Effect of supplied humic acid and seed number per row on sesame (*Sesamum indicum* L.) growth and yield

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Abstract

A field experiment was conducted at the College of Agriculture, University of Baghdad, Abu Ghraib, to study the effect of humic acid application and seed number per row on yield. Analysis of variance indicated that plant density had a significant effect on most traits. Sowing at a density of 30 × 0 g·ha⁻ ¹ resulted in the shortest days to flowering (41.00 days), while a density of 60 × 12,000 g·ha⁻ ¹ produced the highest number of branches per plant (10.06 branches). The treatment 30 × 12,000 g·ha⁻ ¹ gave the highest number of capsules per plant (115.40 capsules) and also resulted in the largest leaf area (2,677.55 cm²). The highest number of seeds per capsule was recorded for the treatment 60 × 12,000 g·ha⁻ ¹, reaching 56.70 seeds. Increasing the level of humic acid led to a higher seed yield, which reached 4.88 t·ha⁻ ¹. The study concluded that increasing the amount of organic fertilizer enhances seed yield in sesame by promoting leaf expansion, which in turn increases photosynthetic efficiency. This results in a higher number of capsules per plant, greater seed weight, and ultimately an increase in seed yield per unit area (t·ha⁻ ¹).

Key words. humic acid, number of seeds per row, sesame

Introduction

Sesame (*Sesamum indicum* L.) is considered one of the oldest oilseed crops known to humankind and belongs to the family Pedaliaceae. Its importance lies in the fact that it is a rich source of oil, constituting approximately 50–60% of the seed weight. Sesame oil is characterized by a high content of unsaturated fatty acids, as well as the presence of bioactive compounds such as sesamol, sesamolin, and sesamin. These compounds act as antioxidants, conferring high oxidative stability and resistance to rancidity, which has earned sesame oil and called a king of vegetable oils (1,2) In addition to, sesame seed cake remaining after oil extraction contains a high protein content ranging from 20–25%, making it an important source of essential amino acids for both human and animal nutrition (3). The utilization of sesame is not limited to nutritional purposes; it is also used in pharmaceutical and cosmetic industries and is considered an economically and strategically important crop in many producing countries. Sesame cultivation is widespread across many regions of Asia and Africa, including India and China, as well as Sudan and Nigeria. These countries are considered among the major global centers of sesame production, where the crop contributes to providing a good income for farmers and supports both local and global industries (4). In the Arab world, the cultivated area of sesame reached approximately 5 million hectares, with a total production of about 1.3 million tons in 2020 (5). In Iraq, sesame has been cultivated since ancient times in the northern and central provinces; however, its productivity remains low compared with the global average. Yield was estimated at approximately 1,100 kg ha⁻ ¹ in 2021, whereas the global average yield exceeds 1,900 kg ha⁻ ¹ (6). This low productivity is mainly attributed to limited

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adoption of modern agricultural technologies and the scarcity of applied studies focusing on improving plant spacing and the use of modern organic amendments. The success of sesame production largely depends on plant density and the number of plants per unit area. When a high number of seeds are sown within the same row, plants compete with one another for water, nutrients, and light, which reduces the growth of individual plants. Conversely, when plant density is too low, the available space is not efficiently utilized and canopy coverage becomes weak, leading to a reduction in total yield (7). Therefore, determining the optimal number of seeds per row is one of the most important factors contributing to increased sesame productivity and improved crop characteristics.

