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Enhancing the sustainability of some *Triticum aestivum* L. varieties through the application of different types of nutrients

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Abstract

experiment was conducted in Mosul during 2025 season. It was implemented using a randomized complete block design (RCBD) with 45 experimental units of 2 m² each. The experiment included two factors: the first factor involved three bread wheat varieties (Arabia, Benko, and Pharaonia), and the second factor involved the type of fertilization, which included five types (control, humic, amino acids, neutral NPK, and a mixture of fertilizers). Fertilization was applied one and a half months after germination. The experiment aimed to compare the varieties used and the types of fertilization applied to reduce use of chemical fertilization. results showed that the Arabia variety was superior in terms of number of spikes. m^{-2} (336.84), grain yield (3154.95 kg/ha), harvest index (41.07%), and gluten content (32.22%). While the Benko variety excelled in the number of branches (8.52), the Pharaonia variety excelled in plant height (134.84 cm), flag leaf area (35.98 cm²), and number of spikes. m^{-2} (113.95), and biological yield (13308.3 kg. ha^{-1}). Regarding fertilization, the mixed fertilizer treatment was superior in all studied traits. In a two-way interaction, the Arabiya variety, under the mixed fertilizer treatment, excelled in grain yield and number of spikes m^{-2}.

Keywords: sustainability, Triticum aestivum L, nutrients, humic Fertilization, amino acids.

I. INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is world's first strategic crop, contributing more than 20% the total daily calorie and protein intake of the global population (Ram et al., 2024). With world's population projected to reach approximately 9.7 billion by 2050, demand for wheat is expected to increase by about 60% compared to current levels (FAO, 2023). This rapid population growth, coupled with Faced with water scarcity, declining soil fertility, and harsh climate change, traditional wheat production systems are under immense pressure, threatening their sustainability. While the agricultural revolution has relied heavily on chemical mineral fertilizers (especially NPK) to achieve unprecedented productivity gains, excessive and unbalanced use of these fertilizers has led to numerous negative environmental consequences, including soil salinization, groundwater contamination with nitrates, reduced soil organic matter, and increased greenhouse gas emissions (Gong et al., 2009; Ahmad et al., 2018; Alhayali et al., 2026). Therefore, the shift towards smarter, more sustainable, and environmentally friendly farming systems has become an urgent necessity, not merely a supplementary option (Al-totonjy et al,. 2024; Al-Dahi et al., 2026). In this context, Integrated Nutrient Management (INM) has emerged as a promising approach for achieving both productive and environmental sustainability. This approach relies on the balanced application of organic, mineral, and biological nutrient sources to improve soil fertility, increase fertilizer use efficiency, and reduce environmental losses (Al-Dahi et al., 2026; Bharali et al., 2017). Among the most important organic components that have garnered increasing attention in recent research are humic acids, which have been to improve soil physical structure, increase its water and nutrient retention capacity, and stimulate root and plant growth through plant hormone-

