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L-Tryptophan Blended Novel Organic Potassium Fertilizer Developed from Fruit and Vegetable Waste Enhanced Cotton Growth and Yield through Efficient Nutrient Acquisition

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ABSTRACT

Organic plant nutrition has been considered cost effective and environmentally benign, since it utilizes cheap and frequently available harmful organic waste material by converting into useful products. This study was conducted in cotton crop (cv. SAU-1) to test the efficacy of a novel potassium (K) enriched, L-tryptophan blended organic fertilizer, developed from fruit and vegetable waste. This field experiment was laid out in a randomized complete block design, involving the single and integrated application of six varying doses of inorganic and novel organic K fertilizers, i.e. 00-00 (control), 30-00, 00-30, 30-30, 60-00, 00-60 kg K ha⁻¹, with three repeats. The crop received recommended doses of nitrogen (N) and phosphorus (P) (160-80 kg ha⁻¹, respectively). Overall, K fertilization showed a significant enhancement in stem diameter, number of sympodia, number of bolls, seed cotton yield (86.4, 61.5, 84, 78%, respectively), and the accumulation of N, P and K (74, 75 and 264%, respectively). The results revealed that L-tryptophan blended novel organic K fertilizer integrated with equal amounts of inorganic K fertilizer (30-30 kg ha⁻¹) enhanced seed cotton yield and nutrient accumulation more than any other treatment. The correlation analysis suggested that K nutrition positively influenced nutrient accumulation, especially K, in cotton plants, which in turn, promoted its various growth traits and ultimately led to increased seed yield. We conclude that the integrated application of inorganic K fertilizer with K-enriched, L-tryptophan blended novel organic fertilizer in equal amounts (30 kg K ha⁻¹ each) enhance cotton growth, seed cotton yield, and improves nitrogen, phosphorus and potassium accumulation and use. Further experiments are warranted to validate these results.

KEYWORDS: Cotton, Potassium, L-tryptophan, Inorganic fertilizer, Organic fertilizer

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is a significant crop for Pakistan, yet its average yield remains significantly lower than the global average (GoP, 2024). The primary cause of cotton production stagnation in Pakistan, aside from several other factors, has been identified as the increased extraction of potassium (K) from Pakistani soils (Zia-ul-hassan *et al.*, 2011).

The soils of Pakistan are considered adequate as far as their K status is concerned (Zia-ul-hassan *et al.*, 2011). Despite K being adequate, K mining from Pakistani soils may result in its deficiency. For this reason, various areas of Sindh province have been assessed for its soil K status, including district Mirpurkhas (Saraz *et al.*, 2023), Tando Allahyar (Jamali *et al.*, 2023), and Shaheed Benazirabad for site specific K fertilizer management (Mari *et al.*,

2025), whereby site-specific K deficiency has been recorded.

It has been documented that K is found deficient in different important soil series of Pakistan (Zia-ul-hassan

and Arshad, 2008). In cotton cultivation, K has been regarded as the most crucial nutrient that contributes to yield and quality (Zia-ul-hassan *et al.*, 2011; Sarwar *et al.*, 2024). The less dense and ineffective root structure of cotton is the primary source of its higher K requirements when compared to other crops (Zia-ul-hassan & Arshad, 2010; Zia-ul-hassan and Arshad, 2011; Kusi *et al.*, 2021).

Potassium is a vital element impacting the physiology and biochemistry of green plants directly (Delgado *et al.*, 2024). In order to provide a certain yield, cotton requires K nearly as much as nitrogen. For this reason, a sufficient supply of K is essential

for the growth and development of cotton. It results from the vital functions of K in osmoregulation, membrane transport, pH stabilization (Delgado *et al.*, 2024) leaf area expansion, CO₂ assimilation, and photosynthesis (Rawat *et al.*, 2022).

In plants, L-tryptophan is recognized as a physiological precursor of auxins. Research indicates that compared to auxins, L-tryptophan has a more beneficial impact on plant growth and yield (Channa *et al.*, 2013; Mastoi *et al.*, 2013; Shah *et al.*, 2019; Gondek & Mierzwa-Hersztek, 2021). It is an important amino acid that functions as an osmolyte, regulates ion transport, influences stomatal opening, and helps detoxify the harmful effects of toxic metals (Karnwal & Dohroo, 2018).

Potassium deficiency typically arises during the boll filling stage, as the developing bolls become the primary sink for available K, accompanied by a simultaneous decline in root growth (Sekhon & Singh, 2013). According to Koshki and Armin (2016), the reproductive plant parts accumulate approximately 80% of K that cotton absorbs. Cotton frequently exhibits symptoms of K deficiency on soils that are not thought to be K deficient for other crops, suggesting that it is more susceptible to low soil K availability than the majority of important field crops. Additionally, compared to other important row crops, the cotton root system has a low density, and K, which is relatively immobile in soil, diffuses slowly (Yang *et al.*, 2016). Therefore, even in soils high in available K, cotton may suffer from K deficiency (Koshki & Armin (2016).

Potassium-deficient plants exhibit symptoms, including bronzed, thick, and leathery leaves that lack necrosis or defoliation but tend to snap when bent. Additionally, various irregularities are observed as part of the K deficiency (Li *et al.*, 2021). Potassium deficiency also results in reduced leaf area and increased specific leaf weight of cotton, which can lead to early maturity of the plant. Under field conditions, premature leaf senescence is also observed in K-deficient cotton plants, which may lead to increased disease susceptibility and accelerated leaf aging (Qiao *et al.*, 2015).

