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Effects of Humic Acid Applications on Growth and Yield of Garlic (*Allium sativum* L.) in Kandahar, Afghanistan

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ABSTRACT

Garlic (*Allium sativum* L.) is one of the most important vegetable crops and a common culinary spice used daily by most people around the world. Humic acid can enhance garlic growth and yield, and previous studies have reported that its application improves these traits. Although the effects of humic acid combined with other nutrients on the growth and quality of garlic have been studied, further comprehensive investigations are still needed, especially in Afghanistan's bioclimatic conditions. Therefore, the study aimed to examine the effects of humic acid on the growth and yield of garlic. The specific objective of the study was to determine the optimal amount of humic acid for promoting the growth and yield of garlic in Kandahar. A filed experiment was conducted at the research farm of Afghanistan National Agricultural Sciences and Technology University (ANASTU), using Randomized Complete Block Desing (RCBD) with five treatments To (no Humic acid), T1 (10 Kg ha^{-1} Humic acid), T2(15 Kg ha^{-1} Humic acid), T3 (20 Kg ha^{-1} Humic acid), and T4 (25 Kg ha^{-1} Humic acid) each replicated trice. The results showed that plant height, No. Leaves of plant^{-1}, and leaves length increased significantly by 30.40%, 28.21%, and 19.97% respectively, compared to the control at harvest; moreover, Bulb weight, bulb polar diameter, bulb equatorial diameter, No. Of cloves bulb^{-1}, cloves weight, cloves length, clove diameter, and bulb yield also significantly increased by 68.79%, 59.42%, 20.72%, 17.38%, 26.50%, 36.36%, 47.28%, 71.09 %, respectively, in comparison to the control. It is concluded that the highest growth and yield of garlic was recorded in the treatment where 25 kg ha^{-1} Humic acid was applied.

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INTRODUCTION

Garlic (*Allium sativum* L.) is a globally important vegetable crop, and as a common culinary spice, it has been cultivated and consumed across the globe since ancient times (Petropoulos et al., 2018; Sunanta et al., 2023). Furthermore, the consumption of garlic and its supplements has been shown to reduce the risk of diabetes and cardiovascular disease, while also boosting the immune system with antibacterial, antifungal, anti-aging, and anticancer properties (Sunanta et al., 2023).

Humic substances, derived from the physical, chemical, and microbiological conversion of biomolecules, are vital to soil humus. Humic acid has been shown to have a beneficial effect on crop growth and yield (Salihi et al., 2024). The foliar application of Humic Acid stimulated the parameters such as biomass and plant height, and increased levels of photosynthetic pigments and agricultural productivity (Vioratti et al., 2023). Spraying the soil with humic acid resulted in a significant increase in the vegetative growth of garlic plants and improved yield characteristics, achieving a high value at a concentration of 4 mL L-1, compared to plant spray treatments (Abayaty, 2019). Furthermore, humic acid treatment (1 ml L^{-1}) was significantly higher as compared to the control treatment in terms of the number of leaves (9.55 leaves $plant^{-1}$) and leaf area (8.27 dcm^2 $plant^{-1}$), number of cloves per head (42.05, head-weight (81.33), and total yield (24.39 $tons.h^{-1}$) (Al-obeidi & Al-obeidi, 2023).

Moreover, the spraying of humic acid (1.5 g L-1) significantly increases the vegetative growth characteristics of garlic, including the number of leaves per plant (6), stem diameter (5.6 mm), and relative chlorophyll content (69.78 SPAD) (Hassan Yousif, 2019). At the same time, application of humic acid (10 kg ha^{-1}) increased plant height (111.8 cm), Number of leaves (9.365 Leaf plant-1), leaf area (98.80 dcm $plant^{-1}$), total chlorophyll (82.63 mg 100 g^{-1} Fw), dry weight of shoots (14.34 g $plant^{-1}$), head diameter (6.600 cm $head^{-1}$), head weight (75.20 g $head^{-1}$), total yield (20.04 ton ha^{-1}) and percentage of dry matter (39.75%) (Al-Mharib et al., 2025).

