Research Article

Effectiveness of Nano Potassium on Growth and Yield of Spring Maize (*Zea mays* L.) Grown under the Heat Stress

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Abstract | This study aimed to produce strong plants that are resistant to environmental stress represented by high temperatures to record levels and to coincide with the flowering period of maize grown in the spring season in a hot climate, where temperatures reach 46°, to determine the best concentration of nano potassium (K) fertilizer and the best date for addition that affects growth and yield of maize. An experiment was carried out in a field in the Mwailha Zone northeast of Babylon in clay loam soil during the spring season of 2023.Factorial experiment with a completely randomized block design (RCBD) was used with three replicates that included spraying three concentrations of K nano fertilizer (0, 1000, 2000, 3000) mg.L^{-1} refer to us(K_0, K_1, K_2, K_3). three times for spraying nano potassium: The first time (D_1) spraying at the age of 4 true leaves, the second time (D_2) at the beginning of the male flowering and appearance of pollen, and the third time (D_3) at the beginning of female flowers (silk) which is the critical stage of growth. The results were as follows:K_3 concentration was significantly superior in vegetative growth characteristics and yield (plant height, leaf area, biological yield, number of cobs, and total grain yield (195.22 cm, 0.72 m^2, 20.67 ton h^{-1}, 2.12 cobs per plant^{-1}, 11.24 tons. ha^{-1}) Addition of fertilizer at the second date (D_2) was significantly on other addition treatments. K_3D_2 interaction significantly increased all growth and yield characteristics compared with different interactions.

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Keywords | Maize, Foliar application, Heat, A biotic stress, Temperatures, Fertilizer. Time of addition

Introduction

Corn grown during the spring season in Iraq suffers from high temperatures because the flowering date coincides with June and July with temperatures rising to high levels of more than 43°C, meaning this temperature is much higher than the ideal rates for growth and flowering of maize, which leads to drought It kills pollen and reduces the percentage of fertile flowers which negatively affects formation of corn cobs, which leads to formation of empty cobs and a decrease in grain yield and quality (Al-Sahuki, 1990). Found that heat stress and high temperatures are among the factors most responsible for the global decline in maize production (Hejazi *et al*., 2020; Weisany *et al*., 2023; Ahmed *et al*., 2022). Therefore the flowering process requires the availability of many nutrients to help the formation of flowers including potassium which is considered one of the important elements and plays a major role in the various stages of a plant's life because it is responsible for activating more than 120 enzymes important for physiological processes and activating hormones and growth regulators, auxins and gibberellins which are necessary for the formation of flowers. Thus increasing the number of grains (Abu Dahi, 1989). During the past few years, Potassium plays a major role in reducing the effects of heat and drought by helping transport photosynthetic materials, and helping roots to penetrate deeper into the soil, to reduce moisture absorption (Zahoor *et al.*, 2017; Zahedi *et al.*, 2020; Huang *et al.*, 2023). Many researchers have noticed the possibility of using nanotechnology to increase the efficiency of fertilizers used in the agricultural field which depends on the use of nano scale bodies with a high ability to preserve nutrient ions and release them slowly when they are needed which leads to benefiting from the nutrients and increasing efficiency of use and improvement of plant health (Hamid, 2025) found that vegetative stage requires large amounts of potassium K after completion of formation of vegetative parts in plant efficiency of the root decreases in meeting needs of newly formed vegetative parts of this important element in processes of building the vegetative and flowering system and sites where grains are filled with manufactured materials which means exposure tissues lead to aging and early death. Foliar application is characterized as a quick and efficient method to provide the K requirements of grassy plants including corn. Compared to adding fertilizer directly to the soil, spraying nano potassium fertilizer at a concentration of 2000 mg L^{-1} has recorded significant increases in the height of plants, chlorophyll content, and dry weight of grains. From a physiological standpoint, potassium fertilizer contributes to delaying the aging of maize plants (Kazar, 2022; Al-Zwaini, 2021) Spraying fertilizer on a shoot plant's system preserves the plant's leaves and its activity during the process of photosynthesis until the plant arrives full maturity, regulates the transfer of nutrients, especially nitrogen, phosphorus, and potassium between the plant parts and the new and old leaves, and increases the ability of the roots to absorb these elements from the soil solution (Hamid et al., 2025; Che *et al.*, 2022; Pegah *et al.*, 2020) found that nano potassium can reduce the negative effects of drought stress and improve plant resistance against drought stress, (Ali *et al.*, 2019) also found that potassium plays an important role in increasing the thickness of the cell wall, which increases the plant's ability to withstand various biological stresses such as diseases, and insects, and environmental stresses such as drought and high temperature when potassium and other elements are balanced.

