



Enhancing Tomato (*Solanum lycopersicum* L.) Productivity Through Potassium and Nano-Zinc Supplementation in Protected Cultivation Systems

Zahraa J M AL-Musawi ^{1*}, Haneen Mohammed Jassim ², Sarab Kareem Abbas ³, Mustafa Hameed Al-Majdi ⁴, Douaa Haider Mehdi ⁵

¹⁻⁴Department of Horticulture and Landscape, College of Agriculture, Al-Qasim Green University, Hillah, Iraq

⁵Agriculture Extension and Training Office, Ministry of Agriculture, Hillah, Iraq

* Corresponding Author: **Zahraa J M AL-Musawi**

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Abstract

A controlled greenhouse experiment was undertaken during the 2021–2022 growing season in the Al-Tahiriya region, north of Babylon Governorate, Iraq (32°36'59' N, 44° 22' 25'E), on loamy soils, to study the effects of foliar application of potassium (K) and nano-zinc (Zn) on vegetative & reproductive growth of tomato (*Lycopersicon esculentum* Mill. cv. Wejdan). The experiment was laid out in a randomised complete block design (RCBD) with three replications, consisting of four Levels of potassium sulfate K (0, 25, 50, and 75kg/ha) and four concentrations of nano zinc (0, 1, 2 and 3g/L) treatment. Foliar treatments were applied at an interval of 30 leaf days, starting 40 days after transplanting and continuing until 70 days after transplanting. Results were analysed using the Least Significant Difference test at a $P \leq 0.05$ significant level. Application of potassium at 75 kg ha⁻¹ significantly enhanced vegetative growth, viz. plant height, number of leaves per plant, leaf area, shoot dry weight, chlorophyll content, leaf nitrogen content and leaf concentrations of phosphorus and potassium. Potassium fertilisation at 75 kg ha⁻¹ also increased flowering with an average of 16.20 inflorescences per plant and 14.05 flowers per inflorescence. Foliar application of nano-zinc at 3 g/ L increased the plant height, number of leaves, leaf area, shoot dry weight, chlorophyll content, leaf N, P and K contents, and number of inflorescences and flowers per inflorescence with averages of 215.45 cm, 50.58, 177.75 cm², 221.08 g, 50.93 SPAD, 1.72%, 0.56%, 1.92%, 16.15/ plant and 13.83/ inflorescence, respectively. The interaction between the combined application of 75 kg/ha of K and 3 g/L nano-Zn induced significant ($P \leq 0.001$) the highest values for all vegetative and reproductive parameters measured to indicate interaction between the two nutrients, revealing the benefits of utilising potassium and nano-zinc under certain levels of foliar treatments of tomato produced under protection.

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Keywords: Potassium, Phosphorus, Nano-Zinc, Tomato (*Solanum lycopersicum* L.), Greenhouses

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops cultivated in Iraq. To meet the growing demand for food and the need for protecting crops from environmental conditions, many Iraqi farmers have adopted the protected cultivation of crops, especially greenhouses, so the problem of the availability and application of some macro- and micro-nutrients was taken into consideration to achieve the optimum yield and suitability of the tomato crop. Chaterji and others have drawn attention in recent work to the status of potassium (K) in Iraqi soils. K plays an important role in plant physiology and metabolism. K is necessary for the osmotic potential, enzyme activation, cellular homeostasis, respiration, and protein metabolism ^[1].

It has been observed that there is a greater demand for K in greenhouse cultivation than in the open or under similar conditions of explosive cropping, etc. [2]. Advancement in the availability of K has been found to appreciably increase the productivity of vegetable crops under cover [3]. Increasing amounts of K have also been responsible for the relatively higher dry matter in tomato fruits [4]. It has also been shown that in tomato cultivation, application of K promotes the formation of clusters [5, 6]. Maximum yields of about 86.4 tons/ha have been obtained with good rates of fertiliser potash, due to increases in rooting and water and nutrient use efficiency associated with good irrigation [7].