On the other hand, humic acid increased garlic yield by approximately 5 tons ha-1 (Mohammadi et al., 2024; Akpan et al., 2025). The highest garlic yield was obtained with the application of humic acid at 20 kg ha-1 and salicylic acid at 1.5 mM (Mohammadi et al., 2024). Additionally, the application of humic acid (1.5 g L-1) demonstrated a significant effect on yield and bulb quality, with the highest value recorded for cloves weight (4.9 g) and cloves number. $bulb^{-1}$ (97.67), bulb weight (28.47 g) and bulb length (4,28 cm), cloves length (2.72 cm) and cloves diameter (2.67 cm) (Hassan Yousif, 2019). Fertilizing garlic plants with (30 m^3/fed) farmyard manure, 50 NPK, and 4 kg/fed potassium humate was effective for achieving high yield and best quality, as well as decreasing the harmful effects of chemical fertilizers on the environment and human health (Abdelkader, 2019).

Garlic is one of the most significant vegetables and culinary spices, offering numerous health benefits for humans. Recently, demand for garlic has increased globally (Sunanta et al., 2023). On the other hand, the excessive application of mineral fertilizers has harmed soil and water, leading to soil erosion and other environmental issues in many parts of the world, including Afghanistan, particularly in garlic fields. Therefore, there is an urgent need to improve garlic production sustainably in order to meet the increasing demand for garlic. At the same time, the application of organic fertilizers, including humic acid, which is an organic matter, in crop production not only increases crop growth and yield but also mitigates soil erosion and other environmental challenges caused by the excessive use of mineral fertilizers. While Humic acid is a natural biological substance and able to increase the growth and yield of crops, including garlic sustainably, increasing the availability of nutrients in soil, reducing the application amount of mineral fertilizer, and improving soil physical and chemical features (Zheng et al., 2022; Yang & Antonietti,2020). The application of Humic acid on garlic has been evaluated in previous research, for instance, the combined effects of Humic acid with other fertilizers on the growth, yield, productivity, morphology, and quality of garlic (Al-Mharib et al., 2025; Mohammadi et al., 2024; Kumar et al., 2024).

Furthermore, most previous studies have focused on the foliar application method of Humic acid with other nutrients (Mohammadi et al., 2024; Al-Obeidi, 2023; Hassan Yousif, 2019). Moreover, limited information is available regarding the effects of Humic acid alone on the growth and yield of garlic, particularly when used in conjunction with irrigation. Further comprehensive investigation is still needed, especially in Afghanistan's bioclimatic conditions. Thus, the experiment was conducted to evaluate the effects of applying humic acid only with irrigation on the growth and yield of garlic simultaneously. The objectives of the study are as follows:

- To examine the effects of Humic acid on the growth and yield of garlic.
- To investigate the favorable amount of Humic acid that increases both growth and yield of garlic at the same time in the study area.

METHOOD AND MATRAILS

A field experiment was conducted at the research farm of Afghanistan National Agricultural Sciences and Technology University (ANASTU), in Dand District, Kandahar, Afghanistan (31º 30ˈ N longitude, 65 º 50 ˈ E latitude, 1010 m Altitude) during the 2024-25 season. Local variety "Spina Hoza" (White Garlic) grown in 16m² plots with a total net experimental area of 240 m². Garlic bulbs were planted in rows with a space between them, and the plants were spaced 20 cm apart. Randomized Complete Block Design (RCBD) was selected for the experiment, which contains five treatments: To (no Humic acid), T1 (10 Kg ha^{-1} Humic acid), T2(15 Kg ha^{-1} Humic acid), T3 (20 Kg ha^{-1} Humic acid), and T4 (25 Kg ha^{-1} Humic acid) replicated trice. The Humic Acid (Potassium humate, 40% humic acid and 7% potassium) was sourced from the local market as a water-soluble granule and applied to the relevant treatments based on plot size. The amount of fertilizer was calculated accordingly. The fertilizer is split into two parts, mixed in irrigation water, and applied after germination and at 30 DAS of garlic growth stages, respectively. During the experiment, all agronomic local practices, such as irrigation, fertilization (50 kg ha-1 N and 50 kg ha-1 P2O), and pest and disease management, were implemented regularly at a reasonable time.

