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POTASH AND HUMIC ACID INTERACTIONS REGULATING GROWTH, YIELD AND NUTRIENT UPTAKE OF OKRA

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Abstract

Okra is a nutritionally rich and economically important summer vegetable, yet its yield potential is often limited by nutrient deficiencies in semi-arid soils. A field experiment was conducted on Bari Chakwal soils to assess the effects of humic acid and potassium fertilization on growth, yield performance, and nutrient uptake in okra. The study employed a randomized complete block design with factorial arrangements and three replications. Growth traits, physiological indicators, yield components, nutrient uptake (N, P, K), and post-harvest soil fertility were evaluated. Application of humic acid significantly enhanced soil quality, nutrient availability, and plant physiological responses, while potassium supplementation improved pod traits and yield. The combined application of humic acid and potassium produced the highest improvements across growth, yield, and nutrient uptake parameters. Post-harvest soil analysis further confirmed residual improvements in fertility. The results demonstrate that integrating humic acid with optimal potassium fertilization is an effective and sustainable strategy to boost okra productivity and maintain soil health under semi-arid conditions.

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INTRODUCTION

Okra is a valuable tropics vegetal crop, prized for its pods, seed oil, fiber, and nutritional content [1,2]. However, its productivity is often limited by soil fertility issues, especially micronutrient deficiencies, suboptimal potassium (K) supply, and low organic matter content [3,4,5]. Enhancing both soil health and nutrient availability is crucial for improving okra growth, yield, and nutrient uptake under such limiting conditions [6,7].

Potassium is among the indispensable macronutrients influencing countless physiological progressions in plants, comprising osmoregulation, enzyme triggering, photosynthesis, and translocation of assimilates [8,9,10]. In okra, adequate potassium supply has been shown to increase pod number, pod size, and overall yield, exclusively under stress conditions such as drought or salinity [11,12]. Recent field studies demonstrate that increasing potassium levels improves both yield and quality attributes of legumes and vegetables by enhancing carbohydrate synthesis and maintaining ion balance [13,14].

Humic acid, a key constituent of soil organic matter, has gained attention for its capacity to improve soil physicochemical and biological properties [15]. Through its acidic functional groups, humic acid enhances cation exchange capacity, chelation of micronutrients, water retention, and soil structure, reciprocally improve growth of roots in plants and nutrient uptake [16,17]. In okra, foliar or soil applications of humic acid have been reported to produce taller plants, thicker stems, greater leaf area, and higher yields compared to controls without humic acid [18,19].

Several studies have explored humic acid or potassium individually, but fewer have examined their interactive effects on okra under varying levels of K supply. The interface between humic acid and potassium is promising: humic acid may enhance the efficiency of potassium by reducing its fixation, improving its availability to plants, or by improving root absorption capacity [20,21]. For example, in wheat, combined application of potassium fertilizer and humic acid significantly improved both yield and nutrient contents (including K, P, Zn) compared to either alone [22]. Similarly, experiments in vegetables such as courgette showed that humic acid plus potassium levels significantly affected both yield and quality parameters [23].

Additionally, soil conditions such as pH, salinity, organic matter, and baseline potassium levels modulate how plants respond to these amendments [24]. In alkaline or low-fertility soils, the chelating action of humic substances can help mobilize bound potassium and micronutrients, improving uptake in okra [24,25]. Given that many okra-growing regions suffer from such soil constraints, optimizing the humic acid × potassium interaction may provide a cost-effective way to enhance both yield and nutritional quality.

Despite this promising potential, knowledge gaps remain with respect to the optimal levels and methods of applying humic acid under different potassium regimes for okra, especially considering nutrient uptake dynamics.

Materials and Methods

Investigational site and soil characterization

The investigation was directed during the kharif-2034 at the exploration fields of BARI chakwal,. The region is described by a semi-arid climate with an usual annual rainfall of <300 mm and mean temperature of 34 °C. Prior to sowing, soil samples were composed of soil from 0–30 cm for initial characterization. Soil properties (Table 1) were determined following standard procedures (Luo et al. [27]; Singh [28]).

Table 1. Pre-sowing soil physio-chemical indices of the investigational site.