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like effects (El-Ghamry & Mosa, 2023; Irani Takleh et al., 2025). In parallel, macronutrients (nitrogen, phosphorus, and potassium) play a pivotal role in determining crop yield; however, their effectiveness is significantly enhanced when combined with organic matter, which acts as a precursor to their absorption. As for micronutrients (such as zinc, iron, selenium, and iodine), their importance is no longer limited to quantitative productivity only, but has extended to include the nutritional quality of grains, as more than two billion people around the world suffer from "hidden hunger" resulting from a lack of these elements in grain-based diets (Prasad et al., 2024; Ram et al., 2024). However, the response of different wheat varieties to these types of nutrients varies considerably depending on the genetic makeup of each variety, soil conditions, climate, and application method (foliar spraying or soil application). Some varieties may respond well to humic acid under drought conditions, while others exhibit higher efficiency in micronutrient uptake and conversion to grain (Ahmed et al., 2024; Bakry et al., 2016). Therefore, identifying the best integrated practices suitable for each variety individually presents a significant research and application challenge. this study aims to enhance the sustainable production of certain bread wheat varieties by applying different types of nutrients (Humic, fulvic, macronutrients, micronutrients, and combinations thereof), and to evaluate impact of these applications on growth traits, yield components, final yield, and some nutritional quality indicators. The study also analyzes the interactions between varieties and nutrient types to provide practical field recommendations applicable to sustainable farming systems. A study by Ahmed et al. (2024) to effect of six humic acid levels (from 4.5 to 14.5 kg/ha) on wheat in an arid climate. results showed that highest level (14.5 kg/ha) resulted in a 22% increase in plant height, a 157% increase in spike weight, a 93% increase in the number of grains. Spike^{-1}, and 49.36% increase in grain yield compared to the control treatment. A study by Kumar et al. (2023) applied an integrated nutrient management system to wheat (variety K-1006) for two yspikes, combining chemical fertilizer with organic fertilizer. The highest values were recorded for plant height, number of tillers. m², leaf area index (LAI), spike length, and biological yield. In a study by Bakri et al. (2016), humic acid (20 mg. L^{-1}) and 4 levels of chelated zinc (0, 1.5, 3, and 4.5 g. L^{-1}) were applied to two wheat cultivars, (Seds-1 and Seds-13). highest zinc level (4.5 g. L^{-1}) yielded the best results for all studied traits. The triple interaction (Seds-13 + humic acid 20 mg. L^{-1} + zinc 4.5 g. L^{-1}) resulted in the highest values for grain yield. Spike^{-1}, biological yield, grain yield, and protein content. Prasad et al. (2024) analyzed the relationship between yield traits and micronutrient content in the F2 generation of wheat. Path analysis showed that the number of grains per spike and chlorophyll content were the traits most positively correlated with yield.

II. Materials and Methods

experiment was to be implemented in the Nimrud district/ Mosul during 2025 season. This study included two factors: first, three wheat varieties (Arabia, Benko, and Pharaonia); and second, five types of fertilization (humic acid, amino acids, neutral NPK, a mixture of fertilizers, and a control treatment) to compare the varieties, fertilization types, and their interactions. land was to be equipped and divided into equal experimental units of 2 m² each. Irrigation was based on rainfall, with supplemental irrigation as needed. The planting process was carried out in rows, with a distance of 15 cm between each row. Fertilizers were added by spraying them on the leaves after a month and a half of germination. experiment was carried out using a randomized complete block design (RCBD) with two factors: first factor being varieties of broad beans, and the second factor being the types of fertilization, with three replicates. The experiment included 45 experimental units, in which the fertilizers were randomly distributed according to each variety, and comparisons were made between the means using the Duncan multi-range method.

III. Results and Discussion

Plant Height (cm) :Table (1) shows a significant effect of study factors on plant height. highest significant value for this trait was obtained with Pharaonia variety, reaching 134.84 cm, compared to the Arabian and Benko varieties, which were 71.01 cm and 71.73 cm, respectively. This may be attributed to the genetic factor specific to each variety and its interaction with environmental factors, which is consistent with (Prasad et al., 2024; Ram et al. 2025). The type of fertilizer had a significant effect on plant height. highest plant, 97.88 cm, was observed with mixed fertilizer treatment, compared with the control and other treatments. This may be attributed to supplying plant with all necessary nutrients through mixing fertilizers, which positively

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impacted stem cell division and elongation. This is consistent with Lodhi et al. (2024). results also indicate a significant two-way interaction between the study factors. The highest plant height was recorded when Pharaonia variety was treated with any fertilization, reaching 135.85 cm, 135.38 cm, 135.39 cm, and 140.84 cm, respectively, while the lowest significant value was recorded in the control treatment, at 126.75 cm.

Table (1) Effect of variety and fertilizer type in plant height (cm).

varieties	Type fertilization					Effect of varieties
	control	Humic	Amino acids	N.P.K	Mixture	
Arabia	64.65ed	72.33cd	70.95cd	75.88 c	75.88 c	71.01b
Benko	62.84 e	73.06 cd	72.22 cd	73.63 c	76.93 c	71.73 b
Pharaonia	126.75 b	135.85 a	135.38 a	135.39 a	140.84 a	134.84 a
Effect of Fertilization	84.75 c	93.74 ab	92.85 b	93.41 ab	97.88 a	

Values followed by identical letters do not differ significantly from each other at a probability level of 0.05.