On the other hand, a study conducted by Ali *et al.* (2016) explained potassium acts as a transporter of nutrients from roots to leaves, grains, or cobs. The study aims to produce strong corn plants that are resistant to high temperatures by feeding the plant with appropriate nutrients and providing the appropriate need and time in addition to overcoming heat stress resulting from the significant rise in temperature during the critical flowering period.

Materials and Methods

Plant materials

A field experiment was conducted in the spring season of 2023 in Muwailha Zone, northeast of Babylon governorate in a clay mixture soil. Which is classified as a hot and dry area in the summer (Table 7) which leads to the killing of pollen (male pollen die when the temperature reaches 43°) and the lack of fertilization during the flowering period which leads to the failure of maize cobs to form due to the significant increase in temperature to high levels (Al-Sahuki, 1990). Random soil samples were taken to a depth of 0-30 cm, air-dried, and ground to pass through a sieve with a hole diameter of 2 mm. The soil suspension was filtered to conduct chemical analyses. PH was estimated using the Conductivity Bridge device as previously reported (Haynes, 1980). Available potassium was estimated using an a flame photometer according to the method (Black, 1965). Cation exchange capacity was estimated according to the method proposed by Page *et al.* (1982), a special method for calcareous soils, organic matter was estimated by wet digestion according to the method of Walkley and Black, and available nitrogen was extracted with a KCl (2N) solution and the ammonium was estimated with Keldahl device. Table 6 shows the physical and chemical characteristics of field soil.

Treatments and experimental design

A factorial experiment was conducted in a randomized complete block design (RCBD) with three replications that included three concentrations of potassium nano fertilizer, K_1= 1000 mg.L^{-1}, K_2= 2000 mg.L^{-1}, K_3= 3000 mg.L^{-1} (Table 8) and the fourth concentration K0 included only water spraying as a control treatment, there are three spraying time, first: spraying at the age of 4 true leaves (D_1), second before the beginning of male flowering (D_2), and third spraying before the beginning of female flowering and appearance of silk which is the critical stage of growth (D_3), in addition to addressing the necessary fertilizer recommendation for the soil. To determine the plant response to foliar feeding and to represent the control treatment for the entire experiment. Urea (46% N) was used as a source of nitrogen, triple superphosphate (20.24% P) was used as a source of phosphorus, and potassium sulfate (41.50% K) was used as a source of potassium, Nitrogen, and potassium fertilizer were added in two equal quantity to the soil, the first at planting and the second 45 days after the first addition. As for phosphate fertilizer it was added only at planting. Seeds of synthetic variety Bohouth 106 were planted on 10/4/2023, and harvested on 15/8/2023. Use distilled water to dissolve K fertilizer and a 20-liter backpack sprayer to spray with 0.02% of cleaning fluid to reduce surface tension and ensure complete wetness of the leaves to help the fertilizer penetrate through the cuticle layer of the plant leaves.

The following characteristics were studied

Plant height (cm); leaf area (m^2); biological yield (ton. ha^{-1}), number of (cobs per plant^{-1}), total grain yield (ton ha^{-1}). The least significant difference (LSD) test was used to compare means at a probability level of 0.05, according to the RCBD design in the Genstat12 program (Steel and Torrie, 1980).