Potassium is a mobile nutrient in plants, so its deficiency symptoms are generally expected to appear in older leaves. However, in many cases, the symptoms unusually appear in the newer leaves instead (Dong *et al.*, 2004). Moreover, the deficiency of K results in significant losses for cotton growers by reducing both fiber yield and quality. Plant responses to K deficiency can vary throughout the growing season, influenced by climatic conditions and various other environmental factors.

Organic fertilizers are cost-effective and environmentally friendly source of plant nutrients. These organic fertilizers coming from different sources contain variable amounts of nutrient contents (Hazra, 2016). Previous research found that K-enriched organic fertilizer enhanced growth, yield,

and K content of maize crop (Channa *et al.*, 2013; Mastoi *et al.*, 2013; Shah *et al.*, 2019; Kubar *et al.*, 2013; Shujrah *et al.*, 2024).

Different organic sources containing considerable amount of K have been utilized in varying crops and found highly significant, such as moringa leaf extract in maize (Rind *et al.*, 2024) and bottle gourd (Noor *et al.*, 2024), and bonemeal in wheat (Talpur *et al.*, 2025). Moreover, organic fertilization with or without chemical fertilization was found significantly better in enhancing cotton growth (Shi *et al.*, 2023).

Our previous research findings advocated the significance of utilizing fruits and vegetables organic waste material as value-added fertilizer products by converting them into potassium (K) enriched organic fertilizer blended with an auxin precursor L-tryptophan in enhancing crop growth, biomass production, crop yield, nutrient accumulation and promoting soil health (Arshad *et al.*, 2007; Channa *et al.*, 2013; Kubar *et al.*, 2013; Mastoi *et al.*, 2013; Shah *et al.*, 2014; Shah *et al.*, 2019).

The existing literature, however, provides limited insights into the role of organic K nutrition in improving cotton yield and nutrient dynamics along with saving inorganic K fertilizer input. Keeping in mind the importance of organic fertilizers and the high cost of inorganic K fertilizers, this field study was designed to evaluate the use of inorganic K nutrition and organic K fertilizer blended with L-tryptophan. The main hypothesis was that the integrated inorganic and organic K nutrition might be beneficial in improving the growth, yield and nutrient accumulation of cotton, while saving inorganic K fertilizer input.

MATERIALS AND METHODS

Experiment details: The field experiment was conducted at the Latif experimental Farm, Sindh Agriculture University, Tandojam, Pakistan following a randomized complete block design with three repeats. Pure quality breeder's seeds of cotton (cv. SAU-1) were sown in the experimental plots measuring 30m² (5m × 6m) through drilling method following standard production technology.

Treatment details: The treatments involved single and integrated application of six varying doses of inorganic and novel organic K fertilizers, i.e. 00-00 (control), 30-00, 00-30, 30-30, 60-00, 00-60 kg K ha⁻¹, with three repeats. The details of preparing novel organic fertilizer product and its related nutritional and other quality traits are provided in our previous studies in detail (Arshad *et al.*, 2007; Channa *et al.*, 2013; Kubar *et al.*, 2013; Mastoi *et al.*, 2013; Shah *et al.*, 2014; Shah *et al.*, 2019).

Fertilizer application: A blanket dose was applied to all experimental units at 160-80 kg N-P₂O₅ ha⁻¹ through urea and DAP, respectively. Inorganic K fertilizer was supplied using potassium sulphate (50% K₂O). Organic K fertilizer was prepared by first enriching with inorganic K fertilizer in requisite

amounts in different batches representing various organic K fertilizer treatments utilizing fruits and vegetable waste on a mechanical composting unit that was designed for this specific purpose. This organic K fertilizer was further value-added by blending with an auxin precursor L-tryptophan. The details of this novel technique may be referred from our previous work (Arshad *et al.*, 2007). Full dose of P, along with half dose of N, was applied through broadcasting at the time of sowing. The leftover N was supplied to the crop at first irrigation. The inorganic and organic K fertilizer treatments were supplied at the time of first irrigation through banding along cotton seed rows.

Soil analysis: Soil samples were collected from the experimental field at the depth of 0-20 cm. The samples were brought into the laboratory and analyzed for various soil properties (Ryan *et al.*, 2001). The experimental soil was heavy in texture, i.e. silty clay (clay 41%, silt 44%, sand 15%), alkaline in nature (pH: 7.9), non-saline (EC: 1.2 dS m⁻¹), low in organic matter (0.52%), deficient in ABDTPA-P (3.6 mg kg⁻¹), and marginal in ABDTPA K (115 mg kg⁻¹).

Collection of data: The crop was harvested at maturity. Five randomly selected plants were harvested from each plot to record different agronomic observations, viz. sympodia per plant, stem diameter, number of bolls per plant, and seed cotton yield.

Plant analysis: Three fully expanded upper canopy leaves were randomly collected from each of five

representative plants to determine leaf N through Kjeldahl method, and P and K using wet digestion method (Ryan *et al.*, 2001; Zia-ul-hassan *et al.*, 2011).

Statistical analyses: The collected data were subjected to analysis of variance and mean separation using Statistix ver. 8.1. The treatment means were separated by Tukey's honestly significant difference (HSD) test at alpha 0.05.