The growth parameters, such as plant height, number of leaves per plant, and leaf length, were measured regularly. Plant height was measured from the soil surface to the tip of the plant using a ruler. The number of leaves per plant was manually counted. Leaf length was also measured by ruler in centimeters. Moreover, relative chlorophyll (SPAD) values, using a SPAD-502 (Minolta, Japan), were also recorded at the maximum growth stage of garlic.

Furthermore, yield parameters, including the number of cloves per bulb, bulb length, bulb diameter, bulb yield per plant, and total yield, were measured. The number of cloves per bulb was manually counted, bulb length was measured using a ruler (cm), bulb diameter was measured using a Vernier caliper, and bulb yield per plant and total yield were measured using a laboratory balance. All data was arranged, and the averages were calculated using Microsoft Excel computer software. All data were subjected to analysis of variance (ANOVA) using SPSS (Statistical Package for the Social Sciences, version 26), and the Duncan test was performed to compare means at a $p < 0.05$ significance level.

FINDINGS

Plant Height

Plant height was significantly influenced by the application of humic acid at various growth stages (Table 1). At 60 days after sowing (DAS), a steady increase in plant height was observed with increasing levels of humic acid from low to high concentration. The shortest plants were recorded in the control treatment (T1), measuring 33.66 ± 0.63 cm, while the tallest plants were noted in the highest humic acid level (T5), reaching 45.86 ± 0.81 cm. Treatments T3 and T4 were statistically equal to each other. A similar trend continued at 120 DAS, where plant height increased from 55.00 ± 0.75 cm in the control to 69.06 ± 0.69 cm in T5, which was comparable to T3 and T4. At harvest, the tallest plants were observed in T5, recording 109.32 ± 0.43 cm, which was significantly higher than all other treatments. The control treatment recorded the lowest height of 83.83 ± 0.30 cm compared to the humic acid-treated treatments.

Number of Leaves

The number of leaves per plant was significantly affected by different levels of humic acid at 60 and 120 DAS and at harvest (Table 1). At 60 DAS, the number of leaves per plant ranged from 5.03 ± 0.18 in T1 to 6.10 ± 0.05 in T5. Treatments T2, T3, and T4 produced 5.43 ± 0.03, 5.43 ± 0.18, and 5.57 ± 0.09 leaves per plant, respectively. All treatments receiving humic acid resulted in significantly more leaves as compared with the control. At 120 DAS, the highest number of leaves (7.23 ± 0.03) was recorded in T5, followed by T4 (7.03 ± 0.21) and T3 (6.90 ± 0.05). The control recorded the lowest number of leaves per plant at this stage (6.03 ± 0.03). The number of leaves per plant increased across all treatments at harvest. The maximum was observed in T5 with 9.36 ± 0.08 leaves/plant, which was significantly at par with T4 (9.10 ± 0.15). The control treatment resulted in a minimum number of leaves (7.30 ± 0.05).

Leaves length

Leaf length of garlic plants was significantly influenced by different levels of humic acid at all observed growth stages (Table 1). At 60 DAS, leaf length ranged from 20.67 ± 0.23 cm in the T1 to 25.14 ± 0.78 cm in T5, showing a steady increase with higher humic acid levels, whereas T3 and T4 treatments were significantly at par with T5. At 120 DAS, maximum leaf length was observed in T5 (44.94 ± 0.09 cm), whereas T2, T3, and T4 were significantly at par with each other. The minimum leaf length (36.11±1.66 cm) was recorded in T1. Leaf length, at harvest, had increased significantly in all treatments. The longest leaves were recorded in T5 (85.64 ± 0.34 cm), whereas T2, T3, and T4 were significantly at par with each other. The minimum leaf length (71.38±0.09 cm) was recorded in T1.