Results and Discussion

Plant height (cm) and leaf area (m^2)

It is noted from Tables 1, 2 that concentrations of K_1, K_2, and K_3 gave a significant increase superior to the concentration of K0, amounting to 13.84, 31.05, and 32.33 cm in plant height, and 0.05, 0.07, and 0.17 m^2, respectively,in leaf area of maize plants, increase in height and leaf area of plants by increasing K concentrations is attributed to the role of potassium in reducing the water potential of the roots and improving their ability to absorb water and nutrients, which leads to improved growth and cell division and an increase in their size and expansion. This result is consistent with what was found by (Beeresha and Jayadeva, 2020) spraying nano potassium on maize plants led to a significant increase in vegetative growth and yield. It appears from Tables 1 and 2 that there is a difference in plant height and leaf area according to the time of addition. Times D_2 and D_3 which had significant differences, outperformed the time of addition D_1 by 6.77 and 3.88 cm in plant height, respectively, and by 0.09 and 0.09 m^2 in leaf area respectively, the reason for the increase in height and leaf area may be attributed to fact that the addition occurred during the stage of growth expansion and elongation of the cells so it was an ideal time to meet the plant's needs for potassium which is considered basic growth requirement. Abu Jadallah (2018) states that the availability of necessary nutrients during the vegetative growth period has a positive effect on increasing vegetative growth indicators. As for the interaction between the two factors K_3D_2 recorded the highest average 202cm, superior to the rest of the interactions.

Table 1: *Effect of nano potassium, application time, and interaction on plant height (cm).*

Mean: K	Nano potassium spraying dates			Nano potassium
	D_3	D_2	D_1	
162.89	160.77	164.73	163.17	K_0
176.73	178.33	176.77	175.10	K_1
193.94	195.33	189.17	188.33	K_2
195.22	188.00	00. 202	195.67	K_3
K, D=10.8	182.53	185.42	178.65	Mean: D
	D=5.42			L.S.D$_{.05}$, K=5.82

** K=nano potassium concentrations; D= time of addition.*

Table 2: *Effect of nano potassium, application time, and interference on leaf area (m^2).*

Mean: K	Nano potassium spraying dates			Nano potassium
	D_3	D_2	D_1	
0.55	0.54	0.56	0.54	K_0
0.60	0.64	0.59	0.57	K_1
0.62	0.67	0.68	0.52	K_2
0.72	0.78	0.78	0.60	K_3
K, D= 0.057	0.65	0.65	0.56	Mean: D
	D=0.028			L.S.D$_{.05}$,K= 0.033

** K=nano potassium concentrations , D=time of addition.*

Biological yield, number of cobs, and total grain yield

The results of statistical analysis in Tables 3, 4, 5 indicate that there is a significant contribution of potassium concentrations (K_1, K_2, K_3) compared to K0 with an increase of 0.93, 2.34, and 4.35 ton h^{-1}, respectively, in biological yield and 0.23, 0.21, and 0.61, respectively for the number of cobs.plant^{-1}, and 0.76, 1.88, and 3.15