Recent studies in the field of fertilization indicate a growing interest in the use of organic fertilizers and bio stimulants as partial or complete alternatives to chemical fertilizers, due to their positive effects on plant growth and productivity. Humic acid is considered one of the most important of these compounds, as it contributes to improving the physical and chemical properties of soil by enhancing aeration efficiency and increasing water-holding capacity, in addition to stimulating beneficial soil microorganisms. Moreover, humic acid enhances nutrient availability, promotes root growth, and increases the efficiency of water and nutrient uptake, which is directly reflected in improved plant growth and yield (8,9). Meta-analysis results showed that the application of humic acid increased average crop yields by 12% and improved nitrogen use efficiency by 22% (10). In addition, other studies have demonstrated that its use enhances plant tolerance to environmental stresses such as drought and salinity (11). Although several studies have investigated the effects of plant density or the use of organic fertilizers individually on sesame production, research examining the interaction between the number of seeds sown per row and the application of humic acid remains limited, particularly under local environmental conditions. This gap is even more evident under Iraqi soil conditions, which are characterized by variable salinity levels and the presence of gypsum in some regions. Accordingly, the present study was conducted to elucidate the combined effects of these two factors on improving growth, yield, and quality traits of sesame, and to identify the most suitable agronomic practices that can be adopted to enhance productivity and achieve higher economic returns for farmers in Iraq. The aim of this study is to investigate the effect of the organic fertilizer humic acid and its interaction with plant density on the growth, yield, and seed characteristics of sesame (*Sesamum indicum* L.)

Material and Methods

The field experiment was conducted at the experimental site of the College of Agriculture, University of Baghdad / Abu Ghraib, located at latitude 33.318249° N and longitude 44.212467° E, at an elevation of approximately 34 m above sea level. The experiment was conducted in a silty loam soil that was relatively homogeneous in its physical and chemical properties. To characterize soil properties prior to planting, laboratory analyses were performed on soil samples collected from a depth of 0–30 cm. The results indicated a soil pH of 7.6, organic matter content of 1.3%, total nitrogen of 0.07%, available phosphorus of 9.2 mg kg^{-1}, and available potassium of 135 mg kg^{-1}, indicating that the soil had moderate fertility with a tendency toward low fertility. Local variety of sesame seeds were sown on July 5, 2025, following a Randomized Complete Block Design (RCBD) in a factorial arrangement with three replicates.

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The experiment included two main factors: The number of seeds sown per square meter was set at three levels: 10, 15, and 20 seeds m^{-2} and Humic acid was applied at three levels: 0, 6,000, and 12,000 g ha^{-1}.

"Data were statistically analyzed according to the Randomized Complete Block Design (RCBD). Treatment means were compared using the Least Significant Difference (LSD) test at a 0.05 probability level.

Results and Discussion

Days to flowering

The results of the statistical analysis (Table1) showed significant differences between the treatments of seed number per row and humic acid fertilization levels. Sowing 30 seeds per row resulted in the shortest number of days from sowing to flowering, averaging 44 days, compared with sowing 60 seeds per row, which averaged 50 days. Increasing the number of seeds per row leads to greater competition among plants for available growth factors such as light, nutrients, and water, thereby delaying flowering (12). Regarding the interaction between seed number per row and humic acid levels, sowing 30 seeds per row with 0 g ha^{-1} humic acid resulted in the shortest number of days to flowering, compared with sowing 60 seeds per row with 12,000 g ha^{-1}. Higher hemic acid levels stimulate cell division and expansion, thereby increasing vegetative growth at the expense of reproductive growth and flowering (13).

Table 1. Effect of plant density (seeds row^{-1}) and humic acid rates (g ha^{-1}) on the number of days to first flowering of sesame.

Number of seeds per row (seed row^{-1})	Humic levels (g-hc^{-1})(			Average number of branches on a plant
	0	6000	12000	
30	41.00 f	44.67 d-f	47.00cc	**44.22 c**
45	43.00 ef	48.00 cd	49.67 bc	**46.88 b**
60	46.33 ce	52.33 ab	54.00 a	**50.88 a**
Humic averages	43.44 b	48.33 a	50.88 a	

Number of main branches (branches $plant^{-1}$)