Average Bulb Weight

As shown in Table 2, the average bulb weight of garlic was significantly affected by the application of different levels of humic acid. The control treatment (T1) recorded the lowest

Table 1. *Effect of different levels of humic acid on the growth of garlic*

Treatment	Plant Height (cm)			No. of leaves per plant			Leaf length (cm)		
	60 DAS	120 DAS	At harvest	60 DAS	120 DAS	At harvest	60 DAS	120 DAS	At harvest
T1 (Control)	33.66±0.63 d	55.00 ± 0.75c	83.83± 0.30e	5.03±018 c	6.03± 0.03c	7.3± 0.05c	20.67±0.23 c	36.11± 1.66c	71.38± 0.09c
T2 (10 kg/ha)	37.73 ± 0.69 c	61.26 ± 0.46b	90.72 ± 0.46d	5.43 ± 0.03 cb	6.7 ± 0.15b	7.5 ± 0.25c	22.11± 0.18 b	41.44± 0.34b	79.31 ± 0.66b
T3 (15 kg/ha)	41.26± 0.29 b	67.00 ± 0.0.41a	96.45± 0.41c	5.43± 0.18 cb	6.9 ± 0.05 ab	8.43± 0.18b	24.11± 0.18 a	40.67 ± 0.25 b	80.04± 0.29b
T4 (20 kg/ha)	42.33 ± 0.29 b	66.26 ± 0.52 a	102.40± 0.46b	5.57 ± 0.09 b	7.03 ± 0.21 ab	9.10± 0.15a	24.87 ± 0.14 a	41.51 ± 0.17 b	79.97± 0.52b
T5 (25 kg/ha)	45.86 ± 0.81 a	69.06 ± 0.69 a	109.32± 0.43a	6.10 ± 0.05 a	7.23 ± 0.03 a	9.36± 0.08a	25.14 ± 0.78 a	44.94 ± 0.09 a	85.64± 0.34a

average bulb weight of 33.10 ± 0.17 g, while the highest weight was obtained in T5 (55.87 ± 0.44 g), which was followed by T4 (45.92 ± 0.30 g).

Bulb Polar Diameter

The polar diameter of garlic bulbs was significantly at ($p<0.05$) influenced by different levels of humic acid. The data presented in Table 2 show that the polar diameter of the bulb increased progressively with the application of humic acid. The smallest polar diameter (6.13 ± 0.09 cm) was recorded in the control treatment (T1). In contrast, the largest polar diameter was observed in T5, which reached 7.99 ± 0.06 cm, indicating a substantial improvement over the untreated plants. T3 was at par with T4, which showed increasing values of polar diameter 6.49 ± 0.04 cm and 6.63 ± 0.12 cm, respectively.

Bulb Equatorial Diameter

Significant differences in bulb equatorial diameter were observed among treatments due to the application of humic acid, as presented in Table 2. The equatorial diameter of garlic bulbs increased consistently with higher levels of humic acid. The smallest equatorial diameter was recorded in T1 (4.15 ± 0.09 cm), while the maximum was observed in T5 (5.01 ± 0.06 cm). T2, T3, and T4 recorded 4.25 ± 0.06 cm, 4.38 ± 0.02 cm, and 4.47 ± 0.02 cm, respectively.

Number of Cloves

The data on the number of cloves per bulb are presented in Table 1. The data reveal that the maximum number of cloves/bulb (11.95±0.04) was recorded in T5, which was followed by T4, where garlic produced 11.73±0.06 cloves/bulb, whereas T1 produced the minimum number of cloves/bulb (10.18±0.07).

Average Clove Weight

As shown in Table 2, the average clove weight of garlic bulbs was significantly influenced by the application of humic acid. The lowest average clove weight was recorded in T1, which produced cloves weighing 3.66 ± 0.08 g, whereas the highest value was observed in T5, with an average clove weight of 4.63 ± 0.12 g. A progressive increase in clove weight was observed with increasing levels of humic acid. T2 and T3 recorded average clove weights of 3.71 ± 0.04 g and 3.83 ± 0.07 g, respectively, and were statistically at par, indicating no significant difference between them.

Clove Length

Clove length of garlic bulbs responded significantly to different levels of humic acid, as presented in Table 2. The shortest cloves were recorded in the control treatment (T1), with an average length of 2.36 ± 0.90 cm, while the longest cloves were observed in T5, measuring 3.23 ± 0.14 cm.