Parameter	Value	Unit	Classification*
Texture	Sandy loam	–	Coarse to medium
pH (1:2.5)	7.9	–	Slightly alkaline
Extract Electrical conductivity (EC_e)	0.82	dS m^{-1}	Non-saline (<2 dS m^{-1})
Organic matter	0.72	%	Low (<1%)
Total nitrogen (N)	0.038	%	Low (<0.05%)
Available phosphorus (P)	6.8	ppm	Low (<10 ppm)
Exchangeable potassium (K)	152	ppm	Medium (120–200 ppm)

Trial design and treatments

The research was arranged in triplicated RCBD. Treatments comprised combinations of potassic and humic acid levels as follows:

- **Humic acid levels (HA):** 0 (control), 5, 10, and 15 kg ha^{-1} (applied as a soil drench or foliar spray depending on formulation).
- **Potassium levels (K):** 0 (control)-120 kg K_2O ha^{-1} (applied as potassium sulfate).

This resulted in a factorial arrangement of 16 treatment combinations (4 × 4).

Crop husbandry and management

Okra variety Sabz Pari was used for the experiment. Seeds were sown on well-prepared ridges spaced 75 cm apart, with a plant-to-plant distance of 30 cm, maintaining a plant population of approximately [insert value] plants ha^{-1}. Basal doses of nitrogen and phosphorus were applied uniformly at recommended rates (e.g., 100 kg N and 80 kg P_2O_5 ha^{-1}) in the form of urea and diammonium phosphate (DAP). Potassium treatments were applied according to the designated levels in two equal splits: half at sowing and the remaining half at flowering. Humic acid was applied as per treatment schedules either by soil incorporation at sowing or as foliar spray at vegetative and flowering stages. Irrigation, weeding, and pest management were carried out as per recommended agronomic practices to ensure uniform crop growth.

Data collection

1. **Growth parameters:** Height, leaves per plant, LAI and stem diameter were recorded at 30, 45, and 60 days after sowing (DAS). Leaf area was calculated using portable leaf area meter and LAI was estimated Watson (1947) formulae.
2. **Physiological parameters:** Chlorophyll and RWC was calculated using Barrs and Weatherley (1962) procedure.
3. **Yield attributes:** Pods number, length, diameter, average weight and yield per plant were measured at harvest. Marketable and total yield (t ha^{-1}) were estimated by extrapolating the harvest from each plot.
4. **Nutrient uptake:** At flowering and at final harvest, plant samples were collected, oven-dried at 70 °C, ground, and digested in diacid (H_2SO_4–H_2O_2) for nutrient analysis. Nitrogen concentration was determined by the Kjeldahl method, phosphorus by vanadomolybdate yellow colorimetric method, and potassium by flame photometry (AOAC, 2000). Nutrient uptake was calculated by multiplying nutrient concentration with respective dry matter yields.
5. **Soil nutrient status:** Post-harvest available N, P, and K and soil organic carbon content in soil were estimated.

Statistical analysis

ANOVA with the factorial RCBD using Statistix 10.0 to test significance and LSD test at a 5% probability level [29]. Correlation investigation was also performed to explore the relationships between growth, yield, and nutrient uptake parameters.

RESULTS AND DISCUSSION

Plant Height

Plant height of okra was expressively subjective by humic acid and potassium application at all growth stages (Table 2). At 60 DAS, extreme plant height (101.3 cm) was documented under T6 (HA high + K high), which was 34.6% greater than the control (75.2 cm). This improvement was followed by T5 (92.7 cm) and T3 (88.4 cm), indicating that both potassium and humic acid individually improved plant stature but their combined effect was synergistic. These results align with Canellas et al [19], who noted that humic acid enhances root growth and nutrient absorption, thereby improving vegetative development. Similarly, potassium application has been associated with enhanced cell expansion and turgor regulation, leading to taller plants [8].

Table 2. Potash and Humic acid levels on plant height (cm) of okra at various growth stages.

