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Impact of Phosphorus Levels and Application Techniques on Cotton Growth and Yield in Sahiwal, Pakistan

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Abstract

Phosphorus (P) application plays a crucial role in cotton growth by enhancing reproductive development and seed cotton yield. This study, conducted at the Adaptive Research Station in Sahiwal from 2021 to 2022, examined the effects of various phosphorus application methods on the productivity of cotton cultivar MNH-1020. A randomized complete block design (RCBD) with three replications was employed, incorporating seven phosphorus treatments, including control (T1, no P) and different combinations of band placement, broadcast, and fertigation at 57 kg and 85 kg P_2O_5/ha. Results from Kharif 2022 indicated that the highest seed cotton yield (3119 kg/ha) was recorded in T7 (85 kg P_2O_5/ha, with half broadcast at sowing and half fertigated 60 days after sowing). The second highest yield (3022 kg/ha) was observed in T5 (85 kg P_2O_5/ha applied fully at sowing). In contrast, the lowest yield (2106 kg/ha) was obtained from T1 (control). A significant positive correlation (R^2 = 0.95 and 0.87) was observed between boll density, boll mass, and seed cotton yield. The findings suggest that applying 85 kg P_2O_5/ha, with a split application between sowing and 60 days post-sowing, optimizes phosphorus availability and improves cotton yield.

Keyword: Agro-climatic conditions, Boll mass, Broad cast, Correlation, Fertigation,
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Introduction

Phosphorus is an essential nutrient required for plant growth, participating in energy transfer and metabolic processes. Pakistani soils, predominantly alkaline and calcareous, have low phosphorus uptake efficiency, limiting cotton production (FAO, 2021). Cotton, a key cash crop, serves as a primary raw material for the textile industry while generating employment (Rana et al., 2020). In 2020, global cotton cultivation spanned 33.1 million hectares, producing 136 million bales and contributing 35% to total fiber production (FAO, 2021). In Pakistan, the textile sector accounts for 24% of agricultural value addition and 60% of foreign exchange earnings.

Farmers frequently apply excessive nitrogenous fertilizers while underutilizing phosphorus and potassium, disrupting nutrient balance essential for plant growth (Ali & Khan, 2007). Studies indicate that improper fertilizer use leads to abiotic stress, negatively affecting cotton yield (Shah et al., 2017). The integration of mineral fertilizers has been shown to enhance soil nutrient availability, improving crop productivity (Fontana et al., 2020). Research by Stewart et al. (2005) demonstrated that fertigation is an effective method for phosphorus delivery, optimizing nutrient absorption and boosting lint production. Additionally, split fertigation minimizes fixation, ensuring efficient phosphorus uptake (Shah et al., 2006).

Fertigation, a modern approach, involves applying plant nutrients through irrigation systems rather than the conventional broadcast method. This technique ensures the availability of both soil moisture and fertilizers at the right time, enabling better phosphorus utilization by crops (Stewart et al., 2005). It also optimizes the fertilizer application schedule for maximum efficiency throughout the growing season.

Fertigation of phosphorus has also been shown to enhance maize production (Hussein, 2009). Similar findings were reported by Makhdum et al. (2001) and Ahmad et al. (2007), who observed increased total dry matter yield following phosphorus application in cotton. Din et al. (2014) reported that seed cotton yield varied significantly based on both the application method and timing of phosphorus fertilization. Fertigation resulted in 15% higher yield (2152 kg ha^{-1}) compared to band placement. Similarly, applying phosphorus in three splits led to a 9% higher yield than a single full-dose application as basal dressing. Yield-contributing parameters were also improved when phosphorus was applied in splits through fertigation.

Therefore, this study was designed to evaluate the response of cotton to varying phosphorus levels and application methods on seed cotton yield (SCY kg ha^{-1}) in the agro-ecological conditions of Sahiwal, Pakistan.

Materials and Methods

Experimental Site and Study Design

A field study was conducted at a farmer's field near the Adaptive Research Station, Sahiwal, during the second week of March in 2021 and 2022. The primary objective was to evaluate the efficacy of different phosphorus (P) treatments and application methods on cotton productivity. The goal was to identify optimal fertilization practices to enhance crop yields and improve cotton production.

The study followed a randomized complete block design (RCBD) with three replications. Seven phosphorus treatments were tested, including T1, which served as the control with no phosphorus application. T2 involved the application of 57 kg P/ha as a full dose at sowing using the band placement method. T3 consisted of 57 kg P/ha applied entirely

through fertigation 30 days after sowing. In T4, phosphorus was applied at 57 kg P/ha, with 50% broadcast at sowing and the remaining 50% fertigated 30 days post-sowing. T5 included a full dose of 85 kg P/ha applied at sowing through band placement. T6 involved 85 kg P/ha, with half applied through fertigation at 30 days and the other half through fertigation at 60 days. T7 comprised 85 kg P/ha, where half was broadcast at sowing and the other half fertigated at 60 days after sowing.

