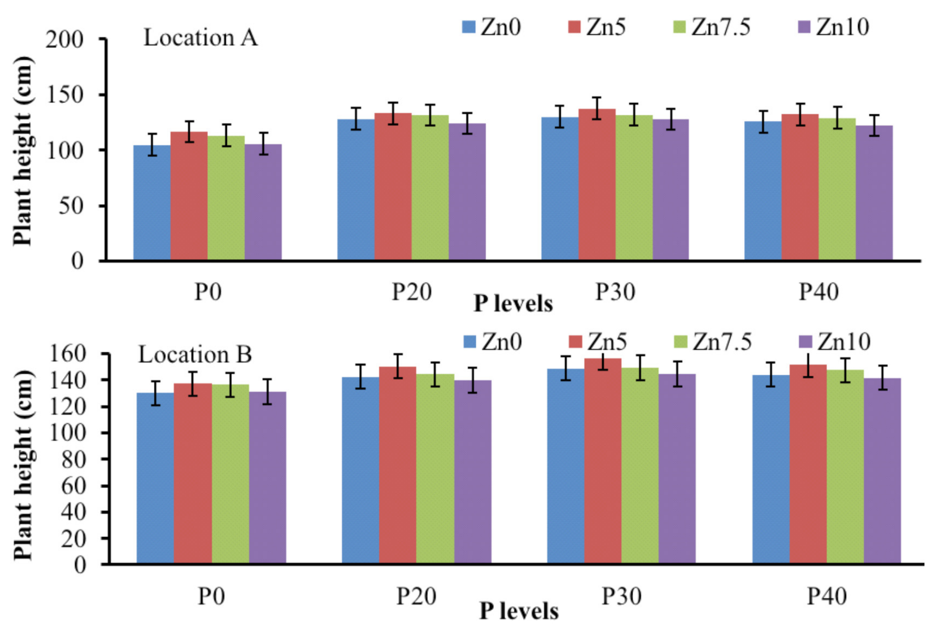

Fig. 1. Effect of different levels of P and Zn on cotton plant height

the application of P_{30} at 137.5 cm and 156.7 cm, respectively, at RRS and JSWF. According to the results, plant height increased when P and Zn levels increased. The plant height improved by 12.23% and 15.62% with P @ 20 and 30 kg ha^{-1} and effect of P @ 40 kg ha^{-1} was at par with P @ 20 kg ha^{-1} (producing similar increase of 12.23%) whereas plant height was enlarged by 5.82% and 2.73% with Zn @ 5 and 7.5 kg ha^{-1} and decreased by 1.63% with Zn @ 10 kg ha^{-1}. Phosphorus is an essential component of DNA, the genetic material that helps plants to grow and reproduce. It significantly affects cell division and expansion, thereby influencing plant height (Assuero *et al.,* 2004). Hence, the improved nutrient accessibility stimulated increased nutrient absorption, leading to robust growth and development in plants. These outcomes align with the observations of Bhuiyan *et al*. (2008) and Ahmad *et al*. (2009), who reported a gradual improvement in the height of the main stem with varying levels of phosphorus application. Zinc plays an important role in increasing plant height by promoting chlorophyll synthesis and photosynthetic processes. It also increases cell division and elongation, raising plant metabolism and resulting in higher plant growth parameters than in the control. Zinc fertilization effects on plant height are similar to those of Naik and Das (2007), who discovered that an adequate zinc supply accelerated enzymatic activity and is necessary for the synthesis of tryptophan, an auxin precursor that is involved in the synthesis of auxin, which is involved in cell elongation. According to Oren and Basal (2006) and Saleem *et al*. (2010a), the plant height increased compared to the control when Zn and P were applied, respectively. Gobi and Vaiyapuri (2012) and Yaseen *et al*. (2013) reported that plots with P @ 90 kg ha^{-1} combined with Zn @ 5 kg ha^{-1} showed increased plant height.

