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EFFECT OF INORGANIC FERTILIZER COMBINATION AND FOLIAR APPLICATION OF ORGANIC NUTRIENT ON GROWTH AND YIELD TRAITS OF MAIZE

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SUMMARY

The recent maize experiment commenced in the 2022 fall crop season at the District Al-Hussainiya, Kerbala, Iraq. The experiment comprised two factors, with the first factor a combination of different levels of nitrogen (0, 150, and 300 kg N ha^{-1}) with corresponding labels, N_0, N_1, and N_2, respectively, and three levels of potassium (0, 80, and 160 kg K ha^{-1}) symbolized as K_0, K_1, and K_2, respectively. The second factor was a foliar application of organic nutrients (potassium humate) with two concentrations (1 and 2 g L^{-1}). The organic nutrient application occupied the main plots, while the inorganic fertilizer combinations were in the subplots. The experiment used the maize cultivar 'Sumer,' planted in clay mixed soil in a randomized complete block design (RCBD) with a split-plot arrangement and three replications. The results showed a significant effect of adding fertilizer combinations of nitrogen and potassium and foliar application of the organic nutrient potassium humate (2 g L^{-1}) individually and in combinations in most growth, yield, and quality-related traits. The combination of inorganic and organic fertilizers also revealed a significant superiority in enhancing the plant height, number of leaves, ear length, grain rows per ear, grains per row, grain yield, and the percent oil and protein in the maize grains. The interaction between the two study factors contributed to reducing the used amount of mineral fertilizer to 50%, as there was no significant difference between the fertilizer combinations of nitrogen and potassium 150 N + 80 K and 300 N + 160 K kg ha^{-1} in addition with organic nutrient application at the rate of 2 g L^{-1}.

Keywords: maize ***(****Zea mays* L.), fertilizer combination, nitrogen and potassium, organic nutrient, potassium humate, growth and yield traits

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Key findings: A significant improvement in growth, yield, and quality traits of maize resulted from fertilizer combinations of nitrogen and potassium (N_1K_1 and N_2K_2) combined with foliar application of organic nutrients (potassium humate) at the rate of 2 g L^{-1}.

INTRODUCTION

Zea mays L. is a cereal crop of great importance and has the third position after wheat and rice crops, and its production is in continuous development worldwide (Kandil, 2013). Economical crops, including maize, always need nutrients in equal amounts for plant growth and development. Nitrogen, phosphorus, and potassium are the macro-nutrients plants require in relatively large quantities, and their deficiency has a detrimental effect on growth and productivity (Ali *et al*., 2014). Therefore, as and when the level of these nutrients in the soil decreases as a result of depletion by the plant, stabilization in the soil, and washing outside the root zone, these macro-nutrients require adding to the soil to obtain sustainable growth, development, and high productivity (EL-Shal, 2016).

The worldwide increase in the population may reach 9.7 billion by 2050 (Desa, 2017), and to combat the food shortage, high-productivity cultivars characterized by depleting fertilizer (NPK), causing the need to provide fertilizers at high rates to increase food production, especially in developing countries. In farming, the low rate of net return has led to the emergence of a global problem due to unbalanced fertilization and the wrong use of agricultural practices (Lira-Saldivar *et al*., 2013). Mineral fertilization has a prime role in increasing nutrient readiness, as it works to enhance the total grain yield (Hasan and Saad, 2020). Crops are the most consuming commodity that absorbs mineral fertilizers since they may consume 22.5% of the total nitrogen, phosphorus, and potassium fertilizers (Heffer *et al*., 2013).

Maize production incurs most effects from poor soil fertility that requires the addition of fertilizers to meet the crop's nutrient requirements (Nanganoa *et al*., 2020). Nitrogen is one of the most essential macro-elements that limit maize production (Baral and Adhikari, 2015). It is also the most necessary element in many field crops, as it works to produce protein and nucleic acids, which are the most crucial molecules used in various physiological processes of crop plants (Mahmoud, 2017). Potassium is also an essential nutrient for field crops, with several positive effects on plants, such as its role in processing carbon metabolism, activating enzymes, and developing resistance to diseases and insects (EL-Shal, 2016). The fertilizers needed by the crop plants vary according to the type and variety of the plant, as well as the stage of plant growth, the fruits produced, and the grain quality formed (Ali *et al*., 2014).

Using organic matter is one of the alternative methods to boost vegetative growth and increase the productivity of maize and other crops (Gao *et al*., 2020). Organic matter may directly or indirectly impact crop growth and production by improving the physical properties of the soil, which contributes to improving the root environment, leading to increased plant growth and development (Iqbal *et al*., 2014). Organic material contains a massive group of plant nutrients that directly and indirectly contribute to increased plant progress and maturation by containing elements needed by the plant and affect the readiness of the nutrients found in the soil as it works to increase crop production with better quality. Plant nutrients are vital to plant buildup by containing different elements beneficial to plants that contribute to forming amino acids involved in creating proteins and regulating osmotic pressure (King *et al.*, 2020).