Macronutrients are not the only nutrients essential for plant growth and development; micronutrients such as zinc (Zn) are also acquired via root uptake during normal growth. Zinc is involved in the structure and functions of key enzymes in anabolic and catabolic reactions, including catalase, peroxidase and cytochrome oxidase [8]. The element is also involved in chlorophyll biosynthesis and the formation of various cellular components such as cytochromes and phytoferritin, affecting nucleic acid metabolism [9]; it plays a role in protein synthesis and the formation of tryptophan, a precursor of the plant hormone indole-3-acetic acid (IAA), involved in cell division and elongation. Zinc deficiency in tomato plants typically exhibits as stunted plant growth, slender stems, upward-turned leaves and irregular leaf mottling [10].

Soil conditions in the centre of Iraq are predominantly alkaline, due to high lime content, which negatively affects

the bioavailability and uptake of essential nutrients, including zinc [11]. Recent surveys reported that some 83% of soils across Iraq suffer from a lack of zinc nutrition [12].

Given the above hurdles, the current work evaluates the interactive impact of potash fertilisation and foliar sprays of nano-zinc on vegetative and flower growth of the Wajdan tomato variety, grown under protected cultivation.

2. Materials and Methods

2.1. Study Location and Experimental Setup

The experiment was conducted during the two growing seasons of 2021–2022 in the Al-Tahiriyah area (Al-Musayib project), 30 km north of Babylon Governorate, Iraq (32°36'59" N, 44°22'25" E) over an area of 450 m² in a plastic greenhouse. The tomato hybrid 'Wijdan' (F1), developed by PetoSeed Inc., West Chicago, IL, USA, was used in these experiments and is permitted for cultivation in Iraq.

To obtain optimum conditions to promote nutrient depletion, the top 30 cm of soil was removed and replaced with a mixture of equal volumes of soil and peat moss (1:3). The substrate was thoroughly watered, and covered with polyethene sheets (150 µm in thickness) for 2 months to give rise to a sterilisation effect caused by solarisation [12]. Soil samples were taken at a depth of 0–30 cm at three random locations, homogenised, and analysed for their physicochemical properties using methods recommended by [13]. The properties of the soil are shown in Table 1.

Table 1: Soil Characteristics for the Experiment

Soil Characteristic	Unit	Value
Ece.	DS/ m	3.4
pH	---	7.6
Organic matter	gm/ kg soil	8.9
CEC	C mole/ kg soil	18.7
CaCO ₃	gm/ kg soil	201
Available N		23.7
Available P	mg/ kg soil	7.2
Available K		126.4
Bulk density	gm/ cm ³	1.47
Sand		458.4
Silt	gm/ kg soil	370.6
Clay		171.0
Texture		Loam

2.2. Greenhouse Design and Planting Protocol

The greenhouse was arranged into five cultivation beds, each 150 cm wide, separated by a 50 cm wide irrigation channel and a 100 cm wide walkway. The beds were irrigated two days before transplanting. Tomato seedlings of 40 days were transplanted once the third to the fourth true leaf had emerged. Plants were spaced at 40 cm on either side of each bed. The emitters were placed on the bed, 10 cm from each plant, with a drip line width providing a cache of 1m from either end of the greenhouse to provide for uniform irrigation. Cultural treatments: Standard cultural operations were practised uniformly for all treatments, viz., staking, pruning to a single stem,

removal of lateral branches and senescent leaves, hoeing; fertilisation with ammonium sulphate 225 kg/dunum; triple superphosphates 100 kg/dunum; two split doses during vegetative and flowering stages respectively; in accordance with the practice for greenhouse tomatoes [14].

2.3. Experimental Design and Treatments

The experiment consisted of 16 treatments in a two-factor factorial arrangement within a randomised complete block design (RCBD) with three replications. The first factor included four levels of potassium sulfate (K₂SO₄, 41% K): 0, 25, 50, and 75 kg/ha. The second factor comprised four concentrations of nano-zinc: 0, 1, 2, and 3 g/L.