The results of the statistical analysis (Table 2) showed significant differences between the treatments of seed number per row and humic acid fertilization levels for the trait of number of branches per plant. Sowing 30 seeds per row produced the highest mean of 9.10 branches $plant^{-1}$, compared with sowing 60 seeds per row, which resulted in a mean of 6.73 branches $plant^{-1}$. Increasing the number of seeds per row leads to greater competition among plants for growth factors such as water and nutrients, thereby reducing photosynthetic efficiency (14). The results of the statistical analysis (Table 2) also showed significant differences among humic acid fertilization levels. The control treatment (0 g ha^{-1}) produced the lowest

ISSN 2072-3857

number of branches per plant, averaging 6.62 branches plant⁻ ¹, compared with the highest fertilization level (12,000 g ha⁻ ¹), which resulted in the highest mean of 9.13 branches plant⁻ ¹. Increasing humic acid application promotes greater branching in plants (15). Regarding the interaction between seed number per row and humic acid levels, sowing 30 seeds per row with 0 g ha⁻ ¹ humic acid produced the lowest number of branches per plant, averaging 5.03 branches plant⁻ ¹, whereas sowing 60 seeds per row with 12,000 g ha⁻ ¹ humic acid resulted in the highest number, averaging 10.06 branches plant⁻ ¹. Higher levels of humic acid enhance branch formation in the plant (16).

Table 2. Effect of plant density (seeds row⁻ ¹) and humic acid rates (g ha⁻ ¹) on the number of main branches (branches plant⁻ ¹) of sesame.

Number of seeds per row (seed row^{-1})	Humic levels (g-hc^{-1})(			Average number of branches on a plant
	0	6000	12000	
30	5.03 e	7.03cd	8.13 bc	**6.73 c**
45	6.73 d	7.40 cd	9.20 ab	**7.78 b**
60	8.10 bc	9.13 ab	10.06a	**9.10 a**
Humic averages	6.62 c	7.85 b	9.13a	

Leaf area (cm² plant⁻ ¹)

The results of the statistical analysis (Table 3) showed significant differences between the treatments of seed number per row and humic acid fertilization levels for the trait of leaf area (cm² plant⁻ ¹). Sowing 30 seeds per row produced the highest mean leaf area of 2,677.55 cm² plant⁻ ¹, compared with sowing 60 seeds per row, which resulted in a lower mean of 2,677.55 cm² plant⁻ ¹. Increasing the number of seeds per row leads to greater competition among plants, which reduces leaf area (17). Furthermore, significant differences were observed among humic acid fertilization levels. The control treatment (0 g ha⁻ ¹) produced the lowest leaf area, averaging 2,316.24 cm² plant⁻ ¹, whereas the highest level (12,000 g ha⁻ ¹) resulted in the highest mean of 2,915.03 cm² plant⁻ ¹. Application of humic acid enhances cell division, elongation, and expansion, thereby increasing leaf area (18). Regarding the interaction between seed number per row and humic acid fertilization levels, sowing 60 seeds per row with 0 g ha⁻ ¹ humic acid produced the lowest mean leaf area, averaging 2,305.63 cm² plant⁻ ¹, whereas sowing 60 seeds per row with 12,000 g ha⁻ ¹ humic acid resulted in the highest leaf area, averaging 2,677.55 cm² plant⁻ ¹. Increasing the level of humic acid application enhances leaf area (19).

Table 3. Effect of plant density (seeds row⁻ ¹) and humic acid rates (g ha⁻ ¹) on plant leaf area (cm² plant⁻ ¹) of sesame.

