

Optimizing Potassium Application Timing and Rates for Enhanced Cotton (*Gossypium hirsutum* L.) Productivity in a Wheat-Cotton Cropping System, Punjab, Pakistan

Liaqat Ali¹, Muhammad Shahid², Muhammad Shahbaz^{3*}, Sidra Batool⁴, Amna Batool⁵, Shakila Yasmeen³, Muhammad Tariq⁶, Ishtiaq Hassan⁶

¹Adaptive Research Station, Sahiwal, Punjab, Pakistan,

²Directorate of Agriculture (FT&AR) Vehari zone, Punjab, Pakistan,

³Directorate of Agriculture (FT&AR), Sheikhpura zone, Punjab, Pakistan,

⁴Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan,

⁵Govt. College University, Faisalabad, Sahiwal Campus, Punjab, Pakistan,

⁶Directorate General Agriculture (FT & AR), Lahore, Punjab, Pakistan.

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Abstract

Cotton (*Gossypium hirsutum* L.) is an important cash crop in Pakistan, yet its yield is constrained by a range of biotic and abiotic stress factors. Imbalanced fertilizer use is a key abiotic factor reducing yield, while potassium (K) is an essential macronutrient that regulates photosynthesis, water balance, fiber quality, and boll development. To assess the effect of K management, a two-year field study was carried out during the Kharif seasons of 2020 and 2021 using a randomized complete block design with three replications. Four treatments were tested: T1, 93.75 kg ha⁻¹ in two splits (½ at sowing + ½ at flowering); T2, 93.75 kg ha⁻¹ in three splits (⅓ at sowing + ⅓ at flowering + ⅓ at boll formation); T3, 125 kg ha⁻¹ in two splits (½ at sowing + ½ at flowering); and T4, 125 kg ha⁻¹ in three splits (⅓ at sowing + ⅓ at flowering + ⅓ at boll formation). Results showed that T4 significantly improved yield and yield components, recording seed cotton yield of 2,431 kg ha⁻¹, 22.8 bolls plant⁻¹, and boll weight of 3.15 g. Treatment T3 performed similarly, producing 2,367 kg ha⁻¹ yield, 21.2 bolls plant⁻¹, and 2.86 g boll weight. The lowest performance was noted in T1, with yield (2,132 kg ha⁻¹), 19.2 bolls plant⁻¹, and 2.58 g boll weight. The study concludes that applying 125 kg K ha⁻¹ in three splits at sowing, flowering, and boll formation is the most effective strategy to enhance cotton productivity.

1. Introduction

Cotton (*Gossypium hirsutum* L.) is considered a significant fiber and economic crop in Pakistan's agricultural sector significantly contributing to the national economy through textile export, employment, and oilseed production. It is grown for its high-quality fiber and oil and contributes significantly to both the agricultural and industrial sectors by

supplying employment opportunities and raw materials to the textile sector (Rana *et al.*, 2020). During the year 2021-22, it was grown on an area of 1937 thousand hectares and produced 8.329 million bales in Pakistan, which was about 35% of the total fiber production globally and the 3rd leading producer of cotton, 4th country with highest area under cotton production, and 39th in average productivity (Anonymous, 2022). Its production employs 17% of people, earns 60% of

*Corresponding Author: Muhammad Shahbaz

Email: shahbazsms2014@gmail.com

foreign exchange, and contributes 0.6% to country's GDP and 2.4% of the value addition in agriculture. Despite its economic significance, cotton productivity has been declining as a result of multiple biotic and abiotic constraints (Saud *et al.*, 2022). Among the abiotic limitations, improper and unbalanced fertilizer management has emerged as a major concern highlighted in recent research (Khan *et al.*, 2017 and Hussain *et al.*, 2021).

Among the essential nutrients, potassium (K) is an essential macronutrient that significantly influences the growth, development, and productivity of cotton crops. It is essential for various physiological and biochemical functions, including enzyme activation, photosynthesis, osmoregulation, and the transport of assimilates. Among all macronutrients, potassium is particularly vital in enhancing boll formation, fiber development, and improving the plant's tolerance against biotic and abiotic stresses. Several researchers have highlighted the importance of potassium in cotton cultivation. According to Pettigrew (2008), potassium deficiency in cotton not only reduces yield but also impairs fiber quality, particularly affecting fiber strength and micronaire. Similarly, Gao *et al.* (2013) showed that potassium supplementation increases drought resistance by regulating stomatal conductance and improving root architecture in cotton plants. Fontana *et al.* (2020) reported that macronutrients, particularly K, are essential in crop productivity through influencing photosynthesis rates, nutrient transport, and fiber quality. Khan *et al.* (2019) explained that potassium is often under-applied in cotton fields across Pakistan, mainly due to historical focus on nitrogen and phosphorus. Despite the acknowledged importance of potassium nutrition in cotton cultivation, information regarding optimized split applications of potassium under Pakistan's diverse agro-climatic conditions remains insufficient. Improvements in crop growth and yield following potassium fertilization are largely associated with its function in enhancing photosynthetic efficiency through regulation of carbon assimilation and maintenance of cellular water balance (Zahoor *et al.*, 2017). In addition, potassium availability facilitates improved nitrogen utilization, leading to enhanced vegetative development and increased yield formation in cotton (Hussain *et al.*, 2021). According to Reddy *et al.* (2013) split application of potassium at early squaring and boll development stages resulted in significantly higher seed cotton yield and better boll retention