Foliar application of potassium sulfate was applied in three split doses at 30-day intervals, beginning two weeks after transplanting. Foliar application of nano-zinc was conducted four times at 30-day intervals, starting on November 25, 2021, prior to flowering. To prevent cross-contamination, plastic barriers were used between plots during foliar spraying, which was carried out early in the morning using 2-L hand-held plastic sprayers after irrigation the previous evening to ensure stomatal opening.

2.4. Data Collection and Measurements

Vegetative Growth Parameters

Six randomly selected plants from each experimental unit were marked for data collection on the following parameters:

- 2.4.1. Plant Height (cm).
- 2.4.2. Total Number of Leaves per Plant.
- 2.4.3. Leaf Area (dm²).
- 2.4.4. Shoot Dry Weight (g).
- 2.4.5. Chlorophyll Content (SPAD).

Nutrient Analysis

Leaf samples (fourth leaf from the apex) were collected post-flowering [15], oven-dried at 70°C to constant weight, and ground. Wet digestion was performed using a 3:5 sulfuric acid to perchloric acid solution on 0.2 g of tissue. Nutrient levels were quantified as follows:

2.4.6. Nitrogen (N): Determined using the Micro-Kjeldahl distillation method [16].

2.4.7. Phosphorus (P): Quantified via spectrophotometry at 882 nm [17].

2.4.8. Potassium (K): Measured using a flame photometer

[18].

Reproductive Growth Parameters

2.4.9. Number of Flower Inflorescences per Plant.

2.4.10. Number of Flowers per Inflorescence.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using the randomised complete block design (RCBD). Means were compared using the Least Significant Difference (LSD) test at the 0.05 probability level. Statistical analyses were performed using SAS software.

3. Results

3.1. Plant Height and Leaf Number

As presented in Table 2, significant differences exist in plant height and number of leaves due to the effects of potassium and nanoscale zinc treatment. 75 kg/ha of Potassium significantly exceeded the control treatment and presented the maximum values for plant height (216.88 cm) and number of leaves (50.48 leaves/plant). The lowest control was obtained (175.25 cm and 39.20 leaves, respectively). The foliar application of nano zinc at 3 g/L significantly improved both plant height and number of leaves, presenting the maximum averages of plant height (215.45 cm) and number of leaves (50.58 leaves/plant), compared to the untreated control with 176.48 cm and 39.30 leaves, respectively. Potassium also influenced defence responses to nano-zinc, where the highest plant height with the most leaves (238.9 cm c. and 56.1 leaves) was observed for 75 kg/ha K and 3 g/L nano-Zn combination. The control treatment without potassium and zinc had the lowest values.

Table 2: Potassium and nano-zinc's effects on plant height and leaf number.

K Kg/ h	Plant height cm				Aver.	Plant leaf number				Aver.
	Nano-zinc gm/ L					Nano-zinc gm/ L				
	0	1	2	3		0	1	2	3	
0	155.2	164.9	186.4	194.5	175.25	34.2	36.8	41.1	44.7	39.20
25	169.6	178.5	196.2	207.3	187.90	36.1	41.5	45.9	50.2	43.43
50	185.7	201.7	212.3	221.3	205.20	42.2	45.9	48.4	51.2	46.93
75	195.4	207.8	225.4	238.9	216.88	44.7	49.1	51.9	56.2	50.48
Aver.	176.48	188.23	205.80	215.45		39.30	43.33	46.83	50.58	
LSD 0.05	Zn 5.98	K 5.98	Zn*K 11.96		Zn 2.35	K 2.35	Zn*K 4.70			

3.2. Leaf Area and Vegetative Biomass

As noted from Table 3, potassium and nano-zinc treatments affected leaf area and shoot dry weight significantly. The 75 kg/ha potassium treatment produced the greatest leaf area (183.70 dm²) and shoot dry weight (221.08 g), whereas the control treatment produced the least values (153.03 dm² and 183.80 g, respectively). Nano zinc applied at 3 g/L also

resulted in significant improvements in leaf area and shoot dry weight, which reached 177.75 dm² and 221.08 g, respectively, compared to the control, which had 151.90 dm² and 185.84 g. The interaction effect was significant with the combination of 75 kg/ha K and 3 g/L Zn having the highest (201.2 dm² and 236.8 g, respectively).