RESULTS

Number of sympodia per plant: Potassium fertilization had a significant impact on the number of sympodia per plant of cotton, irrespective of source, dose or method of K application (Figure 1). Moreover, the data also indicated that integrated organic K nutrition enhanced the number of sympodia more significantly as compared to single application of K through either source at any dose (Figure 1). The data (Figure 1) further demonstrated that the minimum number of sympodia of cotton (13.0) were observed under control treatment (00-00 kg K ha⁻¹). The application of K at 30 kg enhanced sympodia per plant. However, inorganic 30 kg K proved better (17.0) than organic K (16.3). The maximum sympodia per plant (21.0) was noticed at 60 kg K ha⁻¹ applied through integrating inorganic K with organic K followed by sole chemical K (19.0) and sole organic K (17.3), at 60 kg K, respectively (Figure1).

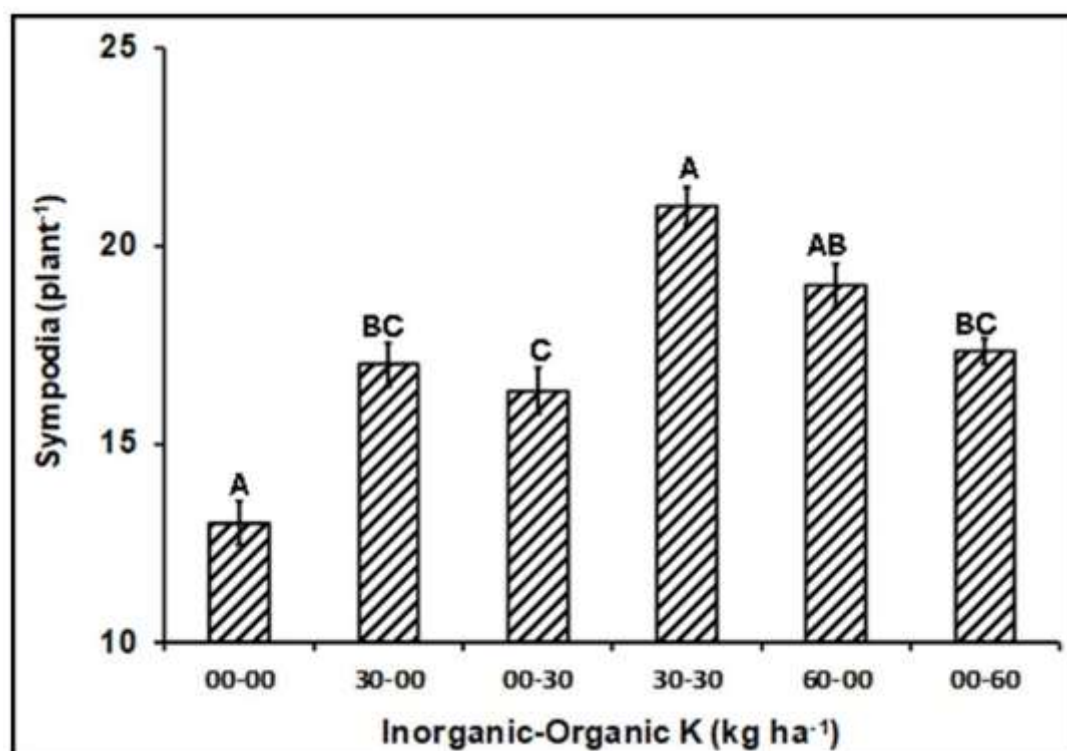


Figure 1. Number of sympodia of cotton plants as affected by potassium nutrition through varying levels of inorganic and organic fertilizers (HSD_{0.05} = 2.5146)

Stem diameter (mm plant⁻¹): Potassium fertilization had a significant impact on the stem diameter (mm plant⁻¹) of cotton, irrespective of source, dose or method of K nutrition (Figure 2). The inorganic K nutrition increased the stem diameter more significantly as compared to organic K nutrition at the similar K dose (60 kg ha⁻¹) (Figure 2). The data (Figure 2) further demonstrated that the minimum stem diameter of cotton (9.6 mm) was recorded under control treatment (no K).

The application of 30 kg K ha⁻¹ enhanced the stem diameter, and this increase was statistically similar in the case of organic K fertilization (14.36 mm) and inorganic K fertilization (14.26 mm). The application of K at 60 kg ha⁻¹ significantly increased stem diameter. The maximum diameter of stem (17.9 mm) was noticed under the sole inorganic K application, followed by integrated K application (17.7 mm) and sole organic K fertilization (17.6 mm) (Figure 2).