Sympodial branches

Cotton yield depends on sympodial branches, as they are the main sites of boll formation. The data presented in Fig. 2 demonstrate the impact of various P and Zn levels on sympodial branches. The least sympodial branches (14.1 and 18.6) were observed with the control (P_0) at RRS and JSWF. It was observed that the maximum number of sympodial branches was obtained with P_{30} at RRS (18.5) and JSWF (25.6). Phosphorus significantly affected the sympodial branches, whereas the Zn and P × Zn interactions had little effect at both locations (RRS and JSWF). The lowest value (16.3) was recorded for the P_0 and Zn_0 treatments, and the highest (22.1) for the P_{30} and Zn_5 treatments, respectively. It was reported that sympodial branches increased by

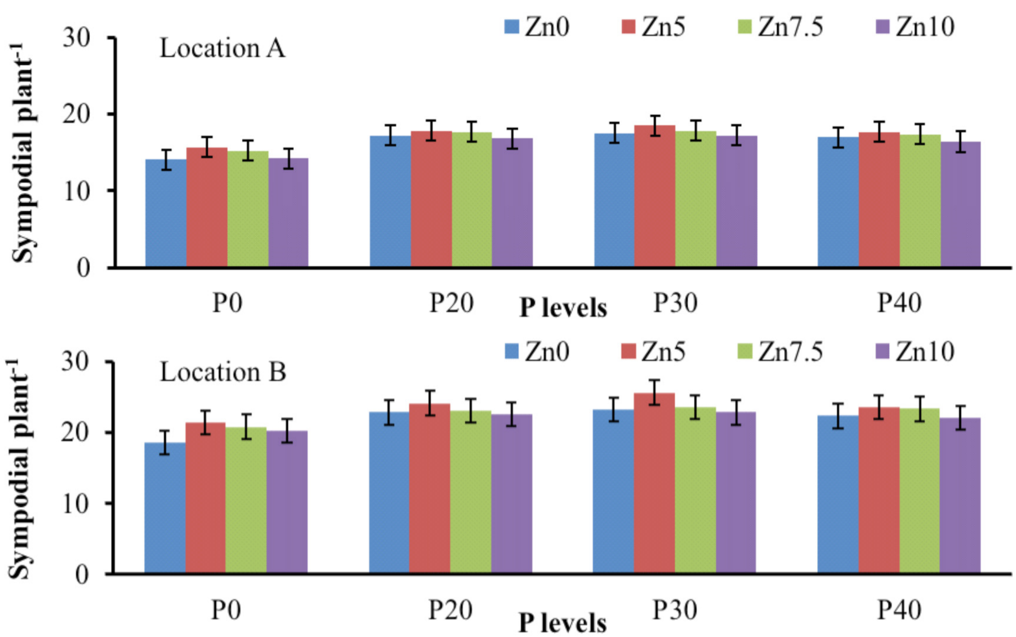

Fig. 2. Effect of different levels of P and Zn on sympodial branches

15.53%, 18.50% and 13.99% by P @ 20, 30 and 40 kg ha^{-1}, whereas it was increased by 7.76% and 3.99% with Zn @ 5 and 7.5 kg ha^{-1} and decreased by 0.37% with Zn @ 10 kg ha^{-1}. Phosphorus is essential for growth, photosynthesis, and cell division, which increases the quantity of fruiting branches. The plants may have had the opportunity to produce additional fruiting branches because metabolite synthesis may have increased as the zinc level in the leaves increased. According to Ahmad *et al.* (2009), Zn treatments at 34 kg ha^{-1} and 50 kg ha^{-1} increased the number of sympodial branches relative to the control.

Number of bolls and boll weight

Table 2 shows the impact of P and Zn levels on the number of bolls. For the number of bolls at RRS and JSWF, the P and Zn effect was significant, but Zn and their interaction were non-significant. The P_0 treatment resulted in the lowest bolls per plant at RRS and JSWF, with 61.4 and 60.7, respectively. The maximum number of bolls plant^{-1} at RRS (80.6) and JSWF (73.1) were obtained from P_{30}. The minimum boll (61.0) was acquired with the treatment of P_0Zn_0 and the maximum (76.8) with P_{30} Zn_5. It was reported that bolls plant^{-1} increased by 12.84%, 16.05% and 12.63% with P @ 20, 30, and 40 kg ha^{-1}, whereas it increased by 5.80% and 2.79% with Zn @ 5 and 7.5 kg ha^{-1}, and decreased by 1.66% with Zn @ 10 kg ha^{-1}. Phosphorus and Zn have been shown to positively impact flower formation and fertilisation biology, resulting in an increase in the number of bolls. These findings align with the research of Soomro *et al*. (2000) and Emara (2016). The higher bolls in plant^{-1} might be attributed to the regulatory action of phosphorus on photosynthesis, leading to enhanced carbohydrate accumulation and sugar metabolism. It may also be attributed to P levels, which lead to more sympodial branches, plant^{-1}. A component of the cell nucleus, P is essential for both cell division and the development of meristematic tissue. This has an exciting effect, increasing the number of balls. Similar results were obtained by Kalaichelvi (2009).