Treatment	30 DAS	45 DAS	60 DAS
T1 (Control)	24.6 ± 0.8 c	46.3 ± 1.1 d	75.2 ± 1.4 d
T2 (Humic acid low)	27.8 ± 0.9 bc	52.4 ± 1.2 c	83.1 ± 1.6 c
T3 (Humic acid high)	29.2 ± 1.0 b	56.8 ± 1.5 bc	88.4 ± 1.7 bc
T4 (K low)	28.6 ± 0.7 bc	55.3 ± 1.4 bc	85.6 ± 1.5 c
T5 (K high)	31.1 ± 0.9 ab	60.2 ± 1.3 b	92.7 ± 1.6 b
T6 (HA high + K high)	33.7 ± 1.1 a	66.5 ± 1.6 a	101.3 ± 1.9 a

Number of Leaves per Plant

Humic acid and potassium fertilization also improved the number of leaves per plant (Table 3). At 60 DAS, T6 produced 22.3 leaves plant^{-1}, which was 52.7% higher than the control (14.6 leaves). Treatments T5 (19.7 leaves) and T3 (18.2 leaves) were statistically superior to control but remained below the combined treatment. The increase in leaf number is attributed to the role of humic acid in stimulating hormonal activity (auxins and cytokinins) and potassium in photosynthate translocation [6]. A greater leaf canopy ultimately favors photosynthetic efficiency and biomass accumulation, corroborating findings by Ayden et al. [22].

Table 3. Potash and Humic acid levels on number of leaves plant^{-1} of okra at diverse growth stages.

Treatment	30 DAS	45 DAS	60 DAS
T1 (Control)	5.4 ± 0.2 c	9.8 ± 0.3 d	14.6 ± 0.4 d
T2 (Humic acid low)	6.1 ± 0.2 bc	11.2 ± 0.4 c	16.9 ± 0.5 c
T3 (Humic acid high)	6.5 ± 0.3 b	12.4 ± 0.5 bc	18.2 ± 0.5 bc
T4 (K low)	6.3 ± 0.2 bc	11.9 ± 0.4 bc	17.5 ± 0.4 c
T5 (K high)	7.1 ± 0.3 ab	13.6 ± 0.5 b	19.7 ± 0.6 b
T6 (HA high + K high)	7.8 ± 0.3 a	15.2 ± 0.6 a	22.3 ± 0.7 a

Leaf Area Index (LAI)

Leaf area index trailed a analogous trend, showing significant increases with shared application of potash and humic acid (Table 4). At 60 DAS, LAI was highest (3.23) in T6, representing a 52.3% improvement over control (2.12). Potassium alone (T5) also enhanced LAI (2.87) compared to control, while humic acid alone (T3) recorded 2.65. Enhanced LAI reflects the cumulative effects of greater leaf number and expanded leaf surface, which improve light interception and canopy photosynthesis. These outcomes are consistent with Aluko et al. [23], who demonstrated that humic substances promote mesophyll development, and with Litardo et al. [24], who emphasized potassium's role in osmotic regulation and cell enlargement.

Table 4. Potash and Humic acid levels on leaf area index (LAI) of okra at diverse growth stages.

Treatment	30 DAS	45 DAS	60 DAS
T1 (Control)	0.78 ± 0.03 c	1.34 ± 0.05 d	2.12 ± 0.06 d
T2 (Humic acid low)	0.89 ± 0.04 bc	1.52 ± 0.06 c	2.43 ± 0.07 c
T3 (Humic acid high)	0.95 ± 0.04 b	1.67 ± 0.07 bc	2.65 ± 0.08 bc
T4 (K low)	0.92 ± 0.03 bc	1.61 ± 0.06 bc	2.54 ± 0.07 c
T5 (K high)	1.04 ± 0.04 ab	1.82 ± 0.07 b	2.87 ± 0.09 b
T6 (HA high + K high)	1.15 ± 0.05 a	2.06 ± 0.08 a	3.23 ± 0.10 a

Stem Diameter

Stem diameter was also significantly affected by treatments (Table 5). At 60 DAS, T6 recorded the maximum stem thickness (2.28 cm), 48.1% higher than the control (1.54 cm). This suggests improved assimilate allocation to structural biomass under adequate nutrient conditions. Both T5 (2.03 cm) and T3 (1.88 cm) were superior to control but inferior to T6. Humic substances enhance nutrient uptake and carbohydrate partitioning, resulting in thicker stems that support higher yield potential [4]. Potassium, being vital in protein synthesis and enzyme activation, also contributes to stem robustness [5].

Table 5. Potash and Humic acid levels on stem diameter (cm) of okra at altered growth stages.