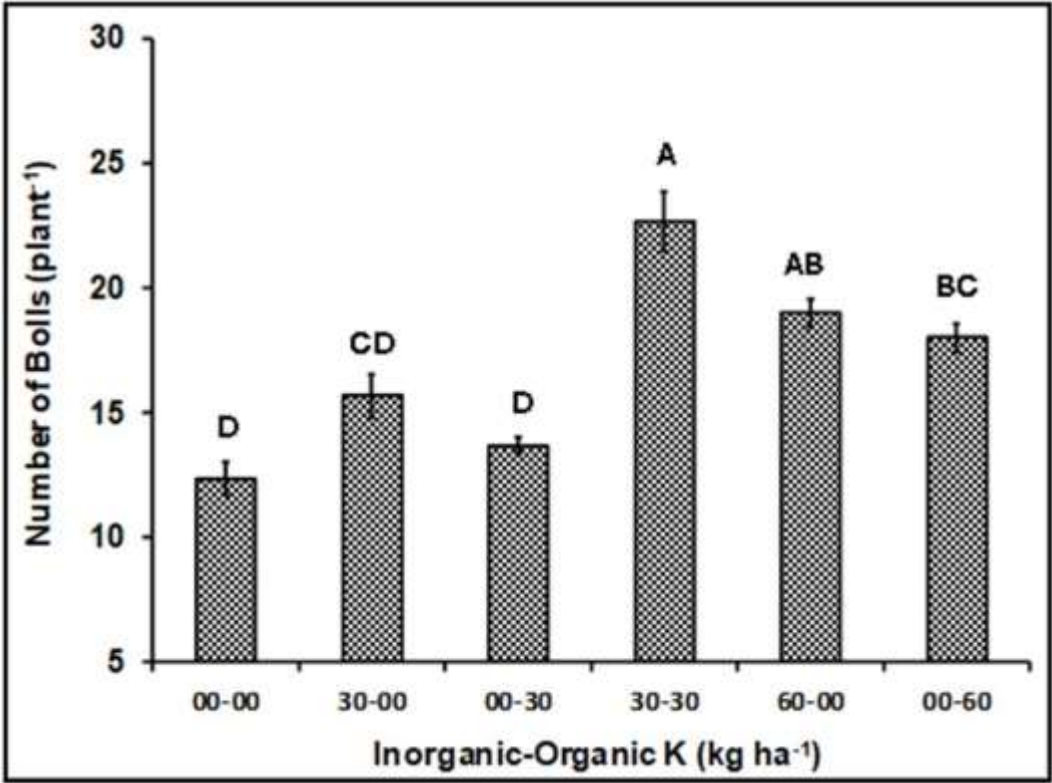


Figure 2. Stem diameter of cotton plants as affected by potassium nutrition through varying levels of inorganic and organic fertilizers (HSD_{0.05} = 2.1373)

Number of bolls per plant: The application of K significantly increased the number of bolls plant⁻¹ of cotton, irrespective of source, dose or method of K nutrition (Figure 3). Moreover, the data also indicated that K supplied to cotton crop by integrated two K sources significantly enhanced the bolls per plant compared to single use of both sources at any dose. The data (Figure 3) further demonstrated that the minimum number of bolls of cotton (12.3) were recorded under control treatment (no K). The application of K at 30 kg ha⁻¹ substantially improved the number of bolls which were higher (15.6) under the treatment of inorganic K fertilizer as compared to organic K fertilizer treatment (13.6). The application of K at 60 kg ha⁻¹ enhanced the number of bolls per plant. The maximum bolls per plant (22.6) were noticed under the combined application of K, followed by sole inorganic K (19.0) and sole organic K (18.0) application (Figure 3).

Seed cotton yield (g plant⁻¹): Potassium nutrition significantly increased the seed cotton yield (g plant⁻¹) of cotton, irrespective of source, dose or method of K nutrition (Figure 4). Moreover, the data also indicated that integrated K nutrition increased the seed cotton yield more significantly as compared to single K nutrition provided by any source and any dose (Figure 4). The data (Figure 4) demonstrated that the minimum seed cotton yield of cotton (9.4 g) was recorded under control treatment (no K). The application of K at 30 kg ha⁻¹ increased seed cotton yield, but the best treatment at this rate was sole inorganic K (12.6 g) over sole organic K (11.0 g). The application of K at 60 kg ha⁻¹ significantly enhanced the seed yield of cotton. At this rate, the integrated application of inorganic and organic K (17.3 g) outperformed other two treatments of same K supply. The sole inorganic K achieved (15.5 g), while sole organic K achieved (15.3 g) seed yield per plant, respectively (Figure 4).