Potassium humate serves as a biocatalyst to improve the soil's physical, chemical, and biological properties, such as organic matter content, water-holding capacity, crop growth stimulation, nutrient uptake increase, and enhanced plant resistance to various stress conditions (Mora *et al*., 2014). In crop plants, its foliar application increases plant resistance to stress conditions, such as plants grown under salinity pressure and water retention capacity (Ameen *et al*., 2019). Potassium humate has a chief role in boosting the process of carbon metabolism, reducing the activity of antioxidant enzymes (peroxidase and catalase), biosynthesis, and ascorbic acid, in addition to synthesizing proteins and carbohydrates in the grains produced, stimulating crop growth, increasing nutrient absorption, and enhancing plant resistance to stress conditions (Osman *et al*., 2017). Abou-Basha *et al*. (2021) explained that spraying with potassium humate on maize at a concentration of 4 g L^{-1} gave the highest significant increase in the traits, such as 1000-grain weight, biological, and grain yields, compared with the control treatment that gave the lowest averages for these traits. Given the importance of the agricultural product and its increasing demand for high-quality and safer food, the pertinent study sought to reduce the amount of nitrogen and potassium fertilizers by interfering with the foliar application of organic nutrient (potassium humate) to find the best fertilizer combination with a positive impact on the growth, yield, and quality of maize.

MATERIALS AND METHODS

Experimental procedure and crop farming

The latest maize experiment commenced in the 2022 fall crop season at the District Al-Hussainiya, Kerbala, Iraq. The experiment comprised two factors, namely, a combination of different nitrogen levels (0, 150, and 300 kg N ha^{-1}) and potassium (0, 80, and 160 kg K ha^{-1}) fertilizers, and the second was the foliar application of organic nutrient (potassium humate) with two concentrations (1 and 2 g L^{-1}). The organic nutrient application occupied the main plots, while the inorganic fertilizer combinations were in the subplots. The experiment using the maize cultivar 'Sumer' in clay loam soil had a randomized complete block design (RCBD) with a split-plot arrangement and three replications (Table 1). Chemical and physical properties assessment of the study soil at a depth of 0–30 cm before maize planting occurred.

Before the experiment, soil preparation included plowing, smoothing, and leveling operations, and then the soil's division into three replications, with each replicate containing 18 experimental units, thus, the total number of experimental units was 54 with dimensions of 3 m^2 × 3 m^2. A space of one meter occurred between the experimental units within one replicate. Placing two or three seeds per hill ensued at the planting depth of 3-5 cm, keeping the rows and plants spacing at 75 cm and 25 cm, respectively, with a plant density of 53333.33 plants ha^{-1}. The irrigation followed immediately after the planting process, and the crop's continuous irrigation during the growing season ran as needed. The weeding process transpired manually within the season to remove the weed plants.

Table 1. Chemical and physical properties of the study soil at a depth of 0–30 cm before maize planting.

Properties		Values
pH		7.2
EC (1:1)		2.68 ds m^{-1}
OM		1.41 g kg^{-1}
N available		30.44 mg kg^{-1}
K available		28.2 mg kg^{-1}
P available		10.8 mg kg^{-1}
Soil separators	Sand	250 G kg^{-1}
	Silt	360 G kg^{-1}
	Clay	390 G kg^{-1}
Texture		Clay loam

Table 2. The composition of the potassium humate.

Properties	Values
pH	9 – 11
Humic and Fulvic acid	85%
Potassium (K_2O)	10% – 12%
Water Solubility	99.8%
Moisture	15%
Appearance	Black Shiny Flakes
Classification	Organic Fertilizer

Fertilization proceeded with mono-superphosphate fertilizer (19% P_2O_5) as a source of phosphorus, with the addition made in one batch when planting for all treatments. The first factor included fertilizer combinations of nitrogen and potassium, urea fertilizer (46% N), and potassium sulfate (50% K_2O) as sources of nitrogen and potassium, respectively. Three levels of nitrogen (0, 150, and 300 kg N ha^{-1}) received labels, N_0, N_1, and N_2, respectively, and three levels of potassium (0, 80, and 160 kg K ha^{-1}) attained symbols as K_0, K_1, and K_2, respectively, with their addition in two split batches. The first dose was a week to 10 days after germination, and the second dose application was during the beginning of the formation of silk threads.