ISSN 2072-3857

Number of seeds per row (seed row^{-1})	**Humic levels (g-hc^{-1}) (**			**Average number of branches per a plant**
	0	**6000**	**12000**	
30	2325.51 f	2715.01 d	2992.14 a	2677.55 a
45	2317.58 f	2698.67 d	2912.18 b	2642.81 b
60	2305.63 f	2644.16 e	2840.78 c	2596.86 c
Humic averages	2316.24 c	2685.94 b	2915.03 a	

Number of capsules per plant

The results of the statistical analysis (Table 4) showed significant differences between the treatments of seed number per row and humic acid fertilization levels for the trait of number of capsules per plant. Sowing 60 seeds per row produced the highest mean number of capsules, averaging 94.22 capsules plant^{-1}, compared with sowing 30 seeds per row, which resulted in the lowest mean of 87.01 capsules plant^{-1}. Increasing the number of seeds per row leads to greater competition among plants, which reduces the number of capsules per plant (20). Significant differences were also observed among humic acid fertilization levels. The control treatment (0 g ha^{-1}) resulted in the lowest number of capsules per plant, averaging 66.1 capsules plant^{-1}, whereas the highest level (12,000 g ha^{-1}) produced the highest mean of 113.26 capsules plant^{-1}. Application of humic acid increases leaf area, which enhances photosynthetic activity and consequently increases the number of capsules per plant (21). Regarding the interaction between seed number per row and humic acid levels, sowing 60 seeds per row with 0 g ha^{-1} humic acid resulted in the lowest number of capsules per plant, averaging 61.37 capsules plant^{-1}, whereas sowing 30 seeds per row with 12,000 g ha^{-1} humic acid produced the highest mean, averaging 115.40 capsules plant^{-1}. Higher levels of humic acid increase plant height, which in turn leads to a greater number of capsules per plant (22).

Table 4. Effect of plant density (seeds row^{-1}) and humic acid rates (g ha^{-1}) on the number of capsules per plant (capsules plant^{-1}) of sesame.

ISSN 2072-3857

Number of seeds per row (seed row^{-1})	Humic levels (g-hc^{-1}) (			Average number of capsules per a plant
	0	6000	12000	
30	71.77 c	95.48 b	115.40 a	94.22 a
45	65.26 c	92.38 b	113.31 a	90.31 a
60	61.37 d	88.57 b	111.08 a	87.01 b
Humic averages	66.13 c	92.14 b	113.26 a	

Number of seeds per capsule

The results of the statistical analysis (Table 5) showed significant differences between the treatments of seed number per row and humic acid fertilization levels for the trait of number of seeds per capsule. Sowing 60 seeds per row produced the highest mean number of seeds per capsule, averaging 50.50 seeds capsule^{-1}, compared with sowing 30 seeds per row, which resulted in the lowest mean of 50.43 seeds capsule^{-1}. Increasing the number of seeds per row leads to a greater number of seeds per capsule due to stem elongation and a reduced number of branches, which decreases competition among individual plant organs (23). Significant differences were also observed among humic acid fertilization levels. The control treatment (0 g ha^{-1}) resulted in the lowest mean number of seeds per capsule, averaging 44.45 seeds capsule^{-1}, whereas the highest level (12,000 g ha^{-1}) produced the highest mean of seeds per capsules 56.60 seeds capsule^{-1}. Application of humic acid increases leaf area, enhancing the translocation of photosynthetic products from source to sink (24). Regarding the interaction between seed number per row and humic acid levels, sowing 60 seeds per row with 0 g ha^{-1} humic acid produced the lowest mean number of seeds per capsule, averaging 44.27 seeds capsule^{-1}, whereas sowing 30 seeds per row with 12,000 g ha^{-1} humic acid resulted in the highest mean, averaging 56.60 seeds capsule^{-1}. Higher levels of humic acid enhance plant height, which in turn increases the number of capsules per plant (25).

Table 5. Effect of plant density (seeds row^{-1}) and humic acid rates (g ha^{-1}) on 1000-seed weight (g) of sesame.