Soil Sampling and Analysis

Pre-planting soil samples were collected from the experimental site for analysis following the methodology described by Ryan et al. (2001). The soil was classified as clay loam with a pH of 8.45, indicating an alkaline nature. Organic matter content was found to be 0.75%, while nitrogen, available phosphorus, and available potassium were measured at 0.038%, 6.5 ppm, and 147 ppm, respectively. The analysis indicated a dense soil texture, alkaline reaction, and deficiencies in organic matter, nitrogen, phosphorus, and potassium, with no signs of excessive soluble salts.

Crop Management and Fertilization

Cotton cultivar MNH-1020 was sown in a well-prepared seedbed, maintaining an inter-row spacing of 75 cm and an intra-row spacing of 22.5 cm to support optimal plant growth. The entire recommended dose of potassium (K_2O) was applied at sowing as sulfate of potash. Phosphorus application was adjusted according to the respective treatment protocols. Nitrogen was supplied at a rate of 150 kg/ha in the form of urea, divided into four equal applications to ensure balanced nutrient uptake and utilization. Weed control was managed through the application of a pre-emergence herbicide, Dual Gold, at a rate of 800 ml/acre. Standard agronomic and phytosanitary measures were implemented throughout the growing season to protect the crop from pests and diseases.

Yield and Growth Measurements

Seed cotton was harvested plot by plot, and the yield was recorded in kilograms per hectare. For further evaluation, ten plants were randomly selected from each treatment to count the number of bolls per plant (NBP). Twenty-five bolls from each treatment were collected to determine the average boll mass.

Agronomic Phosphorus Use Efficiency (PUE)

Phosphorus use efficiency (PUE) was calculated using the formula described by Dobermann (2005):

$$\mathrm{PUE}\left(\mathrm{kg\ yield\ /kg\ P}\right) = \frac{\mathrm{Yt} - \mathrm{Yc}}{\mathrm{Pa}}$$

where Y_t represents the yield (kg/ha) of the phosphorus treatment, Y_c is the yield of the control (kg/ha), and P_a is the amount of phosphorus applied (kg P/ha) in the treatment.

Meteorological Conditions

Throughout the crop growth cycle, the highest recorded temperatures ranged between 43.3 °C and 45.15 °C, while the lowest temperatures varied between 21.67°C and 22.65°C. The cumulative precipitation was recorded at 218.3 mm during the 2022 growing season and 141.8 mm during the 2021 season.

Statistical Analysis

The collected data on yield and yield components were statistically analyzed, and significant differences among treatments were determined using the Least Significant Difference (LSD) test, as described by Gomez and Gomez (1984).

Results and Discussions

The data presented in Table 1 highlight statistically significant **(**$p < 0.05$**)** variations in SCY Kg ha^{-1} and its components in response to different phosphorus fertilizer application methods and dosages under the prevailing agro-climatic conditions of Sahiwal, Pakistan, during the Kharif 2022 season. The highest SCY Kg ha^{-1} of 3119 kg/ha was obtained from treatment T7, which involved the application of 85 kg P/ha, split between broadcasting at sowing and fertigation 60 days after sowing (Table 1). This was closely followed by T5, which yielded 3022 kg/ha. The lowest yield of 2106 kg/ha was recorded for the control treatment T1, which differed significantly from all other treatments. No significant difference was observed between treatments T5, T6 and T3, T4 regarding SCY Kg ha^{-1}. The highest boll weight (BW) was recorded in T7 (2.59 g) and T5 (2.56 g), followed by T6 (2.51 g). The lowest BW of 2.34 g was obtained in T1**.**

Table 1. Response of cotton (*Gossypium hirsutum L.*) to various levels of P and its application methods under agro-climatic conditions of Sahiwal, Pakistan during Kharif 2022.

Tr. No.	**Treatments (kg P /ha)**	**No. of bolls plant^{-1}**	**Boll weight(g)**	**Yield (kg ha^{-1})**
T1	(control, no P)	22.2 F	2.34D	2106 E
T2	57 kg (full P at sowing as band placement)	31.8 E	2.40C	2711 D
T3	57 kg (full P as fertigation after 30 days of sowing)	33.0 D	2.46C	2881 C
T4	57 kg (half P as broadcast at sowing and half P as fertigation after 30 days of sowing),	33.8 C	2.44C	2821C
T5	85kg (full P at sowing as band placement	34.2 B	2.56A	3022B
T6	85 kg (half P as fertigation after 30 days of sowing and half P as fertigation after 60 days of sowing,	35.6 A	2.51B	2963B
T7	85 kg (half P as broadcast at sowing and half P as fertigation after 60 days of sowing)	35.8 A	2.59A	3119A
	LSD	**0.31**	**0.04**	**61.19**

Values not accompanied by a shared letter within a column are statistically significant at a 5% probability threshold indicates a substantial difference between the means.