The second factor was the organic nutrient (potassium humate) added as a foliar spray on the plants with two concentrations (1 and 2 g L^{-1}). The foliar application also ensued in two stages, i.e., the first spray at the 6 to 8 true leaves stage, while the second spray was during the appearance of male inflorescences. The study used a manual sprayer with a dorsal capacity of 16 liters to conduct a foliar application of organic nutrients. The spraying process ran in the early morning with complete wetness of the plants and to avoid high temperatures. Spraying the control treatment (with water only) and using a diffuser (bright cleaning solution) helped reduce the surface tension of the water and ensured complete wetness of the leaves to increase the efficiency of the spray solution. The composition of the potassium humate is available in Table 2.

Data recorded

In each experimental unit for the plant's dry weight, drying the vegetative parts of the plants from each treatment ran in an electric oven at a temperature of 105 °C for 2 h and then at a temperature of 60 °C for 48 h (Horwitz, 1975). The other plant traits studied came from an average of five randomly selected plants from each experimental unit. Measurement for plant height began from the soil surface to the lower node of the male inflorescence. The number of leaves per plant, ear length (cm), rows per ear, grains per row, and grain yield (t ha^{-1}) calculations followed the method according to Al-Mohammadi (1990). The percentage of oil and protein in the grains' measurement relied on the A.O.A.C (1980).

Statistical analysis

Analyzing the data was according to the analysis of variance (ANOVA) as per RCBD with a split-plot arrangement (Gomez and Gomez, 1984). The least significant difference ($LSD_{0.05}$) test compared and separated the mean differences. The statistics software GenStat12 ran the analysis.

RESULTS

According to the analysis of variance, fertilizer combinations, organic nutrient (potassium humate) concentrations, and interactions of fertilizer combinations by organic nutrients showed significant ($P \leq 0.05$) differences for most traits (Table 3).

Plant height

The results indicated that the maize plant height increased significantly with enhancement in the levels of nitrogen and

Table 3. Analysis of variance with two factors (potassium humate and combination of nitrogen and potassium fertilizers), and their interaction for various traits in maize.

Source of variation	d.f.	Plant height (cm)	Leaves plant^{-1}	Ear length (cm)	Rows ear^{-1}	Grains row^{-1}	Grain yield (tons ha^{-1})	Grains oil (%)	Grains protein (%)
Replications	2	3381.00	37.68234	45.5630	39.8608	68.7021	21.92334	10.67467	10.83355
Potassium humate	1	1063.47*	6.16782*	33.8438*	6.9840**	68.5914**	13.1424**	4.8121^{NS}	6.77344*
Error A	2	3.03	0.05174	0.1745	0.0025	0.10618	0.00082	0.52281	0.25152
Fertilizer Combination	8	717.44 **	13.2886**	18.3049**	7.56637**	27.0508**	17.4861**	1.61976**	11.31217**
Potassium humate × fertilizer combination	8	25.10*	0.40165**	0.3357*	0.1888**	0.82058**	0.6765**	0.28162**	0.12598*
Error B	32	10.44	0.02415	0.1079	0.01044	0.08264	0.0553	0.06046	0.04083

Table 4. Effect of spraying with potassium humate and the combination of nitrogen and potassium fertilizers on the plant height.

Fertilizer combination	Potassium humate concentration (g L^{-1})		Means (cm)
	1	2	
N_0K_0	143.99	147.02	145.50
N_0K_1	151.36	155.44	153.40
N_0K_2	153.43	161.34	157.38
N_1K_0	154.65	162.38	158.51
N_1K_1	165.07	181.63	173.35
N_1K_2	167.01	177.39	172.20
N_2K_0	157.47	166.28	161.87
N_2K_1	169.29	181.80	175.55
N_2K_2	171.23	180.12	175.67
Means (cm)	159.28	168.15	

$LSD_{0.05}$ Fertilizer combination: 3.80, Potassium humate concentration: 2.04, Fc × Ph Interactions: 5.14

potassium and their combinations (Table 4). The fertilizer combination N_2K_2 provided the highest average plant height (175.67 cm). However, it did not differ significantly from three other fertilizer combinations (N_1K_1, N_1K_2, and N_2K_1), which amounted to 173.35, 172.20, and 175.55 cm, respectively. The above promising fertilizer combination (N_2K_2) significantly outperformed the rest of the treatments with an increase of 21.00% compared with the control treatment (N_0K_0), which amounted to 145.50 cm in maize crops.

Results further revealed a significant difference in the average plant height by spraying maize plants with the organic nutrient (potassium humate) (Table 4). The organic nutrient at the concentration of 2 g L^{-1} showed the highest average plant height (168.15 cm), with an increase of 6.00% compared with the organic nutrient (1 g L^{-1}), which gave the lowest average plant height (159.28 cm).