ISSN 2072-3857

Number of seeds per row (seed row^{-1})	Humic levels (g-h^{-1})(			Number of seeds per capsules
	0	6000	12000	
30	44.27 c	50.44 b	50.60 a	56.43 a
45	44.46 c	50.40 b	56.14 a	50.36 a
60	44.51 c	50.26 b	56.70 a	50.50 a
Humic averages	44.45 c	50.36 b	56.47 a	

weight of 1000 seeds(g)

The results of the statistical analysis (Table 6) showed significant differences between the treatments of seed number per row and humic acid fertilization levels for 1000-seed weight (g). Sowing 30 seeds per row produced the highest mean 1000-seed weight of 1.48 g, compared with sowing 60 seeds per row, which resulted in the lowest mean of 1.38 g. The increase in seed weight is attributed to larger leaf area and enhanced photosynthetic products, which in turn increase seed weight (26). Significant differences were also observed among humic acid fertilization levels. The control treatment (0 g ha^{-1}) produced the lowest mean 1000-seed weight of 1.30 g, whereas the highest level (12,000 g ha^{-1}) resulted in the highest mean of 1.59 g. Application of humic acid increases leaf area, which enhances translocation of photosynthetic products from source to sink, thereby increasing seed weight (27). Regarding the interaction between seed number per row and humic acid levels, sowing 60 seeds per row with 0 g ha^{-1} humic acid produced the lowest 1000-seed weight, averaging 1.25 g, whereas sowing 30 seeds per row with 12,000 g ha^{-1} humic acid resulted in the highest mean of 1.65 g. Higher levels of humic acid enhance plant height, which in turn increases the number of capsules per plant and seed weight (28).

Table 6. Effect of plant density (seeds row^{-1}) and humic acid rates (g ha^{-1}) on 1000-seed weight (g) of sesame.

Number of seeds per row (seed row^{-1})	Humic levels (g-h^{-1})(			Average number of branches on a plant
	0	6000	12000	
30	1.35 f	1.45 d	1.65 a	1.48 a
45	1.30 g	1.40 e	1.60 b	1.43 b
60	1.25 h	1.35 f	1.54 c	1.38 c
Humic averages	1.30 c	1.40 b	1.59 a	

Total plant yield (t. ha^{-1})

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The results of the statistical analysis (Table 5) showed significant differences between the treatments of seed number per row and humic acid fertilization levels for total plant yield (t ha^{-1}). Sowing 60 seeds per row produced the highest total plant yield, averaging 3.19 t ha^{-1}, compared with sowing 30 seeds per row, which resulted in the lowest mean yield of 1.83 t ha^{-1}. Increasing the number of seeds per row leads to greater competition among plants, which may reduce total plant yield (29). Significant differences were also observed among humic acid fertilization levels. The control treatment (0 g ha^{-1}) resulted in the lowest yield, averaging 1.40 t ha^{-1}, whereas the highest level (12,000 g ha^{-1}) produced the highest mean yield of 3.80 t ha^{-1}. Application of humic acid enhances photosynthetic efficiency, thereby increasing the translocation of assimilates from source to sink (30). Regarding the interaction between seed number per row and humic acid levels, sowing 60 seeds per row with 12,000 g ha^{-1} humic acid resulted in the highest plant yield, averaging 4.88 t ha^{-1}, whereas sowing 30 seeds per row with 0 g ha^{-1} produced the lowest mean yield of 1.07 t ha^{-1}. Higher levels of humic acid increase the number of capsules per plant, which consequently enhances total plant yield (31)

Table 7. Effect of plant density (seeds row^{-1}) and humic acid rates (g ha^{-1}) on total plant yield (t ha^{-1}) of sesame.

Number of seeds per row (seed row^{-1})	Humic levels (g-h^{-1})(			Average number of branches on a plant
	0	6000	12000	
30	1.07 f	1.74 e	2.70 c	1.83 c
45	1.43 e	2.46 d	3.83 b	2.57 b
60	1.70 e	3.00 c	4.88 a	3.19 a
Humic averages	1.40 c	2.40 b	3.80 a	

Conclusion.

We concluded from this study that the application of humic acid at a rate of 12,000 kg ha^{-1} significantly increased the number of branches per plant, the number of capsules per plant, and the number of seeds per capsule, which ultimately resulted in productivity per hectare

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