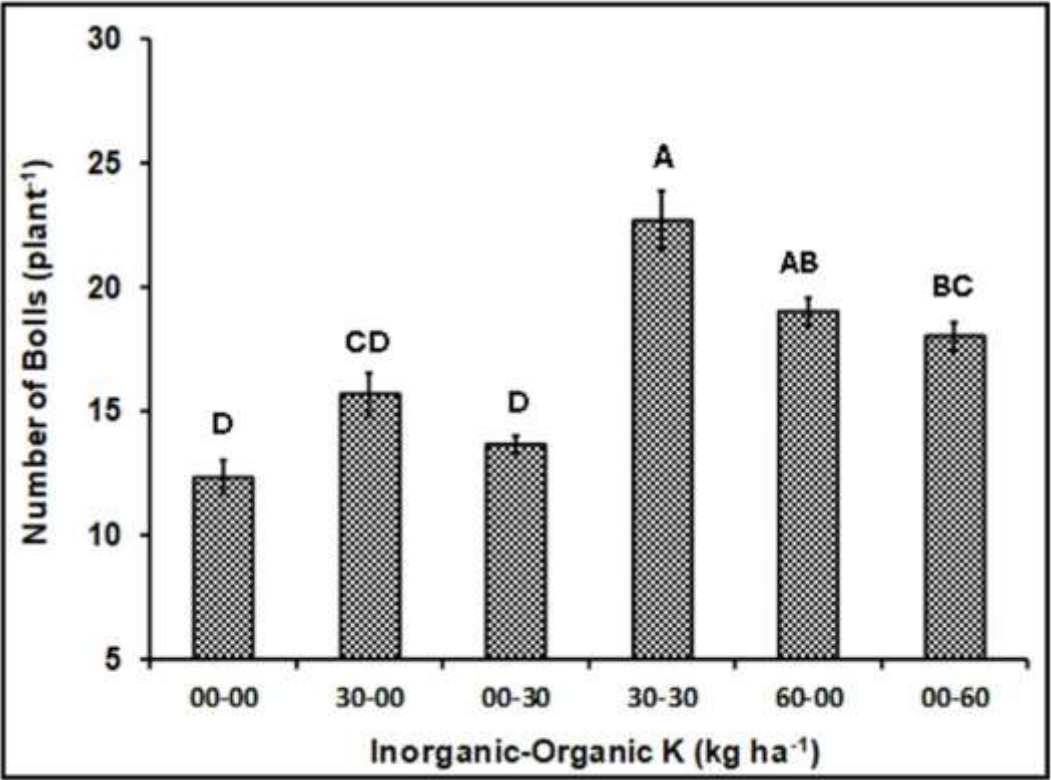


Figure. 3. Number of bolls of cotton plants as affected by potassium nutrition through varying levels of inorganic and organic fertilizers (HSD_{0.05} = 3.7867)

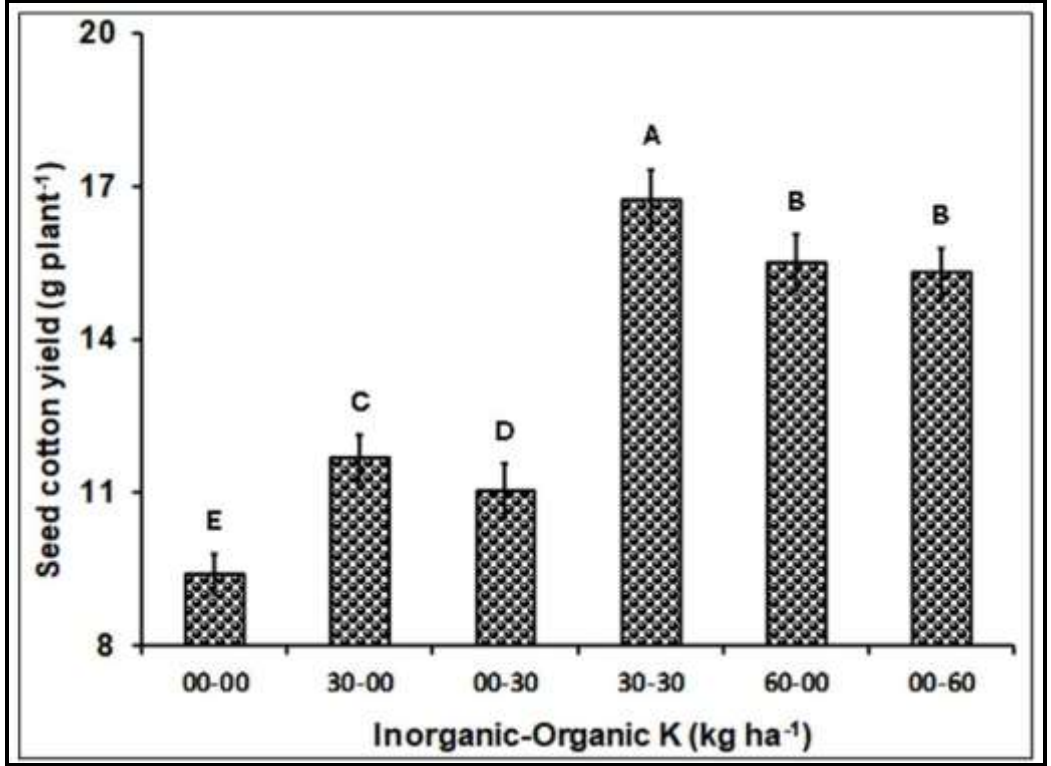


Figure 4. Seed cotton yield of cotton plants as affected by potassium nutrition through varying levels of inorganic and organic fertilizers (HSD_{0.05} = 1.4252)

Nitrogen accumulation (g kg⁻¹): Potassium nutrition significantly increased N accumulation of cotton, irrespective of source, dose or method of K nutrition (Figure 5). Moreover, the data also indicated that the integrated or inorganic K nutrition at 60 kg ha⁻¹ increased N accumulation in cotton more significantly as compared to other treatments. Minimum N accumulation in cotton (2.2 g kg⁻¹) was recorded under control treatment (No K). The application of K fertilizer at 30 kg ha⁻¹ substantially enhanced N accumulation. At this rate, organic K fertilizer (2.8 g kg⁻¹) application alone was found better than inorganic K (2.7 g kg⁻¹). The application of K at 60 kg ha⁻¹ improved N accumulation. The maximum N accumulation at this rate was observed in the case of sole inorganic K fertilizer (3.9 g kg⁻¹) application and integrated application of inorganic and organic K (3.6 g kg⁻¹), followed by sole organic K (3.5 g kg⁻¹) (Figure 5).