ton.h^{-1}, respectively for total grain yield. The reason for the increase in biological yield may be attributed to the effectiveness of potassium in increasing average leaf area and increasing the deposition of photosynthetic products in leaves which is reflected in an increase in carbohydrate content which leads to the stimulation of enzymes that transport carbohydrates to storage tissues in endosperm of grain. This explains the reason for the increase in the weight of grain yield and biological yield in general (Huang *et al.*, 2023; Noaema and Alhasany, 2020; Beeresha and Jayadeva, 2020). We note from Tables 3, 4, 5 that there is a significant increase for two times of adding nano potassium, D_3, and D_2 on D_1 with an increase of 0.8 and 0.44 tons.h^{-1} for biological yield and 0.16 and 0.24, respectively for many cobs. Plant^{-1}, 0.58, and 0.3 tons.h^{-1}for total grain yield. Grain yield increase may be due to an increase in components of yield number of cobs or catalytic activity of potassium for transporting enzymes, so the dry weight of the grain increases when sprayed at the beginning of female flowering. The formation of cobs is the stage of initiation of requirements for the growth of the upper part of the plant and catabolism of lower parts especially nitrogenous and phosphate compounds soluble proteins and carbohydrates. It is noted that there are significant differences between interactions, as interaction K_3D_3 was significantly higher and recorded 20.37 ton h^{-1} with a difference of 4.27 ton h^{-1}. From the lowest interaction K_0D_1 for the biological yield, which recorded 16.10 ton h^{-1}. As for the number of cobs interaction K_3D_3 reached 32.23 ton.h^{-1}. The lowest value of the interaction was recorded at interaction K_0D_1, which amounted to 1.30 cobs.plant^{-1}, highest interaction for grain yield was at interaction K_2D_3, which amounted to 11.20 ton h^{-1}.

Plant height (cm) and leaf area (cm^2)

The increase in height and leaf area of plants by increasing K concentrations is attributed to the role of potassium in reducing the water potential of the roots and improving their ability to absorb water and nutrients, which leads to improved growth and cell division and an increase in their size and expansion, also found that potassium plays an important role in increasing the thickness of the cell wall, which increases the plant's ability to withstand various biological stresses such as diseases, and insects, and environmental stresses such as drought and high temperature when potassium and other elements are balanced (Ali *et al.*, 2019). This result is consistent with what was found by Agaei *et al.* (2020), Beeresha and Jayadeva (2020), Al-Khafagi *et al.* (2023) Spraying nano potassium on maize plants led to a significant increase in vegetative growth and yield. Regarding the time of addition the second factor, the reason for the increase in height and leaf area can be attributed to the fact that the addition occurred during the growth expansion and cell elongation phase, so it was the ideal time to meet the plant's needs for potassium, which is considered one of the basic growth requirements (Abd-El-Aty *et al.*, 2024) indicates that the availability of the necessary nutrients during the vegetative growth period has a positive effect on increasing vegetative growth indicators (Abu Jadallah, 2018; Che *et al.*, 2022; Pegah *et al.*, 2020).

Table 3: *Effect of nano potassium, application time, and interference on biological yield (ton.h^{-1}).*

Mean: K	Nano potassium spraying dates			Nano potassium
	D_3	D_2	D_1	
16.32	16.32	16.54	16.10	K_0
17.25	17.38	17.57	16.81	K_1
18.66	18.64	19.13	18.20	K_2
20.67	20.37	20.90	19.83	K_3
K, D=0.40	18.18	18.54	17.74	Mean: D
	D=0.17			L.S.D$_{.05}$,K=0.20

** K=nano potassium concentrations , D=time of addition.*

Table 4: *Effect of nano potassium, application time, and interference on cobs.plant^{-1}.*

Mean: K	Nano potassium spraying dates			Nano potassium
	D_3	D_2	D_1	
1.51	1.57	1.67	1.30	K_0
1.74	1.83	1.70	1.70	K_1
1.72	1.90	1.77	1.50	K_2
2.12	2.23	2.07	2.07	K_3
K, D= 3.06	1.88	1.80	1.64	Mean: D
	D=0.153			L.S.D$_{.05}$, K=0.177

** K=nano potassium concentrations , D=time of addition.*

Table 5: *Effect of nano potassium, application time, and interference on total yield (ton.h^{-1}).*

Mean: K	Nano potassium spraying dates			Nano potassium
	D_3	D_2	D_1	
8.09	8.07	8.29	7.90	K_0
8.85	8.98	9.06	8.52	K_1
9.97	9.93	10.34	9.65	K_2
11.24	11.20	11.61	10.91	K_3
K, D=0.25	9.55	9.83	9.25	Mean: D
	D=0.13			L.S.D$_{.05}$, K=0.18