Regarding the NBP, the highest values were recorded for T7 (35.8) and T6 (35.6)**,** followed by T5 (34.2)**.** The lowest NBP **(**22.2**)** was observed in T1. The different phosphorus fertilizer application methods and dosages significantly influenced the yield components, including the NBP, BW, and SCY, during the Kharif 2021 and 2022 seasons, as supported by the data in Table 2**.**

Table 2. Response of cotton (*Gossypium hirsutum L.*) to various levels of P and its application methods under agro-climatic conditions of Sahiwal, Pakistan during Kharif 2021.

Tr. No.	Treatments (kg P /ha)	No. of bolls plant^{-1}	Boll weight(g)	Yield (kg ha^{-1})
T1	(control, no P)	17.2 G	2.37D	1969E
T2	57 kg (full P at sowing as band placement)	23.4F	2.45C	2326CD
T3	57 kg (full P as fertigation after 30 days of sowing)	25.2E	2.51C	2473 C
T4	57 kg (half P as broadcast at sowing and half P as fertigation after 30 days of sowing),	26.6D	2.47C	2411C
T5	85kg (full P at sowing as band placement	28.8 B	2.62B	2678B
T6	85 kg (half P as fertigation after 30 days of sowing and half P as fertigation after 60 days of sowing,	27.2 C	2.57B	2591B
T7	85 kg (half P as broadcast at sowing and half P as fertigation after 60 days of sowing)	29.2 A	2.71A	2835A
	LSD	**0.37**	**0.06**	**117.91**

Values not accompanied by a shared letter within a column are statistically significant at a 5% probability threshold indicates a substantial difference between the means.

Yearly Variation in Yield Components

Although BW and the NBP showed statistically significant **(**$p < 0.05$**)** inter-annual variability, SCY Kg ha^{-1} remained consistent across both years. The highest BW in Kharif 2021 was recorded in T7 (2.71 g)**,** followed by T5 (2.62 g) and T6 (2.57 g)**,** which were statistically similar. The lowest BW **(**2.37 g**)** was recorded for T1 (Table 2). The results indicate that T7 consistently outperformed all other treatments regarding SCY Kg ha^{-1}, NBP per plant, and BW across both years of the study, confirming its effectiveness as the optimal phosphorus fertilization strategy (Table 2-3).

Table 3. Response of Cotton (*Gossypium hirsutum L.*) to various levels of p and its application methods under agro-climatic circumstances of Sahiwal, Pakistan during Kharif 2021-22 (mean data)

Tr. No.	Treatments (kg P /ha)	No. of bolls plant^{-1}	Boll weight(g)	Yield (kg ha^{-1})	Agronomic PUE (kg yield/kg P)=Yt−Yc/Pa
T1	(control, no P)	19.7F	2.355E	2037.5 E	-
T2	57 kg (full P at sowing as band placement)	27.6E	2.425D	2518.5D	8.44
T3	57 kg (full P as fertigation after 30 days of sowing)	29.1D	2.485D	2677C	11.22
T4	57 kg (half P as broadcast at sowing and half P as fertigation after 30 days of sowing),	30.2C	2.455D	2616C	10.15
T5	85kg (full P at sowing as band placement	31.5B	2.59B	2850B	9.56
T6	85 kg (half P as fertigation after 30 days of sowing and half P as fertigation after 60 days of sowing,	31.4B	2.54C	2777B	8.71
T7	85 kg (half P as broadcast at sowing and half P as fertigation after 60 days of sowing)	32.5A	2.65A	2977A	11.06
	LSD	**0.46**	**0.03**	**91.22**	

Correlation Between Yield Components and Seed Cotton Yield

Regression analysis revealed a strong positive correlation (R^2 = 0.95, 0.87) between the NBP per plant and SCY Kg ha^{-1}, as well as between BW and SCY Kg ha^{-1} during the 2021–2022 period (Figures 1 and 2). The findings suggest that increasing boll number and BW contributes significantly to higher cotton yields.

Impact of fertilizers levels on cotton growth

To achieve profitable cotton production, farmers are recommended to implement precision soil fertility management strategies, particularly the application of 85 kg P/ha, with half applied as broadcast at sowing and the remaining half as **f**ertigation 60 days after sowing**.** This method ensures optimal phosphorus uptake and utilization by the cotton crop.