The interaction between the two study factors significantly affected increasing the plant height (Table 4). The interaction treatment (N_2K_1 × organic nutrient at the rate of 2 g L^{-1}) achieved the utmost value of plant height (181.20 cm), which was considerably superior to all other treatments except the interaction treatments (N_1K_1, N_1K_2, and N_2K_2 × organic nutrient at the rate of 2 g L^{-1}), amounting to 181.63, 177.39, and 180.12 cm, respectively, and nonsignificant difference. The interaction treatment (N_0K_0 × organic nutrient at the rate of 1 g L^{-1}) was notable at the lowest plant height (143.99 cm).

Leaves per plant

The results enunciated that the fertilizer combination N_2K_2 showed a significant superiority by giving the maximum average number of leaves per plant (15.61 leaves plant^{-}

^{1}) (Table 5). However, the said combination was nonsignificantly different from the fertilizer combination N_2K_1 (15.56 leaves plant^{-1}) and proved substantially superior to the rest of the fertilizer combinations. Fertilization with an increased rate showed 43.43% and 42.88% boost in leaves per plant compared with the control treatment (N_0K_0) (10.89 leaf plant^{-1}).

With a foliar application of organic nutrient (potassium humate) on maize plants at the rate of 2 g L^{-1}, the highest average value emerged (14.58 leaves plant^{-1}), compared with the same compound at a concentration of 1 g L^{-1}, recording the lowest average for the said trait (13.91 leaf plant^{-1}), with the percentage increase was 4.81% (Table 5). As for the interaction between the fertilizer combinations of nitrogen and potassium and the application of the organic nutrient (potassium humate), the interaction treatment (N_2K_1 × organic nutrient at the rate of 2 g L^{-1}) achieved the maximum number of leaves per plant (15.66 leaves plant^{-1}), which was significantly superior to all other interaction treatments except the interactions N_1K_1, N_1K_2, and N_2K_2 × organic nutrient at the rate of 2 g L^{-1}, which amounted to 15.62, 15.57, and 15.63 leaves plant^{-1}, sequentially. The control treatment (N_0K_0 × organic nutrient at the rate of 1 g L^{-1}) was distinct with the minimum value for the said trait (10.49 leaves plant^{-1}).

Ear length

Results revealed that, in maize plants, the ear length significantly increased with the enhancement in mineral fertilization levels and their combinations (Table 6). The fertilizer combination N_2K_2 showed the highest average ear length of 19.88 cm; however, it did not differ significantly from three other fertilizer combinations (N_1K_1, N_1K_2, and N_2K_1), which amounted to 19.65, 19.74, and 19.84 cm, respectively. Although, it was significantly superior to the rest of the treatments, with an increase rate of 27.36% in ear length, compared with the control treatment (N_0K_0), which amounted to 15.61 cm.

A significant difference and improvement was evident in the average ear length of maize plants by spraying with the organic nutrient (potassium humate) at a rate of 2 g L^{-1}, which showed the highest ear mean (18.90 cm), with an increase of 9.13% compared with the low concentration at a rate of 1 g L^{-1} (17.32 cm) (Table 6). The interaction between the two factors (mineral fertilizers and organic nutrient) of the study significantly affected the enhancement of ear length, and the interaction treatment (N_1K_1 × organic nutrient 2 g L^{-1}) achieved the foremost value for the said trait in maize plants (20.75 cm), which was considerably superior to all other treatments except N_1K_2, N_2K_1 and N_2K_2 × organic nutrient 2 g L^{-1}, which amounted to 20.71, 20.73, and 20.70 cm, respectively. However, in the interactions, the control treatment (N_0K_0 × organic nutrient 1 g L^{-1}) gave the lowest value of ear length (15.27 cm).

Rows per ear

The significant superiority of the fertilizer combination N_2K_2 was valid with the utmost average number of rows per ear, numbering 16.45 rows ear^{-1}, followed by the fertilizer combinations of N_1K_1, N_1K_2, and N_2K_1, with 16.41, 16.36, and 16.42 rows ear^{-1}, sequentially (Table 7). Markedly, the lowest average number of rows per ear resulted in the control treatment (N_0K_0), which numbered 13.90 rows ear^{-1}. The foliate application of organic nutrient (2 g L^{-1}) on maize plants revealed the highest average for the said trait (15.66 rows per ear), compared with the organic nutrient application at the rate of 1 g L^{-1} (14.94 rows per ear), which showed a 5.00% increase in rows per ear.

The interaction of fertilizer combinations and spraying of organic nutrient (potassium humate) indicated that the interaction treatment (N_2K_2 × organic nutrient at the rate of 2 g L^{-1}) achieved the maximum number of rows per ear (16.93), which significantly outperformed all other interactions except N_1K_1, N_1K_2, and N_2K_1 × organic nutrient

Table 5. Effect of spraying with potassium humate and the combination of nitrogen and potassium fertilizers on the number of leaves of plant.