compared to a single basal dose. Similarly, findings by Rehman *et al.* (2019) suggest that a potassium rate of 120 kg K₂O ha⁻¹, applied in two splits (50% at sowing and 50% at flowering), improved boll number per plant and fiber strength, and especially under irrigated conditions in Pakistan. Farooq *et al.* (2021) also reported that split application of potassium improved nutrient uptake and yield compared to a single application. Pre-plant and side-dressing of K applications produced significantly greater lint yield (Kusi *et al.*, 2021). Singh *et al.* (1992) indicated that potassium split at three growth stages (sowing, flowering, and boll development) not only increased yield but also improved water use efficiency in semi-arid regions.

Thus, literature supports the idea that both optimum potassium levels and their strategic splitting significantly enhance cotton growth, boll formation, fiber quality, and overall yield. These practices are especially important under intensive cropping systems and climatic stress conditions.

This suggests that not only the quantity but also the timing of potash application is crucial for maximizing its efficiency. Therefore, a strategic approach to potash application adjusting both its time and rate, can enhance not just cotton productivity but also the sustainability of the wheat-cotton system. This study aims to investigate the effect of various levels and timings of potassium application on the yield and yield parameters of cotton under the agro-ecological conditions of wheat- cotton cropping system.

2. Materials and Methods

2.1. Site description and experimental details

Field trials were conducted at a local farmer's plot. under Adaptive Research Station, Bahawalnagar, Punjab, Pakistan, during crop seasons 2020 and 2021 to determine the improvement in cotton productivity through various levels and times of potassium application. The treatments comprised of T1=93.75 kg ha⁻¹ in two splits (sowing + flowering stage), T2=93.75 kg ha⁻¹ in three equal splits (sowing +flowering + boll formation stage), T3=125 kg ha⁻¹ in two splits (sowing + flowering stage), and T4=125 kg ha⁻¹ in three equal splits (sowing +flowering + boll formation stage). The study was conducted using a randomized complete block design (RCBD) with three replications during each cropping season. In both years, the crop was sown during the first week of May, and soil samples were collected from the experimental site prior to planting. These samples

were analyzed following standard procedures. The soil texture of the experimental site was loamy clay with alkaline pH (8.65), 0.86% organic matter, 0.041% nitrogen (N), 6.7 ppm available phosphorus (P), and 142 ppm available K. The values showed that the soil had medium text, alkali in nature, The soil was low in organic matter, deficient in phosphorus and potassium, and had a low concentration of soluble salts, making it unsuitable for achieving an economically viable yield.

2.2 Meteorological data

The average maximum temperature (42.3 and 44.0 °C), minimum temperature (23.6 and 24.4 °C) and total rainfall (177.3 and 121.3 mm) were recorded during years 2020 and 2021, respectively.

2.3 Crop husbandry

BS-15 cotton variety was planted on a prepared seedbed measuring 75 cm between the rows and 22.5cm between the

into kg ha⁻¹. At random 10 plants per treatment were counted to determine the number of bolls per plant and also to determine the boll weight, bolls 25 per treatment were randomly gathered. Agronomic potassium use efficiency (KUE), defined as the ratio of lint yield to the applied potassium rate, calculated using the formula below, adapted from the KUE methodology described by Dobermann (2005).

$$KUE\ (\%) = \frac{Y_t - Y_c}{K_a}$$

Where;

- Y_t is yield (kg ha⁻¹) of treated plots,
- Y_c is yield from control (check plot)
- K_a is the amount of K (kg ha⁻¹) applied in treated plots.