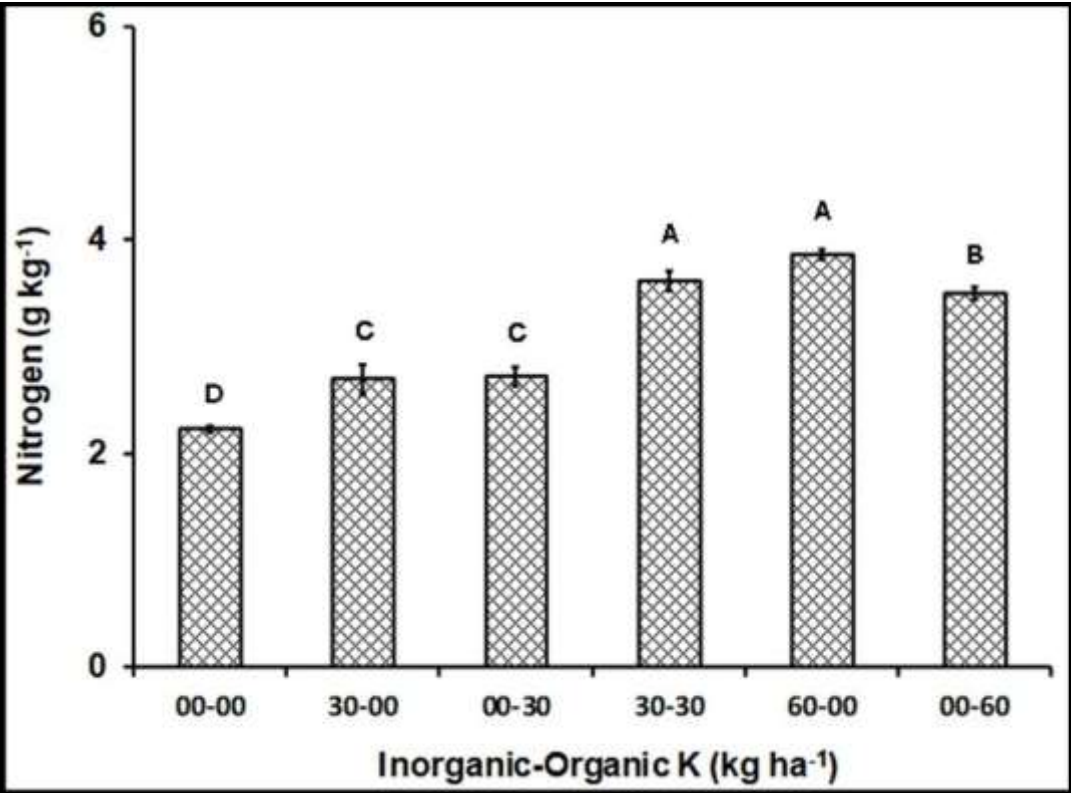


Figure 5. Nitrogen accumulation of cotton plants as affected by potassium nutrition through varying levels of inorganic and organic fertilizers (HSD_{0.05} = 0.3161)

Phosphorus accumulation (g kg⁻¹): Potassium nutrition significantly increased P accumulation (g kg⁻¹) of cotton, irrespective of source, dose or method of K nutrition (Figure 6). Moreover, the data also indicated that integrated K nutrition increased P accumulation of cotton more significantly as compared to other K treatments involving single use of K from two sources at any dose (Figure 6). Further, data demonstrated that the minimum P accumulation of cotton (0.43 g kg⁻¹) was noticed under control treatment (no K). The application of K at 30 kg ha⁻¹ substantially enhanced P accumulation. At this rate (30 kg K ha⁻¹), the application inorganic K fertilizer (0.52 g kg⁻¹) was found better than organic K fertilizer (0.50 g kg⁻¹). Moreover, at the application 60 kg K ha⁻¹, integrated application of inorganic and organic fertilizer of K (0.75 g kg⁻¹) outyielded other K treatments. Sole inorganic K

achieved a P accumulation of (0.70 g kg⁻¹) followed by sole organic K (0.60 g kg⁻¹) (Figure 6). **Potassium accumulation (g plant⁻¹):** As expected, K nutrition significantly increased the K accumulation (g kg⁻¹) of cotton, irrespective of source, dose or method of K nutrition (Figure 7). The data (Figure 7) further demonstrated that the minimum K accumulation of cotton (1.1 g kg⁻¹) was recorded under control treatment (no K). The application of K at 30 kg ha⁻¹ significantly improved K accumulation of cotton. At this rate, inorganic K application (2.5g kg⁻¹) was more superior to that of organic K application (2.4 g kg⁻¹). The application of K at 60 kg ha⁻¹ also increased K accumulation, but the maximum K was noticed under combined application of inorganic and inorganic K (4.0 g kg⁻¹), followed by sole inorganic K (3.7 g kg⁻¹) and sole organic K (3.5 g kg⁻¹) (Figure 7).