Fertilizer combinations	Potassium humate concentration (g L^{-1})		Means (Leaves $plant^{-1}$)
	1	2	
N_0K_0	10.49	11.28	10.89
N_0K_1	13.22	14.45	13.83
N_0K_2	13.39	14.65	14.02
N_1K_0	13.34	14.68	14.01
N_1K_1	14.97	15.62	15.29
N_1K_2	15.07	15.57	15.32
N_2K_0	13.65	13.71	13.68
N_2K_1	15.45	15.66	15.56
N_2K_2	15.59	15.63	15.61
Means	13.91	14.58	

$LSD_{0.05}$ Fertilizer combination: 0.18, Potassium humate concentration: 0.26, Fc × Ph Interactions: 0.27

Table 6. Effect of spraying with potassium humate and the combination of nitrogen and potassium fertilizers on the ear length.

Fertilizer combinations	Potassium humate concentration (g L^{-1})		Means (cm)
	1	2	
N_0K_0	15.27	15.95	15.61
N_0K_1	15.47	16.93	16.20
N_0K_2	15.65	17.09	16.37
N_1K_0	16.53	18.54	17.53
N_1K_1	18.55	20.75	19.65
N_1K_2	18.77	20.71	19.74
N_2K_0	17.61	18.73	18.17
N_2K_1	18.95	20.73	19.84
N_2K_2	19.07	20.70	19.88
Means	17.32	18.90	

$LSD_{0.05}$ Fertilizer combination: 0.38, Potassium humate concentration: 0.48, Fc × Ph Interactions: 0.56

Table 7. Effect of spraying with potassium humate and the combination of nitrogen and potassium fertilizers on the number of rows per ear.

Fertilizer combination	Potassium humate concentration (g L^{-1})		Means (rows ear^{-1})
	1	2	
N_0K_0	13.68	14.12	13.90
N_0K_1	13.97	14.22	14.09
N_0K_2	14.02	14.29	14.15
N_1K_0	14.08	15.28	14.68
N_1K_1	15.90	16.92	16.41
N_1K_2	15.92	16.80	16.36
N_2K_0	14.95	15.45	15.20
N_2K_1	15.95	16.90	16.42
N_2K_2	15.98	16.93	16.45
Means (rows ear^{-1})	14.94	15.66	

$LSD_{0.05}$ Fertilizer combination: 0.12 Potassium humate concentration: 0.05, Fc × Ph Interactions: 0.16

at the rate of 2 g L^{-1}, with 16.92, 16.80, and 16.90 rows per ear, respectively (Table 7). The control treatment of the interaction N_0K_0 × concentration 1g L^{-1} was visible with the minimum value for the said trait (13.68 rows per ear).

Grains per row

By fertilizing the maize plants with nitrogen and potassium fertilizer mixtures, a meaningful increase was remarkable in the average number of grains per row (Table 8). The fertilizer combination N_2K_2 showed the highest average of 34.05 grains per row, with an increase of 20.00% compared with the control treatment (N_0K_0), which gave the lowest average (28.51 grains per row). The above promising treatment had three other combinations following it, i.e., N_1K_1, N_1K_2, and N_2K_1, with values of 33.91, 33.94, and 33.96 grains per row, respectively. There was a significant increase and difference in the average number of grains per row by spraying maize plants with the organic nutrient (potassium humate) at the rate of 2 g L^{-1} (33.12 grains per row), with an increase of 7.00% compared with the lowest concentration of the organic nutrient (1 g L^{-1}), which showed the minimum value for the said trait (30.86 grains per row).

Results further indicated that the interaction treatment (N_1K_1 × organic nutrient at the rate of 2 g L^{-1}) achieved the highest value for grains per row (35.47), followed by the interaction treatments, N_1K_2, N_2K_1, and N_2K_2 × organic nutrient at the rate of 2 g L^{-1} (35.37, 35.41, and 35.44 grains per row, respectively) (Table 8). However, the promising combination was significantly superior to all other interaction treatments. The control treatment with interaction (N_0K_0 × organic nutrient at the rate of 1 g L^{-1}) appeared with the lowest number of grains per row (27.91).

Grain yield

Outcomes implied a significant difference in the average grain yield by fertilizing maize plants with nitrogen and potassium fertilizer combinations (Table 9). The fertilizer combination (N_2K_1) produced the highest

Table 8. Effect of spraying with potassium humate and the combination of nitrogen and potassium fertilizers on the grains per row.