Clove Diameter

Clove diameter was significantly influenced by the application of humic acid, as illustrated in Table 2. The smallest clove diameter was recorded in the control treatment (T1), with a value of 1.29 ± 0.02 cm, while the maximum diameter was obtained in T5 (25 kg ha^{-1} humic acid), measuring 1.90 ± 0.1 cm. T2 was statistically equivalent to T3, which recorded clove diameters of 1.41 ± 0.02 cm and 1.43 ± 0.01 cm, respectively.

Bulb Yield

The bulb yield of garlic showed a marked and statistically significant response to humic acid application, as presented in Table 2. Among all treatments, the highest yield was recorded in T5, reaching 15.98 ± 0.17 tons ha ^{1}, which was substantially higher compared to the control treatment (T1), where the yield remained at 9.34 ± 0.07 tons ha ^{1}. This indicates an impressive increase of over 70% in yield due to the highest dose of humic acid. A consistent upward trend in yield was observed across treatments with increasing levels of humic acid. T2, T3, and T4 yielded 9.73 ± 0.06, 10.01 ± 0.30, and 13.82 ± 0.10-ton ha^{-1}, respectively. Among these, T2 and T3 were statistically at par.

Table 2. *Effect of different levels of humic acid on yield and yield attributes of garlic*

Treatment	Average bulb weight (g)	Bulb polar diameter (cm)	Bulb equatorial diameter (cm)	No. of cloves/bulb	Average clove weight (g)	Clove length (cm)	Clove diameter (cm)	Bulb yield (Ton/ha)
T1 (Control)	33.10 ± 0.17e	6.13 ± 0.09c	4.15 ± 0.09e	10.18 ± 0.07d	3.66 ± 0.08c	2.36 ± 0.90c	1.29 ± 0.02d	9.34 ± 0.07d
T2 (10 kg/ha)	35.9 ± 0.06d	6.17 ± 0.08c	4.25 ± 0.06de	10.37 ± 0.07cd	3.71 ± 0.04c	2.47 ± 0.02c	1.41 ± 0.02c	9.73 ± 0.06cd
T3 (15 kg/ha)	41.23 ± 0.67c	6.49 ± 0.049b	4.38± 0.02bc	10.99 ± 0.06c	3.83 ± 0.07c	2.50± 0.01c	1.43± 0.01c	10.01± 0.30c
T4 (20 kg/ha)	45.92 ± 0.30b	6.63 ± 0.12b	4.47 ± 0.02b	11.73 ± 0.06b	4.14 ± 0.09b	2.76 ± 0.01b	1.69 ± 0.01b	13.82± 0.10b
T5 (25 kg/ha)	55.87 ± 0.44a	7.99 ± 0.06a	5.01 ± 0.06a	11.95 ± 0.04a	4.63 ± 0.12a	3.23 ± 0.14a	1.90 ± 0.1a	15.98 ± 0.17a

DISCUSSION

Increments of plant height of garlic during growth stages and at harvest may be due to the availability of macronutrients such as N, P, and K, which are important in effective crop growth (Attememe, 2009), especially in early stages, in the soil, which the application of humic acid may provide. Furthermore, Humic acid may stimulate garlic roots to absorb N, P, and K, thereby improving growth (Ghasemi et al., 2020). Similarly, Rathor et al. (2025) reported that the application of Humalite, which is rich in Humic acid and organic matter, increased soil nitrogen availability and significantly enhanced the uptake of macronutrients (N, P, and K) in the soil. The availability of favorable amounts of macronutrients may increase cell elongation, which is caused by increases in carbohydrates produced through photosynthesis, especially during the early growth stages of garlic. Similar findings with the application of humic acid increasing plant height were reported by Vioratti et al. (2023) and Al-Mharib et al. (2025). Increases in the number of leaves per plant may also be due to the uptake of a favorable amount of macro- and microelements at the early growth stages of garlic, which is provided by the application of humic acid. The availability and effective uptake of nutrients in early growth stages led to increases in chlorophyll content and photosynthesis, resulting in the production of more carbohydrates. This, in turn, facilitated cell division, promoting rapid growth and the development of additional leaves. Al-Obeidi & Al-Obeidi (2023), Hassan Yousif (2019), and Al-Mharib et al. (2025) also reported that application of humic acid increased the number of leaves in garlic due to increases in chlorophyll, photosynthesis, cell division, and stimulation in plant metabolism.