** K=nano potassium concentrations , D=time of addition.*

Table 6: *Chemical and physical characteristics of field soil before planting.*

Trait	Quantity	Measuring unit	Trait	Quantity	Measuring unit	Composition	Quantity	Measuring unit
PH	7.68	-	NH4	19.93	$mg.Kg^{-1}$	Sand	194	$gm.Kg^{-1}$
EC	3.83	$dS.m^{-1}$	NO3	21.22	$mg.Kg^{-1}$	Alluvial	422	$gm.Kg^{-1}$
			P	23.65	$mg.Kg^{-1}$	clay	384	$gm.Kg^{-1}$
O.M	14.99	$gm.kg^{-1}$	K	205	$mg.Kg^{-1}$	textures	Clay Alluvial	

Table 7: *Minimum and maximum temperature averages, average wind speed, and solar radiation for the year 2023.*

Months	Minimum temperature average	Maximum temperature average	Average wind speed	Total radiation solar
	AT Min C°	AT Max C°	WS Avg m/s	SLR Total Mj/m^2
June	23.28	43.50	2.18	24.00
July	28.54	46.47	2.56	25.00

Agricultural Meteorological Center/ Ministry of Agriculture.Babylon Governorate, Al-Musayyib Station 44.59° Longitude E:Latitude, N: 32.76°.

Table 8: *Ingredients of nano fertilizer and the producing company.*

Rate and how to use	Origin	Company	Fertilizer type
2g/L Spray on plant leaves	British	Trade max	Nano potassium (27 Chelated potassium (W.P)

Biological yield, number of cobs, and total grain yield

The reason for the increase in biological yield may be attributed to the effectiveness of potassium (K) in increasing average leaf area and increasing the deposition of photosynthetic products in leaves which is reflected in an increase in carbohydrate content which leads to the stimulation of enzymes that transport carbohydrates to storage tissues in endosperm of grain. This explains the reason for the increase in the weight of grain yield and biological yield in general (Noaema and Alhasany, 2020; Beeresha and Jayadeva, 2020; Fuda, 2021) indicated in an experiment comparing nano fertilizers with traditional fertilizers in mays yield, as the treatment of adding nano potassium fertilizer achieved the highest seed production rate compared to traditional mineral fertilizers. The timing of adding nano potassium had a major role in increasing the yield in general (Luo *et al*., 2023; Zahoor *et al*., 2017; Zahedi *et al*., 2020). The increase in panicle productivity and grain yield may be due to the appropriate time for spraying potassium at the beginning of female flowering. Cob formation is the stage of initiating the growth requirements of the upper part of the plant and the catabolism of the lower parts, especially nitrogenous and phosphate compounds soluble proteins and carbohydrates. Grain yield increase may be due to an increase in components of yield number of cobs or catalytic activity of potassium for transporting enzymes, so the dry weight of the grain increases when sprayed at the beginning of female flowering (Che *et al*., 2022; Pegah *et al*., 2020).

Conclusions and Recommendations

We conclude from this study using the concentration of the nutrient element, time, and the ideal method of addition led to obtaining positive results, obtaining abundant yields, and overcoming a major problem that occurs during the cultivation of corn during the spring season in Iraq, such as obtaining incompletely formed corn cobs or empty kernels as a result of killing pollen during the flowering period due to significant rise in temperatures during that period of plant's life.

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Novelty Statement

This study is the first to evaluate the effect of different nano potassium concentrations and application timings on spring maize under extreme heat conditions in Iraq, revealing significant improvements in yield and stress tolerance using optimized foliar application.

Author's Contribution

Hayder Hilal Abbas: Research idea, supervision, project administration.
Karrar Falah Hadi Al-Khafagi: Formal analysis, writing original draft.
Yaseen Abd Al-Janaby: Formal analysis, software and figure preparations.

Conflict of interest

The authors have declkared no conflict of interest.

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