Additionally, Ahmad *et al.* (2009) observed, P application @34 kg ha^{-1} boosted boll number, and a higher number of bolls corresponds to a higher expected seed cotton yield. Zinc is essential for boosting photosynthetic and enzymatic activity, especially auxin production, which increases the number of bolls. Additionally, it contributes to the

Table2. Impact of varying P and Zn levels on the number of bolls and boll weight

P levels	Number of bolls plant^{-1}									
	Location A					Location B				
	Zinc levels					Zinc levels				
	Zn_0	Zn_5	$Zn_{7.5}$	Zn_{10}	Mean	Zn_0	Zn_5	$Zn_{7.5}$	Zn_{10}	Mean
P_0	61.4	68.4	66.2	61.8	64.4	60.7	64.1	63.5	61.2	62.4
P_{20}	75.1	77.9	77.3	73.0	75.8	66.5	70.2	67.3	65.2	67.3
P_{30}	76.2	80.6	77.3	74.8	77.2	69.5	73.1	69.8	67.6	70.0
P_{40}	73.8	77.4	75.5	71.5	74.6	67.3	70.6	68.9	66.3	68.3
Mean	71.6	76.1	74.0	70.3		66.0	69.5	67.4	65.1	
LSD(p=0.05)	A= 5.71 B=NS A×B= NS					A= 4.33 B=NS A×B= NS				
P levels	Boll weight (g)									
	Zinc levels					Zinc levels				
	Zn_0	Zn_5	$Zn_{7.5}$	Zn_{10}	Mean	Zn_0	Zn_5	$Zn_{7.5}$	Zn_{10}	Mean
P_0	5.5	6.0	5.5	5.8	5.7	6.1	6.5	6.7	6.2	6.4
P_{20}	6.9	7.9	7.3	7.0	7.3	6.4	6.5	7.4	6.8	6.8
P_{30}	6.2	6.9	7.0	6.8	6.7	6.8	7.4	7.6	7.5	7.3
P_{40}	5.7	6.3	6.3	6.2	6.1	6.4	7.1	7.2	7.3	7.0
Mean	6.07	6.8	6.5	6.4		6.5	6.9	7.2	6.9	
LSD(p=0.05)	A= 0.41 B=0.41 A×B= NS					A= 0.44 B=0.44 A×B= NS				

prevention of square formation and shedding of bolls, which lead to the production of a large number of bolls. These results are in line with those of Rathinavel *et al.* (2000), Makhdomm *et al.* (2010) and Mahmooda *et al.* (2016), who observed a tendency for bolls to increase while zinc was applied to cotton fields.

Table 2 also showed how various P and Zn levels affected boll weight. Zinc and P had a substantial impact on boll weight at RRS and JSWF, but the P×Zn interaction was not significant. The treatment P_0Zn_0 resulted in minimum boll weight of 5.52 g and 6.14 g, respectively, at RRS and JSWF. Maximum boll weight was recorded with $P_{20}Zn_5$ at RRS (7.91 g), $P_{30}Zn_{7.5}$ at JSWF (7.57 g). It was reported that boll weight increased by 16.39%, 16.06% and 8.44% with 20, 30, and 40 kg ha^{-1} P, while it increased by 8.95%, 9.74% and 6.87% with 5, 7.5 and 10 kg ha^{-1} Zn. Phosphorus is recognized to have a significant role in photosynthesis and the synthesis of proteins, lipids, nucleic acids, and other vital compounds, all of which may have an impact on boll weight and additionally, cottonseed. Phosphorus regulates the starch: sucrose ratio and the appropriate photosynthetic mobilization that results in higher boll weight. Similar findings were previously published by Nadeem *et al.* (2004) and Khan *et al.* (2007). Zinc may have a positive impact on leaves' photosynthetic activity, thereby enhancing photosynthate mobilisation and directly affecting boll weight. The application of Zn generally improved the growth and development of cotton plants. The weight and retention of bolls increased as a result of an improvement in the transmission of photosynthates from vegetative plant parts to reproductive systems. According to Taheri *et al.* (2011), increased activity of enzymes involved in glucose metabolism is the reason for the increase in boll weight following zinc management.