Table 3: The impact of potassium and nano-zinc on the area of leaves and the dry weight of vegetation.

K (kg/ha)	Zn (g/L)	Vegetative Dry Weight (g)	Leaf Area (dcm ²)
0	3	197.4	164.3
0	2	191.2	157.6
0	1	178.4	148.5
0	0	168.2	141.7
25	3	205.4	167.3
25	2	196.3	161.4
25	1	190.4	155.3
25	0	179.5	147.2
50	3	221.4	178.2
50	2	209.6	168.6
50	1	203.4	163.1
50	0	187.9	152.6
75	3	236.8	201.2
75	2	225.4	189.1
75	1	215.8	178.4
75	0	206.3	166.1
Average	3	221.08	177.75
Average	2	205.63	169.18
Average	1	196.95	161.33
Average	0	185.84	151.90
LSD (0.05) Zn	—	6.12	5.11
LSD (0.05) K	—	6.12	5.11
LSD (0.05) Zn×K	—	12.24	10.22

3.3. Chlorophyll Content and Nitrogen Concentration

Table 4 also presents significant variations in chlorophyll content and leaf nitrogen concentration in relation to potassium and nano-zinc treatments. The maximum chlorophyll content (51.15 SPAD) was found in potassium application at the rate of 75 kg/ha, while the control yielded a value of 38.20 SPAD, and the 75 kg/ha K treatment also gave a maximum value of 1.76% nitrogen (an increase of 0.35% over the control), but the control yielded a lower value for nitrogen content (1.41%). The highest mean chlorophyll content obtained in response to nano-zinc treatment was

50.93 SPAD at 3 g/L, opposed to the untreated treatment (38.75 SPAD), but a high value of 1.72% was calculated for nitrogen content in the treated leaves for their respective concentrations. The lowest readings were observed in untreated plants (39.72 SPAD) for chlorophyll content and (1.44% urea) for nitrogen content in the untreated group of plants. The interaction of both treatments produced the highest chlorophyll content (57.3 SPAD) with the 75 kg K/ha plus 3 g/L Zn, with the control giving a lower result for the above parameters.

Table 4: Effect of Potassium and Nano-Zinc on Leaf Chlorophyll and Nitrogen

K (kg/ha)	Leaf Nitrogen (%) (Nano-Zn g/L)				Leaf Chlorophyll (SPAD) (Nano-Zn g/L)			
	3	2	1	0	3	2	1	0
0	1.52	1.47	1.36	1.28	43.6	40.1	36.7	32.4
25	1.64	1.56	1.48	1.37	49.7	44.2	40.9	35.8
50	1.79	1.68	1.57	1.51	53.1	50.2	44.7	41.2
75	1.94	1.82	1.71	1.58	57.3	52.8	48.9	45.6
Average	1.72	1.63	1.53	1.44	50.93	46.83	42.80	38.75
LSD (0.05)	Zn: 0.07	K: 0.07	Zn×K: 0.10	—	Zn: 2.34	K: 2.34	Zn×K: 4.68	—

3.4. Phosphorus and Potassium Concentrations in Leaves

Table 5: The data revealed that leaves with potassium and nano zinc have higher phosphorus and potassium concentrations. Treatment with 75 kg/ha potassium resulted in the highest phosphorus (0.64%) and potassium (1.91%) concentrations compared to control (0.37% and 1.56%).

Nano zinc foliar application at 3 g/L also increased nutrient content (0.56% and 1.92%) compared to the control (0.42% and 1.53%). The highest values (0.68% P and 2.27% K) occurred in the combined treatment (75 kg/ha K + 3g/L Zn), with the control showing the lowest concentrations.