Furthermore, the significant increases in bulb weight, bulb polar diameter, and bulb equatorial diameter can be attributed to the effective absorption and translocation of micronutrients provided by the application of humic acid, resulting in an improvement in bulb weight and diameter. The increased availability and absorption of macro- and micronutrients in all growth stages of garlic, particularly during the late growth stage and at harvest, resulted in enhanced assimilation and translocation from the leaves to the bulb, as well as improvements in bulb parameters. These findings are in agreement with those of Al-Mharib et al. (2025) and Kumar et al. (2024).

As well as increments in No. The composition of cloves, including clove weight, clove length, and clove diameter in garlic, may be influenced by the availability of nutrients, and a balance between macro- and microelements may be achieved through the application of humic acid. Humic acid plays a significant role in stimulating enzymes, thereby enhancing metabolism and increasing the translocation and partitioning of photosynthetic products, which leads to improved clove quality parameters. Similar findings of increases in clove parameters were stated by Hassan Yousif (2019) and Kumar et al (2024).

Moreover, the increases in bulb yield resulting from different treatments of humic acid are attributed to the enhanced growth and yield parameters, which may also be due to the increased production of photosynthetic products and high essential nutrients in garlic roots. In addition to the improvement in garlic bulb yield, this may be attributed to the availability of balanced nutrients, stimulated enzyme activity, and effective assimilation and partitioning of photosynthetic products from the source to the sink (bulbs). These findings are confirmed by Al-Obeidi & Al-Obeidi (2023), Al-Mharib et al. (2025), and Mohammadi et al. (2024). Al Mharib et al. (2025) reported that the increases in yield of garlic when humic acid is applied may be attributed to its role in increasing the products of carbon assimilation, thus increasing vegetative growth, and causing an increase in cell division in the disc stem, that is, the new clove formation begins, which enhances the accumulation of synthetic materials in bulbs and increases the bulb yield.

Even though there were limited sources for the experiment, the application of Humic acid may also improve the quality of garlic, as well as the application of Humic acid in combination with other essential mineral fertilizers for garlic, which not only reduces the amount of mineral fertilizer application but also reduces farmers' expenses and improves garlic production sustainably in the future.

CONCLUSION

Garlic is a significant vegetable and culinary spice recognized worldwide. On the other hand, Humic acid is also a natural organic substance that can enhance crop growth and yield, including garlic. The research findings demonstrated that most garlic growth parameters, such as plant height, number of leaves, and leaf length, were significantly increased by the application of different humic acid treatments at all growth stages, including 60 days after sowing (DAS), 120 DAS, and at harvest. For instance, plant height and number of leaves. plant-1, and leaf length increased significantly by 30.40%, 28.21%,19.97% respectively at harvest. Furthermore, yield attributes such as bulb weight, bulb diameter, number of cloves, clove length, clove diameter, clove weight, and bulb yield were also increased significantly by 68.79%, 59.42%, 17.38%, 36.36%,47.28%, 26.50%, and 71.09 % respectively, at the harvest stage by the humic acid treatments. Thus, the application of Humic acid with irrigation significantly increased both growth and yield parameters of garlic in the study area.

Moreover, it is indicated that increasing the application rate of humic acid resulted in corresponding increases in both growth and yield parameters of garlic compared to the control. It is concluded that the highest growth and yield were achieved with the application of 25 kg ha^{-1} humic acid, and this recommendation is supported in the study area. Further research is recommended to explore different types and application methods of humic acid for garlic production under specific soil and local conditions.

AUTHORS CONTRIBUTION

Rahimullah Himatkhwah and Mirwais Khan Afghan conceptualized, designed, and conducted the research. Rahimullah Himatkhwah wrote the results, and Mohammad Sadiq Salihi. Conducted the literature review and were responsible for writing and editing the original manuscript. All authors reviewed and approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data is available from the corresponding author upon reasonable request. All relevant data were generated and analyzed during the current study and have not been deposited in a public repository due to institutional or regional restrictions.

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