Flag Leaf Area (cm²):

results in Table (2) indicate a significant effect of study factors on the flag leaf area trait. The highest significant value for this trait was obtained in Pharaonia wheat variety, reaching 35.98 cm², compared to the other varieties. This may be attributed to the influence of the genetic factor and its responsiveness to environmental conditions, which aligns with Prasad et al. (2024). Furthermore, there is a significant effect of different fertilization types. The largest leaf area, 38.15 cm², was obtained using the mixed fertilizer treatment. This superiority may be due to the availability of a fertilizer mixture that provides all the necessary and essential nutrients the plant needs, including organic matter, micro- and macro-elements, and amino acids simultaneously. This led to an increase in the size of the vegetative mass, including the flag leaf area, which is consistent with (Prakash et al. 2025). results also indicate a significant bilateral interaction between the factors. highest values for flag leaf area were obtained when the three varieties (Arabian, Benko, and Pharaonia) were treated with the fertilizer mixture, reaching 38.58 cm², 37.34 cm², and 38.58 cm², respectively**.**

Table (2) Effect of variety and fertilizer type in flag leaf area (cm^2).

varieties	Type fertilization					Effect of varieties
	control	Humic	Amino acids	N.P.K	Mixture	
Arabia	28.53 d	33.66a-d	32.75a-d	33.38a-d	38.58 a	33.37 b
Benko	27.76 d	32.24 bcd	30.79 cd	33.36 a-d	37.34 ab	32.30 b
Pharaonia	30.43 d	37.43 ab	36.50 abc	36.98 ab	38.58 a	35.98 a
Effect of Fertilization	28.91 c	34.4b	33.35 b	34.57b	38.15 a	

Values followed by identical letters do not differ significantly from each other at a probability level of 0.05.

Number of Branches per Plant: Table (3) shows a significant effect of experimental factors on number of branches per plant. The highest significant value for this trait was observed in the Benko variety, reaching 8.52 branches per plant. This may be attributed to genetic makeup of this variety, its strong response to environmental conditions during growth stages, and its vigorous growth, which enabled it to produce the largest number of branches. This aligns with findings of (Prasad et al. 2024). Furthermore, the variety of fertilizers significantly influenced the number of branches. Plant^{-1}, with highest number of branches (8.29) obtained from the fertilizer mixture treatment. Plant^{-1}. This may be attributed to complementarity between fast and slow nutrient release. Chemical fertilization (NPK) provides nutrients quickly and readily, offering an immediate growth boost, while organic fertilizers release nutrients slowly and gradually through

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decomposition. This provides sustained nutrition for a longer period and contributes to hormonal balance, increasing the number of basal branches in the plant. This aligns with Kaur et al. (2023). The dual intervention of experimental factors significantly affected the number of branches, with the highest number of branches per plant (10.43) obtained when the Benko variety was treated with a fertilizer mixture. Plant^{-1}.

Table (3) Effect of variety and fertilizer type in number of branches. Plant^{-1}.

varieties	Type of fertilization					Effect of varieties
	control	Humic	Amino acids	N.P.K	Mixture	
Arabia	4.38 f	6.00 de	4.93 ef	5.63 e	6.92 cd	5.57 c
Benko	7.04 cd	9.00 b	7.49c	8.86 b	10.23 a	8.52 a
Pharaonia	5.42ef	6.94 cd	6.09 de	6.94 cd	7.72 c	6.62 b
Effect of Fertilization	5.61 c	7.31 b	6.17c	7.14 b	8.29 a	

Values followed by identical letters do not differ significantly from each other at a probability level of 0.05.

Number of spikes. m^{-2}

varieties	Type fertilization					Effect of varieties
	control	Humic	Amino acids	N.P.K	Mixture	
Arabia	288.87 d	355.91 ab	332.32 c	343.92bc	363.19 a	336.84 a
Benko	199.01 f	215.61ef	207.97ef	213.51ef	218.18 e	210.85 b
Pharaonia	147.68 h	172.55 g	161.34 hg	168.84 g	177.26 g	165.53 c
Effect of Fertilization	211.85 d	248.02 ab	233.88 c	242.09 bc	252.87a	