Table 5: The Effect of Potassium and Nano-zinc on Phosphorus% and Potassium% in Leaf

K (kg/ha)	Potassium (%) (Nano-Zn g/L)				Phosphorus (%) (Nano-Zn g/L)			
	3	2	1	0	3	2	1	0
0	1.67	1.61	1.52	1.43	0.43	0.39	0.36	0.31
25	1.73	1.65	1.58	1.47	0.52	0.47	0.41	0.37
50	2.01	1.77	1.64	1.56	0.55	0.49	0.48	0.42
75	2.27	1.97	1.73	1.67	0.68	0.67	0.61	0.58
Average	1.92	1.75	1.62	1.53	0.56	0.51	0.47	0.42
LSD (0.05)	Zn: 0.11	K: 0.11	Zn×K: 0.22	—	Zn: 0.04	K: 0.04	Zn×K: 0.08	—

3.5. Inflorescence and Flower Production

From Table 6, it can be seen that the application of Potassium and nano-zinc had a significant effect on the number of inflorescences and flowers/inflorescence. Potassium at the rate of 75 kg/ha significantly increased the number of inflorescences and flowers/inflorescence (16.20 and 14.05, respectively) compared to the control (10.80 and 9.43). Similarly, application of nano-zinc (3 g/L) gave rise to the

number of inflorescences and flowers/inflorescence as 16.15 and 13.83, respectively, compared to the control (10.28 and 13.25, respectively). Combined effects of Potassium and zinc treatments (75 kg/ha of K + 3 g/L of Zn) also gave the highest results (20.2 inflorescences and 15.8 flowers, respectively) compared to the control (Table 6).

Table 6: Impact of Potassium and Nano-zinc on the Quantity of Inflorescences and Flowers

K (Kg/h)	*Flower No. per Inflorescence* (Nano-Zn gm/L)				Avg.	*Plant Inflorescences No.* (Nano-Zn gm/L)				Avg.
	3	2	1	0		3	2	1	0	
0	10.7	10.1	8.7	8.2	9.43	13.4	11.5	9.7	8.6	10.80
25	13.7	11.8	11.2	9.8	11.63	14.3	12.9	10.8	9.5	11.88
50	15.1	14.5	12.7	11.1	13.35	16.7	14.6	12.8	10.5	13.65
75	15.8	14.7	13.8	11.9	14.05	20.2	17.3	14.8	12.5	16.20
Average	13.83	12.78	11.60	10.25		16.15	14.08	12.03	10.28	
LSD (0.05)	Zn: 0.51	K: 0.51	Zn×K: 1.02			Zn: 0.82	K: 0.82	Zn×K: 1.64		

4. Discussion

The pooled means of Tables 2 to 6 above indicate that both potassium manuring and nano-zinc foliar application significantly enhanced vegetative and reproductive growth parameters of tomato plants. Potassium at 75 kg/ha significantly promoted plant height, number of leaves, leaf area, shoot biomass, chlorophyll content, percentage nitrogen, phosphorus and potassium in foliage as well as number of inflorescences and flowers per inflorescence. Potassium ions activate many enzymes^[19] and assist in the synthesis of proteins and nucleic acids, and photosynthesis^[19]. The regulation of stomatal movements allows optimum use of irrigated water through its increased efficiency^[20; 21]. Sulfur present in potassium sulfate is also used in vital amino acid synthesis (methionine, cysteine and cystine) and by cells in respiration (decarboxylation of pyruvic acid and Krebs cycle)^[22].

Application of nano-zinc 3 g/L had a significant positive effect on all vegetative and reproductive parameters. Formulation of zinc in nano-size and use of foliar application enriches zinc, which instantly gets absorbed by plant parts and translocated in the whole plant, stimulating the activity of plant enzymes, chlorophyll formation and photosynthetic activity^[23; 24]. Zinc is an important element in the formation of cytochromes and ferredoxin, and protein, carbohydrate and lipid biosynthesis, leading to vegetative vigour and better yield. Enhancement in shoot and flowers by the inclusion of works to increase the synthesis of auxins^[25].

5. Conclusions

These results demonstrated that the Potassium and nano-zinc combination synergistically affects the growth and productivity of tomato phytomass under greenhouse conditions for hybrid cultivars with high yield potential that respond to micronutrient supplementation. The statistically significant enhancements observed for all studied parameters of the inflorescence and floral growth undoubtedly are controlled by the synergistic effect of potassium and nano-zinc in combination.

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