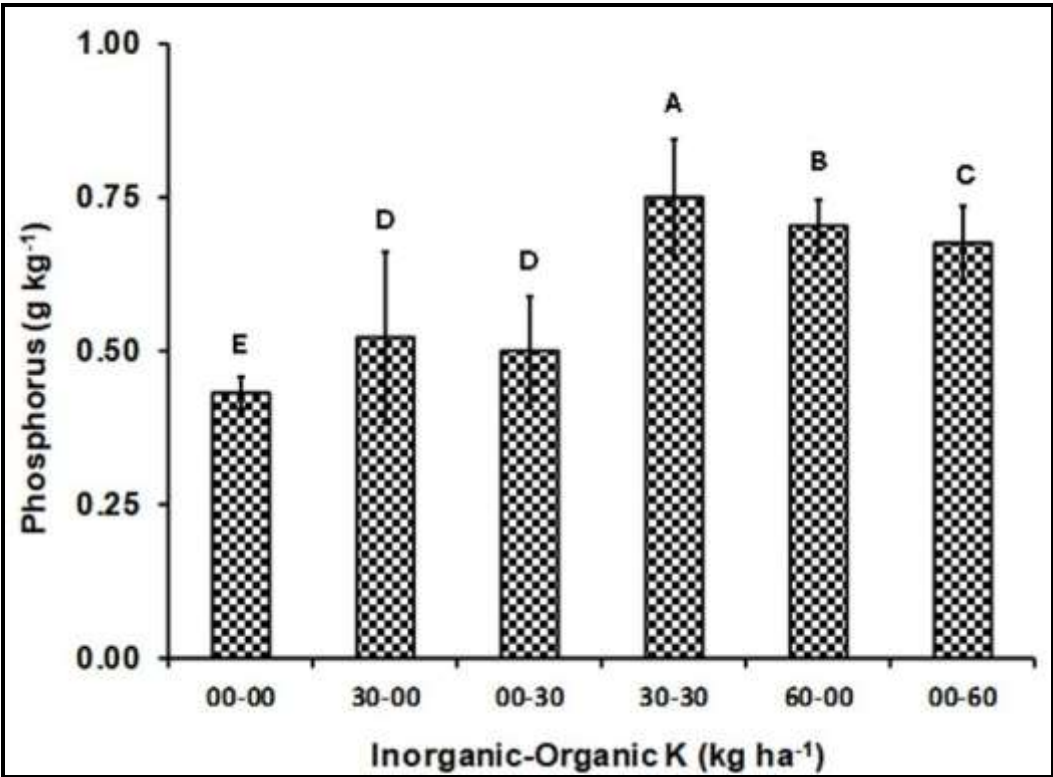


Figure 6. Phosphorus accumulation of cotton plants as affected by potassium nutrition through varying levels of inorganic and organic fertilizers (HSD_{0.05} = 0.0326)

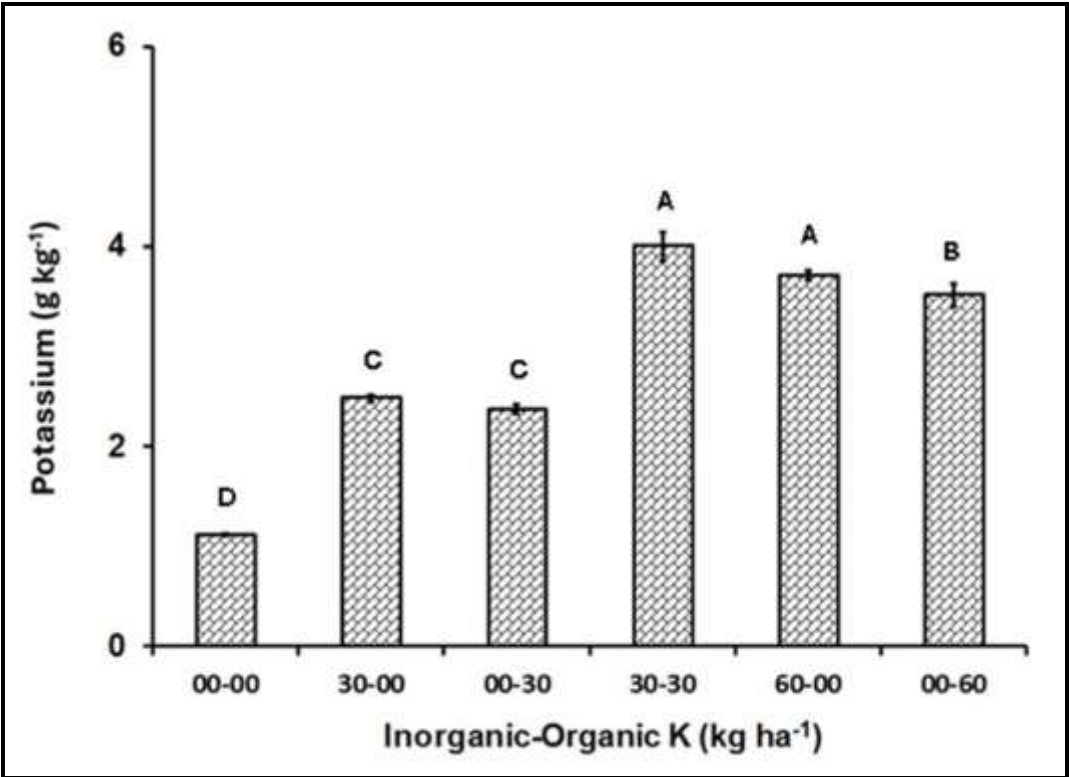


Figure 7. Potassium accumulation of cotton plants as affected by potassium nutrition through varying levels of inorganic and organic fertilizers (HSD_{0.05} = 0.3161)

Relationship of seed yield with nutrient accumulation of cotton: The relationships among various growth traits, seed yield and nutrient accumulation was determined through Pearson’s correlation analysis. The seed cotton yield was significantly ($p<0.001$) related with the accumulation of N (0.876***), P (0.953***), and K (0.924***), in cotton which emphasized that the L-tryptophan blended organic K nutrition of cotton enhanced the accumulation of these nutrients which increased seed cotton yield.