Table (4) Effect of variety and fertilizer type in number of spikes. m^{-2}

The results in Table (4) indicate a significant effect of study factors on trait of number of spikes. M^2, as highest number of spikes was obtained for the Arabia wheat variety, which amounted to 336.84 spikes The number of spikes per square meter (m^{-2}) may be attributed to the influence of genetic factors, the genetic makeup of the variety, the formation of effective tillers that produce and retain spikes until harvest, and the variety's efficiency in distributing carbohydrates uniformly. This aligns with Prasad et al. (2024). Furthermore, type of fertilizer used significantly affected number of spikes m^2. highest significant value for this trait was obtained with the mixed fertilizer treatment, reaching 252.87 spikes per square meter (m^{-2}), compared to other treatments. This may be due to the integration of nutrient sources. Chemical fertilizers provide readily available elements for the plant, especially nitrogen, which is responsible for tillering and vegetative growth. Humic and fulvic acids act as natural reservoirs, releasing elements gradually and reducing loss. Consequently, the plant receives a continuous and balanced supply during the critical tillering stage, resulting in a higher number of spikes. M^2. This aligns with Khalil et al. (2023). The interaction of the two study factors significantly affected number of spikes. M^2, resulting in highest the significant value of this trait in the Arabiaa variety, under the mixing treatment, reached 363.19 spikes.m^{-2}.

Values followed by identical letters do not differ significantly from each other at a probability level of 0.05.

Number of Seeds. Spike^{-1}

results in Table (5) indicate significant effect of factors used in study on the number of seeds per spike. The highest significant value for this trait was obtained with Pharaonia variety, reaching 113.95 seeds per spike, compared to other varieties. This may be attributed to the genetic factor and its suitability to the

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environmental conditions, as this variety has large spikes. It may also be due to the efficiency of this variety in photosynthesis, resulting from the large flag leaf area, which this variety surpassed in comparison to the other varieties, reaching 35.98 cm². This leads to a greater supply of nutrients to the spike. The increase may also be due to hormonal balance, which encourages the plant to increase the number of flowers and florets within the spike and improve grain fixation. This aligns with findings of (Ram et al., 2025; Prasad et al., 2024). results also show that type of fertilization has a significant effect on number of seeds. Spike^{-1}, as treatment of mixing different fertilizers yielded the highest significant value. This trait, which reached 71.07 seeds per spike^{-1}, may be attributed to complementary effect of the fertilizer mixtures. Humic acid increases membrane permeability and improves nutrient availability, while fulvic acid enhances the transport of

varieties	Type of fertilization					Effect of varieties
	control	Humic	Amino acids	N.P.K	Mixture	
Arabia	46.02c-f	49.66 c	47.86 cd	49.16 cd	51.32 c	48.80 b
Benko	38.60 g	41.00 efg	39.72 fg	40.48 fg	42.49 d-g	40.46 c
Pharaonia	103.44 b	117.62 a	113.18 a	116.12 a	119.39 a	113.95a
Effect of Fertilization	62.69 c	69.43ab	66.92 b	68.59 ab	71.07 a	

absorbed nutrients. This leads to increased nutrient absorption efficiency, including NPK and micronutrients, and consequently, an increased number of seeds. Spike^{-1}. This aligns with (Roy et al. 2025). secondary interaction between experimental factors significantly affected number of seeds. Spike^{-1}. highest significant values for this trait were obtained when Pharaonia variety was treated with all types of fertilizers used in the experiment, resulting in 117.62, 113.18, 116.12, and 119.39 seeds per spike^{-1}, respectively, compared to control treatment, which yielded lowest value of 103.44 seeds per spike.

Table (5) Effect of variety and fertilizer type in Number of Seeds. Spike^{-1}.

Values followed by identical letters do not differ significantly from each other at a probability level of 0.05.

biological yield (kg. ha^{-1})