Fertilizer combination	Potassium humate concentration (g L^{-1})		Means (grains row $^{-1}$).
	1	2	
N_0K_0	27.91	29.12	28.51
N_0K_1	29.07	30.55	29.81
N_0K_2	29.56	31.29	30.42
N_1K_0	29.66	32.29	30.98
N_1K_1	32.34	35.47	33.91
N_1K_2	32.51	35.37	33.94
N_2K_0	31.55	33.13	32.34
N_2K_1	32.52	35.41	33.96
N_2K_2	32.67	35.44	34.05
Means (grains row^{-1})	30.86	33.12	

$LSD_{0.05}$ Fertilizer combination: 0.33, Potassium humate concentration: 0.38, Fc × Ph Interactions: 0.48

Table 9. Effect of spraying with potassium humate and the combination of nitrogen and potassium fertilizers on grain yield.

Fertilizer combination	Potassium humate concentration (g L^{-1})		Means (t ha^{-1})
	1	2	
N_0K_0	5.36	5.71	5.53
N_0K_1	6.23	6.68	6.45
N_0K_2	6.65	6.96	6.80
N_1K_0	6.72	7.20	6.96
N_1K_1	8.52	10.66	9.59
N_1K_2	8.92	10.47	9.69
N_2K_0	7.21	7.87	7.54
N_2K_1	9.07	10.60	9.84
N_2K_2	9.13	10.54	9.83
Means (t ha^{-1})	7.53	8.52	

$LSD_{0.05}$ Fertilizer combination: 0.27 , Potassium humate concentration: 0.03, Fc × Ph Interactions: 0.36

average grain yield (9.84 t ha^{-1}) with an increase of 78.00% versus the control treatment (N_0K_0), which gave the lowest average grain yield (5.53 t ha^{-1}), followed by three other mineral fertilizer combinations, N_1K_1, N_1K_2, and N_2K_2, with grain yields of 9.59, 9.69, and 9.83 t ha^{-1}, respectively. The organic nutrient (potassium humate at the rate of 2 g L^{-1}) foliar application on maize plants resulted in the highest grain yield (8.52 t ha^{-1}), compared with the lower concentration of 1 g L^{-1}, which provided the lowest average for this trait, amounting to 7.53 t ha^{-1}, and the percentage of the achieved increase was 13.14%.

As for the interaction between the fertilizer combinations of nitrogen and potassium and foliar application of the organic nutrient (potassium humate), the interaction treatment (N_1K_1 × organic nutrient at the rate of 2 g L^{-1}) achieved the highest value of the grain yield (10.66 t ha^{-1}) (Table 9). The said grain yield was significantly superior to all other interaction treatments except the interaction treatments, N_1K_2, N_2K_1, and N_2K_2 × organic nutrient at the rate of 2 g L^{-1}, which amounted to 10.47, 10.60, and 10.54 t ha^{-1}, sequentially. However, the interaction control treatment (N_0K_0 × organic nutrient at the rate of 1 g L^{-1}) emerged with the lowest grain yield (5.36 t ha^{-1}).

Grains oil (%)

The percentage of oil in maize grains increased immensely with enhancement in the mineral fertilizers (nitrogen and potassium) and their combinations (Table 10). The fertilizer combination N_2K_1 showed the highest grain oil percentage (4.50%), followed by three other fertilizer combinations, N_1K_1, N_1K_2, and N_2K_2, with oil% of 4.46%, 4.47%, and 4.48%, respectively. The above promising combination significantly outperformed the rest of the treatments with an increase of 42.40%, compared with the control treatment (N_0K_0), which amounted to 3.16%.

No significant difference occurred in the average percentage of oil by spraying the maize plants with the organic nutrient (potassium humate) (Table 10). The interaction treatment (N_1K_1 × organic nutrient at the rate of 2 g L^{-1}) showed the highest value of oil% (5.07%), followed by N_1K_2, N_2K_1, and N_2K_2 × organic nutrient at the rate of 2 g L^{-1}), which amounted to 5.02%, 4.98%, and 4.88%, sequentially. However, the interaction of the control treatment (N_0K_0 × organic nutrient at the rate of 1 g L^{-1}) showed the smallest value for oil percentage (3.05%).

Grains protein (%)

The maize grain protein percentage enhanced significantly with a rise in mineral fertilization levels and their combinations (Table 11). The fertilizer combination N_2K_2 produced the highest average protein percentage (11.62%); however, it did not differ significantly from the fertilizer combinations N_1K_1, N_1K_2, and N_2K_1, which produced 11.43%, 11.50%, and 11.53% protein, respectively. However, the above promising fertilizer combination substantially outperformed the rest of the treatments, with an increased rate of 37.84% compared with the control treatment, N_0K_0 (8.43%). Spraying maize plants with the organic nutrient (potassium humate) at the concentration of 2 g L^{-1} showed the highest grain protein content (10.57%), with an increase of 7.20% versus its lowest concentration at the rate of 1 g L^{-1} (9.86%).