Treatment	30 DAS	45 DAS	60 DAS
T1 (Control)	0.82 ± 0.02 c	1.16 ± 0.03 d	1.54 ± 0.04 d
T2 (Humic acid low)	0.91 ± 0.03 bc	1.32 ± 0.04 c	1.76 ± 0.05 c
T3 (Humic acid high)	0.96 ± 0.03 b	1.41 ± 0.05 bc	1.88 ± 0.06 bc
T4 (K low)	0.94 ± 0.02 bc	1.38 ± 0.04 bc	1.82 ± 0.05 c
T5 (K high)	1.05 ± 0.03 ab	1.55 ± 0.05 b	2.03 ± 0.06 b
T6 (HA high + K high)	1.14 ± 0.04 a	1.72 ± 0.06 a	2.28 ± 0.07 a

Chlorophyll Content and Relative Water Content (RWC)

Chlorophyll content increased significantly under nutrient management (Table 6). The highest SPAD value (42.1) was observed in T6, which was 48.2% higher than control (28.4). Relative water content showed a similar pattern, where T6 (86.0%) surpassed control (68.2%) by 26.1%. These improvements indicate better photosynthetic efficiency and water retention under combined humic acid and potassium treatments. Such outcomes are attributed to the role of humic acid in improving membrane permeability and chlorophyll stability [11], and potassium in maintaining cellular osmotic balance under field conditions [8].

Table 6. Potash and Humic acid levels on chlorophyll, (RWC, %), and pods plant^{-1} of okra

Treatment (T)	Chlorophyll (SPAD)	RWC (%)	Number of pods plant^{-1}
T1 (Control)	28.4 ± 0.7 c	68.2 ± 1.1 c	12.3 ± 0.6 c
T2 (HA low)	31.9 ± 0.8 bc	72.5 ± 1.2 bc	15.8 ± 0.7 bc
T3 (HA high)	34.6 ± 0.9 b	76.3 ± 1.3 b	18.4 ± 0.8 b
T4 (K low)	33.8 ± 0.8 b	75.1 ± 1.2 b	17.6 ± 0.7 b
T5 (K high)	37.2 ± 0.9 ab	80.4 ± 1.4 ab	22.1 ± 0.9 ab
T6 (HA high + K high)	42.1 ± 1.0 a	86.0 ± 1.5 a	28.7 ± 1.1 a

Yield Attributes

Significant differences were observed in pod attributes (Table 7). Pod length increased from 9.8 cm in control to 14.6 cm in T6, while pod diameter improved from 1.12 cm to 1.78 cm. Average pod weight was also highest under T6 (16.8 g), representing an 82.6% increase compared to control (9.2 g). The synergistic effect of humic acid and potassium in enhancing pod morphology and weight is likely due to better nutrient assimilation and improved source-sink relations [16].

Table 7. Potash and Humic acid levels on length (cm), diameter (cm) and average weight of pod

Treatment (T)	Pod length (cm)	Pod diameter (cm)	Average pod weight (g)
T1 (Control)	9.8 ± 0.3 c	1.12 ± 0.04 c	9.2 ± 0.5 c
T2 (HA low)	11.3 ± 0.4 bc	1.26 ± 0.05 bc	11.1 ± 0.6 bc
T3 (HA high)	12.5 ± 0.4 b	1.36 ± 0.05 b	12.8 ± 0.6 b
T4 (K low)	12.1 ± 0.4 b	1.34 ± 0.05 b	12.4 ± 0.6 b
T5 (K high)	13.7 ± 0.5 ab	1.52 ± 0.06 ab	14.5 ± 0.7 ab
T6 (HA high + K high)	14.6 ± 0.5 a	1.78 ± 0.07 a	16.8 ± 0.8 a

Pod Yield and Marketable Yield

Pod yield per plant, marketable yield, and total yield were all enhanced by humic acid and potassium (Table 8). Maximum pod yield per plant (0.78 kg) was recorded under T6, which was more than double that of control (0.34 kg). Similarly, marketable yield reached 16.5 t ha^{-1} under T6 compared to only 8.2 t ha^{-1} in control. These findings corroborate those of Jabal [26], who reported increased okra yield with humic acid, and Costa et al. [12], who emphasized potassium's critical role in enhancing reproductive efficiency and fruit set.

Table 8. Potash and Humic acid levels on per plant (kg), marketable and total yield (t ha^{-1}) of okra.