Seed cotton yield

The effect of different P and Zn levels on seed cotton yield is shown in Table 3. Control treatment ($P_0 \times Zn_0$) resulted in the lowest seed cotton yield at both locations, 26.4 q ha^{-1} and 30.1 q ha^{-1}, respectively, at RRS and JSWF. Maximum seed cotton yield was recorded with $P_{20} \times Zn_5$ at RRS, JSWF, at 37.8 q ha^{-1} and 37.2 q ha^{-1}. It was found that P and Zn had significant effects, while the P×Zn interaction was non-significant at both locations. It

Table 3. Impact of varying P and Zn levels on cotton seed and stalk yield

P levels	Seed cotton yield (q ha^{-1})									
	Location A					Location B				
	Zinc levels					Zinc levels				
	Zn_0	Zn_5	$Zn_{7.5}$	Zn_{10}	Mean	Zn_0	Zn_5	$Zn_{7.5}$	Zn_{10}	Mean
P_0	26.4	28.8	26.4	27.7	27.3	30.1	33.0	30.2	31.7	31.2
P_{20}	32.8	37.8	35.1	33.5	34.8	33.5	37.2	36.8	36.1	35.9
P_{30}	29.5	33.0	33.3	32.4	32.0	31.6	35.3	35.6	34.7	34.3
P_{40}	27.3	30.2	29.9	29.4	29.2	31.3	36.2	33.6	32.1	33.3
Mean	29.0	32.4	31.2	30.8		31.7	35.4	34.0	33.6	
LSD(p=0.05)A= 1.94 B=1.94 A×B= NSA= 2.16 B=2.16 A×B= NS										
P levels	Stalk yield (q ha^{-1})									
	Zinc levels					Zinc levels				
	Zn_0	Zn_5	$Zn_{7.5}$	Zn_{10}	Mean	Zn_0	Zn_5	$Zn_{7.5}$	Zn_{10}	Mean
P_0	117.2	130.8	126.6	118.2	123.2	156.4	165.3	164.0	157.6	160.9
P_{20}	143.5	149.1	147.4	139.0	144.8	171.3	181.3	173.5	168.1	173.6
P_{30}	145.7	154.1	147.7	143.1	147.7	179.0	188.4	179.7	174.5	180.4
P_{40}	140.9	148.0	144.3	136.8	142.5	173.1	182.4	177.6	170.9	176.0
Mean	136.8	145.5	141.5	134.3		170.0	179.4	173.7	167.8	
LSD(p=0.05)A= 10.95 B=NS A×B= NSA= 11.19 B=NS A×B= NS										

was reported to increase by 20.74%, 13.29%, and 6.73% with 20, 30, and 40 kg ha^{-1} P, respectively. Whereas, it increased by 11.91%, 7.56%, and 6.20% with 5, 7.5, and 10 kg ha^{-1} Zn, respectively. The beneficial effects of P fertilization on growth parameters, like plant height, branch number, and bolls on the plant, may be the cause of larger seed cotton yields achieved by higher P levels. Additionally, P is linked to improved root system growth, which controls nutrient intake and helps reduce square and boll abscission, resulting in higher yield. These results are corroborated by Ibrahim *et al.* (2009) and Saleem *et al.* (2010a). Gobarah *et al.* (2006) reported similar results, indicating that an improvement in boll setting increased yield. The Zn needs synthesis of tryptophan, an element of indole-3-acetic acid, the main hormone that keeps bolls and bract leaves together in plants, increasing the quantity of bolls and, ultimately, seed cotton yield (Rathinavel *et al.* , 2000). Studies by Somro *et al.* (2000), Ahmad *et al.* (2009), Ahmed *et al.* (2010), Saleem *et al.* (2010b), Emara (2016), and Sawan (2018) have shown similar results, indicating that zinc and phosphorus increased seed cotton yield.

Stalk yield

The impact of P and Zn treatments on variation in stalk yield is shown in Table 3. At RRS and JSWF, the P_0 treatment produced the lowest stalk yields, 117.2 q ha^{-1} and 156.4 q ha^{-1}, respectively. Maximum stalk yield was reported with P_{30} at RRS and JSWF, which was 154.1 q ha^{-1} and 188.4 q ha^{-1}. Phosphorus had a significant effect at both sites, whereas Zn and the P×Zn interaction had no significant effects. Maximum stalk yield (171.3 q ha^{-1}) was reported with P_{30} Zn_5 and minimum (136.8 q ha^{-1}) with P_0 Zn_0. It was reported that stalk yield increased by 12.05%, 15.49% and 12.13% with 20, 30, and 40 kg P ha^{-1}, whereas it increased by 5.89% and 2.73% with 5 and 7.5 kg Zn ha^{-1} and decreased by 1.54% with 10 kg Zn ha^{-1}. Plant height, number of sympodial branches, and the number of bolls per plant were some variables of the yield that were positively impacted by the application of different doses of P, which may have contributed to the increase in stalk yield (Saleem *et al.,* 2010b). P deficiencies are linked to stunted growth and development, which may account for the much lower yield observed with control or 30 kg P ha^{-1} (Havlin *et al.,* 2007). These findings are consistent with studies on soybeans by Khaswa *et al.* (2014) and Begum *et al.* (2015). Applying zinc may have increased yield because of its significant role in regulating auxin levels in plants. Radhika *et al.* (2013) and Yaseen *et al.* (2013) found that applying Zn @ 5.0 kg ha^{-1} to the soil enhanced the production of cotton stalks.