Table (6) shows a significant effect of experimental factors on biological yield. The highest biological yield, at 13308.3 kg. ha^{-1}, was obtained with the Pharaonia variety, compared to other varieties. This is attributed to the superior plant height (134.84 cm), flag leaf area (35.98 cm²), and number of seeds per spike (113.95) of this variety. As can be seen in Tables (1, 2, 5), this may be attributed to genetic factor of this variety and its strong response to environmental conditions during growth stages, as well as its vigorous growth which enabled this variety to produce the largest vegetative mass through efficient photosynthesis and increased nutrient storage in plant parts. This is consistent with (Ram et al., 2025; Prasad et al., 2024). Furthermore, the types of fertilizers used in the study had a significant effect on the biological yield trait, as the highest significant value for this trait was obtained with the mixed fertilizer treatment, reaching 9632.9 kg. The superiority of the fertilizer mixing treatment in all the aforementioned growth traits is attributed to its positive impact on the biological yield. This may be due to the integrated provision of nutrients to the plant, which aligns with Roy et al. (2025). significant two-way interaction of the experimental factors was observed, as the highest significant value for biological yield was obtained with the Pharaonia variety treated with the fertilizer mixing treatment, reaching 14376.5 kg ha^{-1}, compared to the other treatments and the control.

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Table (6) Effect of variety and fertilizer type in biological yield (kg. ha⁻¹).

varieties	Type fertilization					Effect of varieties
	control	Humic	Amino acids	N.P.K	Mixture	
Arabia	2874.83 b	3226.20 a	3200.20 a	3223.53 a	3249.97 a	3154.95 a
Benko	1762.70 e	1902.03 e	1825.73 e	1906.83 e	1929.27 e	1865.31 c
Pharaonia	1903.83 e	2402.57 c	2239.30 d	2334.73 cd	2443.07 c	2264.57 b
Effect of Fertilization	2180.23 c	2510.27 ab	2421.74 b	2488.37 ab	2540.77 a	

Values followed by identical letters do not differ significantly from each other at a probability level of 0.05.

varieties	Type of fertilization					Effect of varieties
	control	Humic	Amino acids	N.P.K	Mixture	
Arabia	6623.1 e	7870.6 d	7885.5 d	8030.7 d	8144.9 d	7711.0 b
Benko	5624.4f	6352.5 e	6181.2 e	6348.4 e	6377.4 e	6176.8 c
Pharaonia	11902.8 c	13642.6 b	13291.9 b	13328.0 b	14376.5 a	13308.3 a
Effect of Fertilization	8050. 1 c	9288.5 b	9119.6 b	9235.7 b	9632.9 a	

Grain yield (kg. ha⁻¹): results in Table (7) indicate a significant effect of the studied factors on grain yield. highest significant value for this trait was obtained with Arabiya variety, reaching 3154.95 kg ha⁻¹. This is attributed to superiority of this variety in number of spikes. M^2, which reached 336.84 spikes. M^{-2}, as shown in Table (4), may be attributed to genetic factors of this variety and its suitability to environmental conditions during growth stages, as well as its vigorous growth, which enabled it to produce a larger number of spikes. This positively impacted grain yield through increased photosynthetic efficiency and enhanced nutrient storage in the spikes and seeds, consistent with Ram et al. (2025). Furthermore, the type of fertilization significantly affected grain yield. The mixed fertilizer treatment resulted in a significantly higher yield of 2540.77 kg. This is due to the superiority of this treatment in all studied traits, which was reflected positively in the quantity of yield. This may be attributed to the complementary effect of mixing the fertilizers, as humic fertilizer increases membrane permeability and improves nutrient availability, while fulvic acid improves the transport of absorbed elements. This led to increased efficiency in nutrient absorption, including NPK and micronutrients, increasing the number of spikes per square meter, then an increase in the number of seeds per spike, and finally an increase in seed yield per unit area. This is consistent with (Kantilal and Meenakshi, 2021; Al-Jubouri, 2026). The two-way interaction of experimental factors had a significant effect on the quantity of yield. The highest significant value for this trait was obtained when the Arabiya variety was treated with all types of fertilizers, as they did not differ significantly from each other, while they significantly outperformed the control treatment.

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Table (7) Effect of variety and fertilizer type in Grain yield (kg. ha⁻¹).

Values followed by identical letters do not differ significantly from each other at a probability level of 0.05.

Harvest Index %: The results in Table (8) indicate a significant effect of the study factors on harvest index. highest harvest index % was obtained with Arabiya variety, reaching 41.07%. This is attributed to the superiority of the Arabiya variety in number of spikes per square meter (Table 4) and yield quantity (Table 7), which were 336.84 spikes. m² and 3154.95 kg. ha², respectively. The biological yield was low for this variety, as shown in Table (6). An increase in grain yield coupled with a decrease or stagnation in the biological yield leads to an increase in the harvest index percentage. type of fertilizer did not have a significant effect on harvest index %, either among different variables or with the control treatment. However, the interaction between experimental factors had a significant effect on harvest index %. highest significant value for this trait was obtained with Arabiya variety, but only with control treatment, reaching 43.69%.