The interaction between fertilizer combinations of nitrogen and potassium and foliar application of the organic nutrient (potassium humate) markedly affected the percentage of protein in grains (Table 11). The highest average maize grain protein (12.06%) appeared with the interaction treatment of N_1K_1 × organic nutrient at the concentration of 1 g L^{-1}, followed by three other interaction treatments, N_1K_2, N_2K_1, and N_2K_2 × organic nutrient at the concentration of 2 g L^{-1}, which amounted to 12.00%, 11.87%, and 11.93%, respectively. However, the interaction of the control treatment (N_0K_0) with the lowest concentration of organic nutrients at the rate of 1 g L^{-1} showed the minimum percentage of protein content (8.25%).

Table 10. Effect of spraying with potassium humate and the combination of nitrogen and potassium fertilizers on grains oil (%).

Fertilizer combination	Potassium humate concentration (g L^{-1})		Means (grains oil %)
	1	2	
N_0K_0	3.05	3.26	3.16
N_0K_1	3.23	3.55	3.39
N_0K_2	3.65	3.69	3.67
N_1K_0	3.66	3.88	3.77
N_1K_1	3.85	5.07	4.46
N_1K_2	3.91	5.02	4.47
N_2K_0	3.70	4.18	3.94
N_2K_1	4.03	4.98	4.50
N_2K_2	4.08	4.88	4.48
Means (grains oil %)	3.68	4.28	

$LSD_{0.05}$ Fertilizer combination: 0.28, Potassium humate concentration: NS, Fc × Ph Interactions: 0.64

Table 11. Effect of spraying with potassium humate and the combination of nitrogen and potassium fertilizers on grains protein (%).

Fertilizer combination	Potassium humate concentration (g L^{-1})		Means (grains protein %)
	1	2	
N_0K_0	8.25	8.62	8.43
N_0K_1	8.37	8.81	8.59
N_0K_2	8.62	9.06	8.84
N_1K_0	9.18	9.87	9.53
N_1K_1	10.81	12.06	11.43
N_1K_2	11.00	12.00	11.50
N_2K_0	10.06	10.93	10.50
N_2K_1	11.18	11.87	11.53
N_2K_2	11.31	11.93	11.62
Means (grains protein %)	9.86	10.57	

$LSD_{0.05}$ Fertilizer combination: 0.237, Potassium humate concentration: 0.587, Fc × Ph Interactions: 0.464

DISCUSSION

Adding the nitrogen and potassium fertilizer combination significantly impacted the maize growth, yield, and quality traits. Nitrogen plays a vital role being a fast-moving macro-element within the plant and contributing to better plant growth and development by enhancing the activity of meristem cells that contribute to cell division and the formation of amino acid (tryptophan), which is the primary material for building auxin, affecting the plant cell division and elongation, leading to an increased plant height (Loddo and Gooding, 2012). Nitrogen also contributes to the formation of plant hormones that activate the cells that enter into the creation of leaves, leading to an increase in the number of leaves in the plant (Zaki and Ahmed, 2023; Hoshan, 2024).

In addition, potassium also plays an influential role in boosting the photosynthesis process and enhancing enzymatic activity, which leads to an elongation of the maize plants' stem, increasing nodes and, thus, improving plant growth (Raza *et al*., 2021). Potassium also contributes to the elongation of the phalanx of the coronary nodes, contributing to raising the number of leaves on the stem node as a result of activating the vital processes that lead to increased plant growth and nutrient manufacturing and transportation (Ali *et al*., 2014). The presented results about maize crop are also analogous to the findings of Al-Yasari and Al-Hilli (2018, 2019) and Al-Yasari (2022), stating the addition of nitrogen and potassium fertilizers increased the growth and productivity and improved the quality traits of various crop plants.

The promising results enunciated the maize plant's response to the foliar application of the organic nutrient (potassium humate) and, due to its positive effects, the plant growth rate hastened, as it contributes to raising the vital activities of the plant and nutrient absorption. It also has a hormonal effect that enhances the plant height through its influences on the cell protoplasm and cell wall, which contribute to accumulative plant cell division and growth (Mahmood *et al*., 2020). The presented findings about the maize crop were also consistent with the findings of Balbaa and Awad (2013), who also reported the maize crop spraying with humic acid led to an increase in plant height by expanding the meristem cell division, as well as providing nitrogen and phosphorus, which is significant in forming nucleic acids (DNA and RNA), increasing the size of plant cells and their division and, thus, escalating plant growth and development, eventually improving the yield-related traits and grain yield (Mahmood *et al*., 2020).