2.4 Statistical analysis

The collected data were subjected to analysis of variance (ANOVA), mean comparisons were performed using the least significant difference (LSD) test at 0.05 probability

Table 1. Effects of various levels and times of potassium application on number of bolls, boll weight, and yield in cotton (*Gossypium hirsutum* L.) during Kharif 2020

Treatments	Description	Bolls per plant (No.)	Boll weight (g)	Yield (kg ha ⁻¹)
T1	Control = zero K ₂ O	15.2 ^E	2.26 ^E	1710 ^E
T2	K ₂ O @ 93.75 kg ha ⁻¹ in 02 equal splits (sowing and flowering).	19.2 ^D	2.58 ^D	2,132 ^D
T3	K ₂ O @ 93.75 kg ha ⁻¹ in 03 equal splits (sowing, flowering, and boll formation).	20.6 ^C	2.69 ^C	2,194 ^C
T4	K ₂ O @ 125 kg ha ⁻¹ in 02 equal splits (sowing and flowering).	21.2 ^B	2.86 ^B	2,367 ^B
T5	K ₂ O @ 125 kg ha ⁻¹ in 03 equal splits (sowing, flowering, and boll formation).	22.8 ^A	3.15 ^A	2,431 ^A
LSD (p≤0.05)		0.53	0.11	50.4

Means not sharing a common letter in column differ significantly by Fisher's protected least significant difference (LSD) at a 5% probability level

plants. At planting, full dose of phosphorus that was in single superphosphate (SSP) was applied and potash in the form of sulphate of potash (SOP) was applied according to treatments. Four equal portions of nitrogen in the form of urea fertilizer were used. Weed management was done using pre-emergence weedicide, i.e., S-metolachlor and a rate of 1976 ml/ha was used. The necessary agronomic processes and plant protection activities were conducted according to the recommendations of the department. Harvesting of the seed cotton was done according to the treatment and then turned

level, following the procedure of Steel and Torrie (1997).

Results

The average data showed that there was a significant correlation (p < 0.05) varied at various levels and times of K application during the kharif seasons of 2020 and 2021. (Table 1 and 2). Highest seed cotton yield (2,431 & 2361 kg ha⁻¹) were produced from T4 (125 kg ha⁻¹ applied in three equal splits at sowing, flowering, and boll formation stages) followed by 2,367 and 2252 kg ha⁻¹ seed cotton yield which

Table 2. Effects of various levels and times of potassium application on number of bolls, boll weight, and yield in cotton (*Gossypium hirsutum* L.) during Kharif 2021

Treatments	Description	Bolls per plant (No.)	Boll weight (g)	Yield (kg ha ⁻¹)
T1	Control = zero K ₂ O	13.6 ^E	2.19 ^E	1590 ^D
T2	K ₂ O @ 93.75 kg ha ⁻¹ in 02 equal splits (sowing and flowering).	20.4 ^D	2.44 ^D	2070 ^C
T3	K ₂ O @ 93.75 kg ha ⁻¹ in 03 equal splits (sowing, flowering, and boll formation).	21.8 ^C	2.53 ^C	2114 ^C
T4	K ₂ O @ 125 kg ha ⁻¹ in 02 equal splits (sowing and flowering).	22.6 ^B	2.62 ^B	2252 ^B
T5	K ₂ O @ 125 kg ha ⁻¹ in 03 equal splits (sowing, flowering, and boll formation).	23.8 ^A	2.72 ^A	2361 ^A
LSD (p≤0.05)		0.71	0.08	60.72

Means not sharing a common letter in column differ significantly by Fisher's protected least significant difference (LSD) at a 5% probability level

was obtained from T3 (125 kg ha⁻¹ applied in two equal splits at sowing and flowering stages) while minimum 2,132 and 2070 kg ha⁻¹ seed cotton yield that obtained from treatment T1 where 93.75 kg ha⁻¹ potassium was applied in two equal splits i.e. sowing and flowering stage (control) during crop seasons 2020 and 2021 respectively.

Regarding boll weight, highest boll weight (3.15 & 2.72 g) was recorded from T4 followed by 2.86 & 2.62 g which was obtained from the plot where T3 was applied and minimum 2.58 & 2.44 g boll weight recorded from T1 (control). Similarly, maximum number of bolls per plant i.e.

22.8 & 23.6 were recorded from T4 followed by 21.2 & 22.6 which were recorded from T3 and minimum 19.2 & 20.4 obtained from T1 during both years 2020 & 2021 respectively. (Table 1 & 2).

The mean data revealed a significant correlation between the number of bolls and seed cotton yield ($R^2 = 0.91$), as well as between boll weight and seed cotton yield ($R^2 = 0.95$) during 2020 and 2021 (Table 3; Figures 1 and 2). These results are consistent with the findings of Hussain *et al.* (2021) and Fontana *et al.* (2020), highlighting that an adequate potassium supply is essential throughout cotton

Table 3. Effects of various levels and times of potassium application on number of bolls, boll weight, and yield in cotton (*Gossypium hirsutum* L.) during Kharif 2020 – 2021. (mean data)