Table (8) Effect of variety and fertilizer type in Harvest Index %.

varieties	Type fertilization					Effect of varieties
	control	Humic	Amino acids	N.P.K	Mixture	
Arabia	43.69 a	41.02 ab	40.60 ab	40.14 b	39.90 b	41.07 a
Benko	31.38 c	29.98 c	29.55 c	30.07 c	30.23 c	30.24 b
	16.06 d	17.61 d	16.85 d	17.51 d	16.99 d	17.01 c
Effect of Fertilization	30.37 a	29.54a	29.00 a	29.24 a	29.04 a	

Values followed by identical letters do not differ significantly from each other at a probability level of 0.05.

Protein Percentage %: Table (9) shows that there is no significant effect of the different varieties used in the study on the protein percentage. However, the type of fertilization had a significant effect on this trait, as the highest significant value was obtained with the mixed fertilizer treatment, reaching 11.63%. This superiority may be attributed to the availability of all the necessary nutrients, which led to increased protein synthesis in the seeds. This is consistent with (Roy et al., 2025; Al-Jubouri, 2026). Similarly, interaction of two factors used in study had a significant effect on protein percentage trait. highest percentage of protein was obtained with Arabiya variety treated with mixed fertilizer treatment, reaching 11.84%, although it did not differ significantly with some other treatments.

Table (9) Effect variety and fertilizer type on Protein Percentage %.

varieties	Type fertilization					Effect of varieties
	control	Humic	Amino acids	N.P.K	Mixture	
Arabia	9.98 d	11.43 ab	11.45 ab	11.34 ab	11.84 a	11.21 a
Benko	10.35 cd	11.39 ab	11.36 ab	11.02abc	11.36 ab	11.09 a
Pharaonia	9.95 d	11.27abc	11.03abc	10.84bcd	11.71 ab	10.96 a
Effect of Fertilization	10.09 c	11.36 ab	11.28 ab	11.07 b	11.63 a	

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Gluten Percentage %: results in Table (10) showed a significant effect of experimental factors on the gluten percentage in the grains. highest percentage of this trait was obtained with the Arabiya variety, reaching 32.22%, compared to other treatments. This may be due to superiority of this variety in most other traits, indicating that it is more efficient in photosynthesis and utilization of available nutrients, in conjunction with the prevailing environmental conditions in the region. This agrees with Kantilal and Meenakshi (2021). The type of fertilization had a significant effect on the gluten trait, as the highest significant values for this trait were obtained with fertilization using seaweed extract and with the mixing treatment, reaching 31.85% and 31.80%, respectively. This may be due to the complementary effect of mixing fertilizers, as humic acid increases membrane permeability and improves nutrient availability, while fulvic acid improves the transport of absorbed nutrients. This agrees with El-Ghamry and Mosa. (2023) The interaction between the experimental factors had a significant effect on gluten content in seeds. highest and most significant percentage was obtained when the Arabiya variety was treated with all fertilizers used in experiment. These fertilizers did not differ significantly from each other but outperformed control treatment.

Table (10) Effect of variety and fertilizer type in Gluten Percentage %.

varieties	Type fertilization					Effect of varieties
	control	Humic	Amino acids	N.P.K	Mixture	
Arabia	29.17 e	33.43 a	32.62 a	32.41 ab	33.48 a	32.22 a
Benko	30.04 de	32.06abc	30.98bcd	30.90 cd	32.31abc	31.26 b
Pharaonia	28.97 e	30.06 de	29.47de	28.95 e	29.61 de	29.41 c
Effect of Fertilization	29.39 d	31.85 a	31.02 bc	30.75 c	31.80 ab	

Values followed by identical letters do not differ significantly from each other at a probability level of 0.05.

IV. Conclusions:

1- Arabiya variety showed the best response to the fertilizers used in the experiment, as evidenced by its superior performance in number of spikes. M^2 and grain yield.

2- Fertilizer mixing treatment was the most effective, as it had a positive and significant impact on most of the studied traits.

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