Foliar application of potassium humate activates the leaf tissue cells to divide and expand them further, which leads to an increase in the number of leaves, causing a positive impact on plant growth and energy because leaves are the main component of photosynthesis in crop plants (Daur and Bakhashwain, 2013). The addition of the mineral fertilizer combination remarkably impacted improving the yield and its components, as nitrogen and potassium contribute to raising the length of the ear through their effect on the photosynthesis and cell division, and, then, transferring the products of the photosynthesis process from the leaves to the different parts of the plant, which eventually enhance the ear length (Ijaz *et al*., 2014). Nitrogen contributes to increasing the leaf area, leading to an increase in the process of carbon metabolism and accumulation of dry matter, reducing the abortion of the ovaries and, as a result, increasing the pollination and fertilization, enhancing the number of rows per ear (Al-Mohammadi, 1990).

Nitrogen plays a vital role in forming proteins, which are then transported during the flowering stage to increase the formation of active flower establishments, reducing the abortion of emerging seeds and, thus, increasing their nodes in the plant and the availability of these nutrients during the flowering period leads to an increase in the number of pollinated flowers and grains per ear (White and Brown, 2010, Al-Dawdi *et al*., 2015). Potassium affects and regulates the process of plant hormones that have to do with flower formation, pollination, and fertilization, which eventually reflects in an increased number of grains per ear and grain yield (Ali *et al*., 2014; Kassie *et al*., 2019). The results indicated an increase in grain yield, which refers to the role of nitrogen and potassium, as nitrogen contributes to increasing the process of carbon metabolism, increasing the formation of chlorophyll, proteins, enzymes, and most growth regulators that have a chief role in increasing the grain yield (Al-Zubede *et al.*, 2016; Al-Maeni and Al-Jubouri, 2017). Potassium, being a macro-element, contributes to the formation and transportation of carbohydrates, proteins, and amino acids, boosting photosynthesis efficiency and, as a result, raising the grain yield (Nejad *et al.*, 2010).

The results also indicated a significant increase in the percentage of oil and protein in the grains, and it may be due to the role of nitrogen and potassium, as the provision of nitrogen is vital in creating amino acids, which is the prime component in forming proteins (Ali *et al*., 2014). The increased content of grains' protein may be due to an increase in the nitrogen content in the leaves, and, during the growth of grains, nitrogen transfer from the leaves to the grains produces proteins, which may also increase the protein content given the nitrogen's important role in protein synthesis (Jan *et al*., 2018; Zakaria, 2018). Potassium also has a principal role in increasing the percentage of grains' protein because of its positive effect in maintaining the activity and effectiveness of the leaves and increasing the process of manufacturing carbohydrates, as it contributes to boosting the activity and efficiency of the enzyme Nitrate Reductase, contributing to the formation of ammonia NH_3, which enters creating amino acids by reducing nitrates No_3 to ammonia NH_3, as ammonia correlate with ketogenic acid to produce amino acids and, thus, the formation of proteins (Halvin *et al*., 2005; Jan *et al*., 2018).

The outcomes showed the maize plant's response to foliar application of organic nutrients (potassium humate) with enhanced yield and its components (Ragheb, 2016; Mahmood *et al*., 2020). As a result of the high content of humic acid, it inhibits the activity of the enzyme (IAA oxidase), which leads to an increase in the activity of auxin (IAA), playing a positive role in stimulating plant growth and roots and adding humic acid to the soil or spraying on the plant is helpful to enriching it with the necessary nutrients and raising the plant's resistance to drought and heat significantly, as well as leading to increased growth and development (Mohana *et al*., 2015). Spraying with the organic nutrient potassium humate enhances the activity and effectiveness of photosynthesis and intensifies the formation of processed nutrients for transport to grains, which leads to an upsurge in grain yield (Ijaz *et al*., 2014; Khafaji, 2015).

Foliar application of the organic nutrients (potassium humate) enhances the concentration of nucleic acids in the plant cell, which are necessary for several biochemical processes within the cell, as the activation of chemical processes leads to increased synthesis of enzymes and increased protein and carbohydrate content in the grains (Osman *et al*., 2017; Zakaria, 2018). Potassium humate also raises the biosynthesis of organic compounds, and it may directly relate to its role in increasing plant tolerance against biological stress and immune system activity, which leads to an increase in metabolism by promoting photosynthesis and starch formation (Osman *et al*., 2017).

CONCLUSIONS

The promising results revealed that a foliar application of the nutrient potassium humate and the spraying of nitrogen and potassium fertilizer combinations increased the vegetative growth. It enhances photosynthesis and, thus, improves the composition of crop components, enhancing the grain yield and quality of maize. The interaction between the fertilizer combination of nitrogen and potassium (N_1K_1) and foliar application of organic nutrients (potassium humate - 2 g L^{-1}) proved the best response in improving maize growth, grain yield, and quality.

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