Correlation between phosphorus and zinc with different growth parameters and seed cotton yield

The results in Table 4 revealed that, at both locations, phosphorus was considerably ($p < 0.05$) positively correlated with yield traits and yield. The correlation values for plant height (0.883, 0.824), sympodial (0.825, 0.809), boll $plant^{-1}$(0.820, 0.884), boll weight (0.295, 0.837), cotton seed yield (0.295, 0.473) and stalk yield (0.823, 0.884), suggesting that yield traits and seed cotton yield were positively dependent on phosphorus. Similarly, among the yield parameters such as plant height (-0.121, -0.147),

Table 4. Zinc and phosphorus correlation with various cotton growth characteristics and yield

Plant parameters	Correlation coefficient value			
	Phosphorus		Zinc	
	Location A	Location B	Location A	Location B
Plant height	o.883*	0.824*	-0.121	-0.147
Sympodial	0.825*	0.809*	-0.987	0.102*
Boll $plant^{-1}$	0.820*	0.884*	-0.984	-0.148
Boll weight	0.295**	0.837*	0.532*	0.817*
Cotton seed yield	0.295*	0.473*	0.524*	0.548*
Stalk yield	0.823*	0.884*	-0.122	-0.129

*Correlation coefficients significant at $p < 0.005$.

sympodial (-0.987, 0.102), boll plant^{-1} (-0.984, -0.148), and stalk yield (-0.122, -0.129) showed a significant ($p < 0.05$) negative correlation with zinc at both locations (Table 4). Whereas, significantly ($p < 0.05$) positive correlations were recorded with boll weight (0.532, 0.817) and cotton seed yield (0.524, 0.548) due to Zn at both locations. P is one of the three nutrients required for cotton growth and development (Sun *et al.*, 2022). According to Sun *et al.* (2018), it may directly affect lint yield by promoting budding and blooming during the intermediate growth stage and increasing maturity and weight in cotton bolls during the late development stage. Phosphate deficiency inhibited photosynthesis and plant growth, thereby affecting biomass accumulation and production (Singh *et al.,* 2013). Sawan *et al.* (2006) found that when phosphorus was added, seed yield increased significantly over the control.

Phosphorus increases the biomass of reproductive organs and nutrient accumulation, which in turn stimulates the growth of more bolls per plant (Iqbal *et al.,* 2020). Zinc may improve the photosynthetic activity of leaves, which improves the mobilization of photosynthetic assimilates and directly affects boll weight (Welch, 1995). The synthesis of tryptophan, a precursor of indole-3-acetic acid, also requires Zn (Oosterhuis *et al.,* 1991). This is the main hormone that prevents the separation of the bolls and bract leaves on the plant. Consequently, the plant produces more bolls, increasing seed cotton yield (Rathinavel *et al.,* 2000). Applications of zinc, as noted by Oren and Basal (2006), and P, as noted by Saleem *et al.* (2010), improved plant growth compared to the control. According to Ahmad *et al.* (2009), compared to the control, 34 kg and 50 kg Zn ha^{-1} increased the number of sympodial branches. Applications of zinc and phosphorus can improve the biology of fertilization and flower formation, increase bolls and their weight (Soomro *et al.,* 2000; Emara, 2016).

Conclusion

In the present investigation, the effects of P and Zn levels on cotton yield and other agronomic traits were evaluated. The results showed that whereas P had significant effects on cotton growth parameters, Zn and P × Zn interaction were not significant. Furthermore, the findings showed that P was significantly ($p < 0.05$) positively correlated with yield parameters and yield. The yield characteristics of plant height, sympodial, boll plant^{-1}, and stalk yield showed a significant ($p < 0.05$) negative correlation with Zn. However, there was a significantly ($p < 0.05$) favorable correlation between cotton seed yield and boll weight when zinc was applied.

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