Treatments	Description	Bolls per plant (No.)	Boll weight (g)	Yield (kg ha ⁻¹)	Agronomic KUE
T1	Control = zero K ₂ O	14.4 ^E	2.22 ^D	1650 ^E	-
T2	K ₂ O @ 93.75 kg ha ⁻¹ in 02 equal splits (sowing and flowering).	19.8 ^D	2.51 ^C	2101 ^D	4.81
T3	K ₂ O @ 93.75 kg ha ⁻¹ in 03 equal splits (sowing, flowering, and boll formation).	21.2 ^C	2.61 ^C	2154 ^C	5.37
T4	K ₂ O @ 125 kg ha ⁻¹ in 02 equal splits (sowing and flowering).	21.9 ^B	2.74 ^B	2309 ^B	5.27
T5	K ₂ O @ 125 kg ha ⁻¹ in 03 equal splits (sowing, flowering, and boll formation).	23.3 ^A	2.93 ^A	2396 ^A	5.96
LSD (p≤0.05)		0.66	0.12	46.71	

Means not sharing a common letter in column differ significantly by Fisher's protected least significant difference (LSD) at a 5% probability level

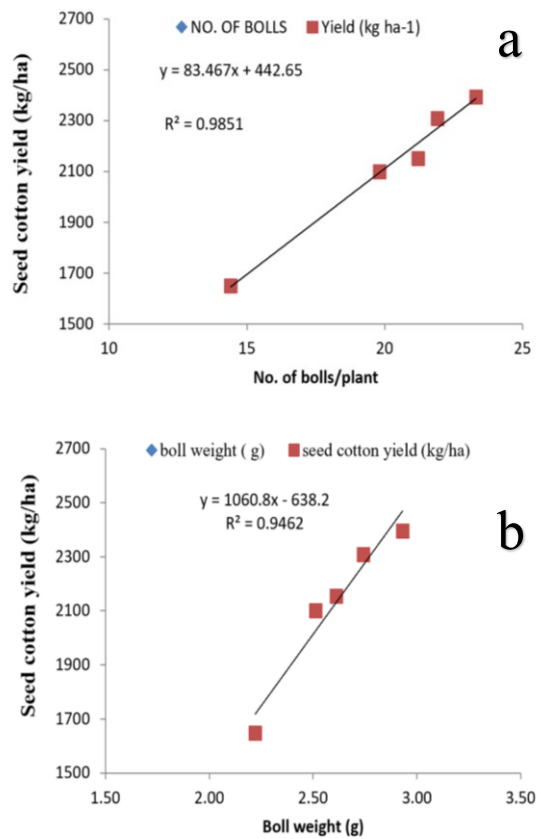


Figure 1. Relationship between (a) No. of bolls per plant and seed cotton yield and (b) boll weight and seed cotton yield.

growth and development, particularly due to its key role in biomass accumulation and yield-determining traits such as boll number and weight. They also came into a conclusion that potash deficiency at any stage of plant growth can slow down plant growth and subsequently yield of seed cotton. Kusi *et al.* (2021) further observed the improvement in cotton plant growth and yield was due to K application, This improvement was associated with an increase in photosynthetic activity, as potassium plays a key role in carbon dioxide assimilation and regulation of cellular turgor. Moreover, potassium fertilization in cotton enhances nitrogen uptake efficiency, leading to improved vegetative growth and overall crop performance ultimately increases yield. The present results are also in agreement with the findings of Tariq *et al.* (2018) and Read *et al.* (2006), The authors reported that the positive response of cotton cultivars to potassium fertilization was attributed to improved

potassium use efficiency, resulting in a significant increase in seed cotton yield when potash was applied at a rate of 120 kg ha⁻¹.

3. Conclusion

The present study demonstrates that both the level and timing of potash application significantly affect cotton growth and yield under the wheat-cotton cropping system. It was found that splitting potassium applications (125 kg ha⁻¹) in three equal doses at sowing, flowering and boll formation) improves K use efficiency and cotton yield by enhancing boll number and weight. Therefore, it is suggested that adopting proper rates and timings of potassium fertilization can serve as a practical and environmentally sound approach for improving cotton yield and long-term sustainability of the wheat-cotton cropping system. Future studies should further explore the economic feasibility, soil health impacts, and residual effects of such nutrient management strategies.

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6. Conflict of Interest

The authors deny any conflicts of interest.

7. Authors' Contribution

Muhammad Shahbaz designed and supervised the study as corresponding author. All other authors (Liaqat Ali, Muhammad Shahid, Sidra Batool, Amna Batool, Shakila Yasmeen, Muhammad Tariq, and Ishtiaq Hassan) participated in experimentation, data analysis, manuscript preparation, and approved the final version.

8. SDGs Addressed

By enhancing agricultural outcomes, this study aligns with SDG 2, targeting Zero Hunger by improving cotton yield through optimized nutrient management. It also supports SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) by encouraging sustainable fertilizer practices and strengthening crop resilience to climate-related stresses

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