Treatment (T)	Pod yield plant^{-1} (kg)	Marketable yield (t ha^{-1})	Total yield (t ha^{-1})
T1 (Control)	0.34 ± 0.02 d	8.2 ± 0.4 d	9.0 ± 0.4 d
T2 (HA low)	0.46 ± 0.03 c	10.9 ± 0.5 c	11.8 ± 0.5 c
T3 (HA high)	0.54 ± 0.03 bc	12.7 ± 0.6 bc	13.6 ± 0.6 bc
T4 (K low)	0.51 ± 0.03 c	12.0 ± 0.6 c	12.9 ± 0.6 c
T5 (K high)	0.65 ± 0.04 b	14.8 ± 0.7 b	15.9 ± 0.7 b
T6 (HA high + K high)	0.78 ± 0.04 a	16.5 ± 0.8 a	17.8 ± 0.8 a

Nutrient Uptake

Nutrient uptake by okra plants showed remarkable increases with combined nutrient application (Table 9). Nitrogen uptake peaked at 77.3 kg ha^{-1} in T6, which was 85.8% higher than control (41.6 kg ha^{-1}). Phosphorus and potassium uptake were also highest under T6 (13.8 and 71.2 kg ha^{-1}, respectively), indicating improved nutrient assimilation and utilization efficiency. Similar responses have been observed in leafy and fruit crops under humic acid application due to improved root activity and cation exchange capacity [16].

Table 9. Potash and Humic acid levels on NPK uptake by okra (kg ha^{-1}).

Treatment (T)	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
T1 (Control)	41.6 ± 1.5 d	7.8 ± 0.3 d	38.4 ± 1.4 d
T2 (HA low)	52.7 ± 1.8 c	9.6 ± 0.4 c	48.2 ± 1.6 c
T3 (HA high)	59.4 ± 2.0 bc	10.8 ± 0.4 bc	53.7 ± 1.8 bc
T4 (K low)	56.2 ± 1.9 bc	10.3 ± 0.4 bc	51.1 ± 1.7 bc
T5 (K high)	65.8 ± 2.2 b	11.9 ± 0.5 b	59.6 ± 2.0 b
T6 (HA high + K high)	77.3 ± 2.5 a	13.8 ± 0.5 a	71.2 ± 2.3 a

Post-Harvest Soil Fertility

Soil nutrient status after harvest showed significant residual effects of humic acid and potassium application (Table 10). Available nitrogen increased from 28.4 mg kg^{-1} (control) to 42.1 mg kg^{-1} under T6, while phosphorus rose from 6.2 to 9.8 mg kg^{-1}. Similarly, exchangeable potassium increased from 128 mg kg^{-1} to 179 mg kg^{-1}. These improvements suggest that the combined application of humic acid and potassium not only benefits crop uptake but also maintains or enhances soil fertility. This aligns with reports by Ampong et al. [15], who noted improved soil nutrient retention and microbial activity with humic acid, and by Costa et al. [12], who highlighted potassium's role in sustaining soil fertility under intensive cropping.

Table 10. Post-harvest soil available NPK under humic acid and potassium treatments.

Treatment (T)	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})
T1 (Control)	28.4 ± 0.9 d	6.2 ± 0.2 d	128 ± 4.1 d
T2 (HA low)	32.7 ± 1.0 c	7.4 ± 0.3 c	141 ± 4.3 c
T3 (HA high)	35.8 ± 1.1 bc	8.0 ± 0.3 bc	152 ± 4.6 bc
T4 (K low)	34.9 ± 1.1 bc	7.8 ± 0.3 bc	149 ± 4.4 bc
T5 (K high)	38.6 ± 1.2 b	8.9 ± 0.3 b	164 ± 4.8 b
T6 (HA high + K high)	42.1 ± 1.3 a	9.8 ± 0.4 a	179 ± 5.1 a

CONCLUSION

The present study revealed that humic acid in conjunction with optimal potassium fertilization, expressively improved okra growth, yield and nutrient dynamics in soil and plants. Humic acid enhanced soil structure, nutrient availability, and water retention, while potassium contributed to efficient physiological and biochemical processes. Their synergistic interaction promoted vegetative and ultimately marketable and total yield. Moreover, nutrient uptake of N, P, and K increased, along with improved soil fertility after harvest, indicating a residual effect. The results suggest that integrating humic acid with appropriate potassium levels is a sustainable strategy to enhance okra productivity and nutrient use efficiency under semi-arid conditions. Such practices not only improve yield and quality but also conserve soil health, offering a feasible approach for resource-efficient and eco-friendly crop production systems.

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