Better nutrient accumulation of cotton due to L-tryptophan blended organic K nutrition, significantly enhanced various growth traits and seed yield of cotton. The N, P and K accumulation was significantly ($p<0.001$) related with the number of sympodia per plant (0.7743, 0.8569 and 0.8923, respectively), stem diameter per plant (0.9151, 0.9145 and 0.9697, respectively), and seed cotton yield (0.8760, 0.9530 and 0.9241, respectively). Moreover, significant ($p<0.001$) relationship of the number of sympodia per plant was noted with the number of bolls per plant (0.8965), stem diameter (0.8377) and seed cotton yield (0.8785). Similarly, significant ($p<0.001$) relationship of number of bolls per plant was noted with the stem diameter (0.7950) and seed cotton yield (0.9487). The relationship between the stem diameter per plant and seed cotton yield (0.8672) was also significant ($p<0.001$). Interestingly, highly significant relationship was also noted between the accumulation of N and P (0.9521), N and K (0.9386) and P and K (0.9678) by the cotton plants. In crux, K-enriched, L-tryptophan blended novel organic K fertilizer enhanced growth and seed cotton yield through better nutrient accumulation.

DISCUSSION

The importance of K in cotton nutrition was studied in present field experiment. Cotton growth, seed yield, and nutrient accumulation were all substantially enhanced by the application of K (Figure 1 to 7). The findings revealed that the K application, either as chemical or organic K, enhanced growth attributes of cotton, i.e. number of sympodia (61.5%), stem diameter (86.4%), number of bolls (83.8%), seed cotton yield (78%), N (73.9%), P (74.4%), and K (264%).

Earlier, it was reported that N-enriched organic fertilizers with L-tryptophan (L-TRP) can be highly

efficient even when applied at relatively low application rates when compared to their raw form. It indicates that organic waste transformed into organic fertilizer is not only enriched with plant available nutrients but can be sustainably supplied to plants at lower doses. The findings of that study revealed that the effect of N and L-TRP-enriched fertilizer applied at 500 kg ha⁻¹ was found equal to the effectiveness of the full recommended N fertilizer. It enhanced wheat production and reduced N fertilizer use by 30% (Zahir *et al.*, 2007b). This approach not only improved crop productivity but also reduced the reliance on costly inorganic inputs, leading to significant cost savings for farmers.

The combined effects of chemical and organic fertilizer application in cotton were assessed in a recent study. The results revealed that chemical and organic fertilizers significantly enhanced cotton growth and positively influenced various soil properties. It was observed that supplementing organic fertilizer (25%) with chemical fertilizer (75%) was found beneficial over other treatments by improving cotton yield (Wang *et al.*, 2025). These findings corroborate with the results of the present research, particularly the role of organic fertilization in influencing the growth of cotton and reducing the chemical fertilizer reliance. Heydarzadeh *et al.* (2021) conducted a field study involving four varying levels of fertilizer applications (organic & inorganic). They reported that organic nutrient sources outperformed inorganic fertilization by significantly improving yield, fiber quality, and oil content. Moreover, nutrient concentrations and photosynthetic parameters were also enhanced by organic fertilizer application.

Lin *et al.* (2024) evaluated the potential of integrating organic and inorganic fertilizers in enhancing cotton productivity and soil health. Interestingly, the application of organic fertilizer alone significantly improved plant height, while the combination of low-dose inorganic and organic fertilizer improved leaf area plant nutrient content. Further the results demonstrated that reduced reliance on inorganic inputs, when combined with organic amendments, substantially contributes to higher yields through positively affecting soil fertility. These results support

the adoption of integrated fertilization as a sustainable cotton production.

Moreover, He *et al.* (2024) reported that reducing inorganic fertilizer up to 24% and integrating it with organic fertilizer can increase cotton growth and yield along with improving economic returns for the farming community by approximately 34%.

In the present study, inorganic and organic K fertilizers were applied alone and in their combination. Recently in similar research, the application of organic-inorganic compound fertilizer improved fiber quality by increasing lint content and fiber length by (1.19% and 5.03%), respectively. Moreover, the negative correlation between micronaire and metric count indicated differing fertilizer effects on fiber fineness. Overall, the integrated fertilizer enhanced fiber traits while maintaining comparable lint yield to inorganic fertilization (Pengbing *et al.*, 2023). The integration of biochar and lignite with poultry manure and inorganic fertilizer significantly enhanced cotton growth and nutrient efficiency. Lint yield improved up to 44% when compared to fertilizer alone. Soil properties were also improved by organic amendment application, as evidenced by the reduction in nitrate leaching (Adeli *et al.*, 2022). Kubar *et al.* (2013) conducted a field experiment by utilizing organic and inorganic K fertilizers in maize, and reported that co-application of organic and inorganic sources of K was found superior to their single applications.

CONCLUSION

We conclude that the integrated application of inorganic K fertilizer with K-enriched, L-tryptophan blended novel organic fertilizer in equal amounts (30 kg K ha⁻¹ each) enhance cotton growth, seed cotton yield, and improves nitrogen, phosphorus and potassium accumulation and use. Further experiments are warranted to validate these results.

CONFLICT OF INTEREST

We declare no competing interests affecting the work reported in this study.

AUTHORS' CONTRIBUTION

Zia-ul-hassan: Conceived idea, developed technology, supervised study, and edited all drafts of manuscript, KAK, Conducted field study and laboratory analysis, NAT: Supervised laboratory work, processed and analysed data, wrote Results chapter, IAJ: Reviewed literature, wrote Discussion and References chapters, JAA: Data presentation and format and style of paper, and IR: Edited final draft of manuscript. All authors endorsed and approved the final draft.

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