The findings align with those of Din et al. (2014), Iqbal et al. (2020), and Fontana et al. (2020)**,** who reported that SCY Kg ha^{-1} and its key components varied significantly depending on both the timing and method of phosphorus application**.** Fertigation was found to be superior to other P-application methods, resulting in a 15% increase in SCY Kg ha^{-1}**.** Similarly, Stewart et al. (2005) concluded that fertigation effectively delivers phosphorus to cotton crops, leading to increased lint yield. The application of phosphorus through split fertigation delayed fixation**,** allowing plants to rapidly and efficiently absorb the nutrient directly from the soil solution. These findings underscore the importance of timing and method of phosphorus application in enhancing cotton productivity under field conditions.

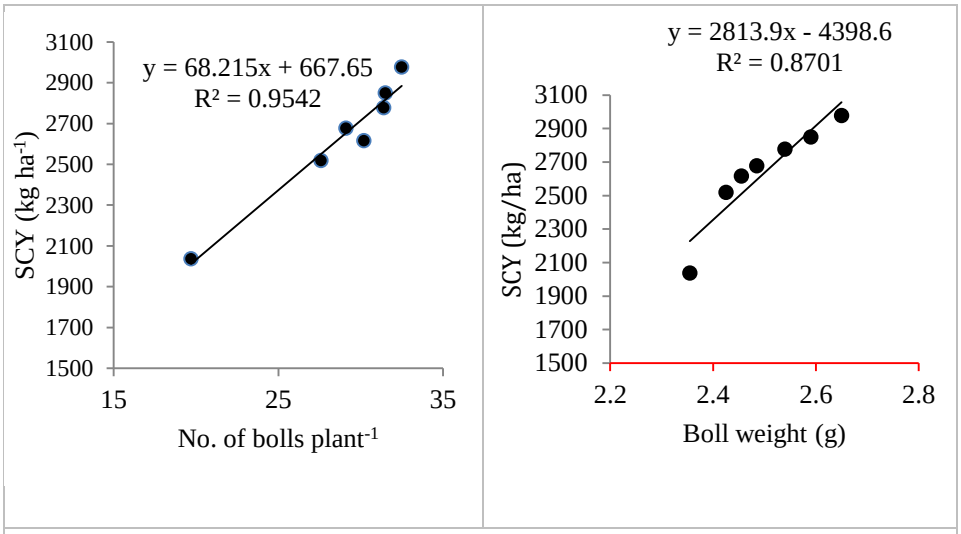

Figure 1. A. Relationship between No. of bolls/plant and seed cotton yield (SCY) (kg/ha) during kharif 2021-22 (B). Relationship between Boll weight and seed cotton yield (SCY) (kg/ha) during kharif 2021-22

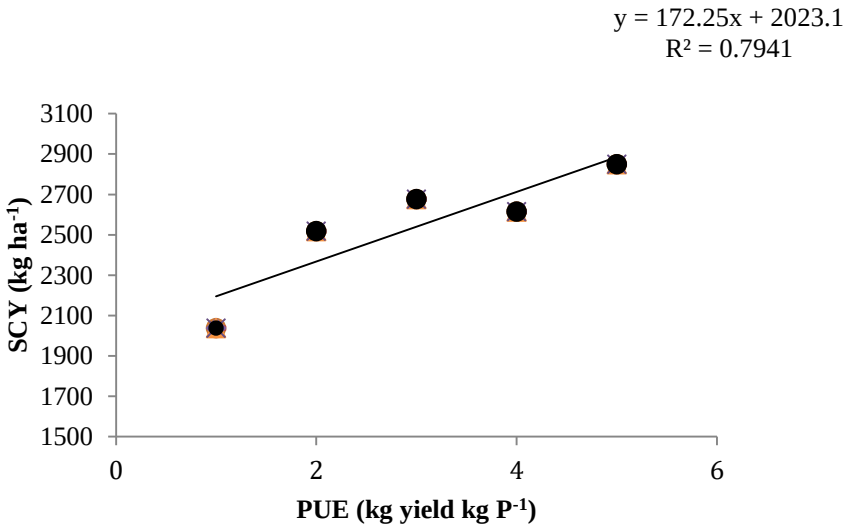

Figure 2. Relationship between Agronomic PUE (kg yield/kg P and Seed cotton yield (SCY) (kg/ha) during kharif 2021-22

Conclusion

This study demonstrated a positive linear relationship between seed cotton yield and increases in both boll number and boll weight, emphasizing the need to optimize these factors to maximize productivity. To achieve profitable cotton production, agricultural practitioners are encouraged to implement precision soil fertility management strategies, specifically applying 85 kg P/ha, with half broadcast at sowing and the remaining half applied as fertigation 60 days after sowing.

Fertigation has proven to be an efficient strategy for phosphorus application, as it delays fixation in the soil, allowing plants to absorb the nutrient quickly and directly from the soil solution, ultimately improving lint yield and overall crop performance.

Competing of Interest

The authors declare that the research was carried without any commercial or financial relationships that could be construed as a potential conflict of interest.

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Consent for publication: All authors submitted consent to publish this research.

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