Effect of mineral fertilization, biofertilizer, and foliar spraying with nano zinc on some element availability in soil and potato plant

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Abstract

A field experiment was conducted in sandy soil during autumn season of 2024-2025 at the Al-Firdaws Agricultural Project location in the Karbala desert. The aim was to study effect of three factors on the availability of some soil nutrients and the growth of potato (Arizona variety). The first factor represented mineral fertilization of macro elements at levels (0, 50, and 100%) of the fertilizer recommendation. The second factor represented nano-zinc spraying at three levels (without spraying, 1, and 2 g L^{-1}). The third factor was the biofertilizer EM1 (without addition, 10, and 20 g L^{-1}). Using a randomized complete block design (RCBD), the results showed the following: The 50% fertilizer recommendation for mineral fertilizer was excelled, and gave the highest average of available soil elements (nitrogen, phosphorus, potassium, and zinc) and the highest average concentration of the above elements in the leaves. The treatment without mineral fertilizer gave the lowest averages for the above-mentioned traits. The bi-interaction treatments (50% fertilizer recommendation for mineral fertilizer + nano zinc spraying at a concentration of 2 g L^{-1}), the treatment (50% fertilizer recommendation for mineral fertilizer + EM biofertilizer inoculation), and the treatment (nanofibrinium zinc spraying at a concentration of 2 g L^{-1} + biofertilizer inoculation) were significantly excelled and gave the highest averages for soil nutrients. Triple interaction treatment (50% fertilizer recommendation for mineral fertilizer + nano zinc spraying at a concentration of 2 g L^{-1} + E2 biofertilizer) was also significantly excelled and gave the highest averages for all traits. The studied treatments, while the treatment without spraying gave the lowest averages mentioned above. From this, we conclude that mineral fertilizers (50%) of the recommended fertilizers achieved excelled in most of the studied traits. In addition, the use of biofertilizers using the EM1 biofertilizer inoculation method led to a significant increase in soil element availability, the nutrient content of potato leaves, and most vegetative growth traits and yield components.

Keywords: Mineral fertilizer, nano zinc, biofertilizer, EM1, element availability, potato.

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Introduction

Mineral fertilizers are among the factors that affect plant yield due to their importance in the formation of the vegetative and root systems, where the roots directly absorb the nutrients contained in mineral fertilizers, and mineral fertilizers perform their function more quickly, allowing plants to grow at a faster rate and achieve a higher yield. Mineral fertilizers are often added in quantities greater than crop needs, which sometimes causes problems related to soil pollution. Therefore, the need to implement a new technology has arisen. It depends on adding biofertilizers, which consist of microscopic organisms that improve plant growth, as adding biofertilizers improves the quality of food production and maintains the ecological balance in it (11). Biofertilizers are considered an inexpensive source of food for plants, an alternative to the use of mineral fertilizers, as they can reduce the use of mineral fertilizers by up to (40-50%). Biofertilizers also have an effect in reducing environmental pollution, whether in soil or water. Biofertilizers are used in agriculture to encourage microorganisms to establish a symbiotic relationship with plants or enhance plant growth by increasing their supply of nutrients, the results of which appear directly on both the plant and the soil. Biofertilizers also support soil life, making it more fertile and balanced (34). In recent years, the world has turned to the use of nanotechnology in the field of agriculture, especially the production of nanofertilizers (14). Nanofertilizers are used instead of traditional fertilizers to meet the plant's need for the necessary nutrients to increase production and reduce the problem of the harmful effects of pollution on the soil and the environment. The advantages of nanofertilizers are the areas of their particles High surface area and increased density, as well as increased interactions on the exchange surfaces of organic and mineral colloids. It is noted through global research that nanofertilizers and foliar fertilization are the current focus of interest, and that current research on the use of nanofertilizers on leaves is more comprehensive than research related to their application in soil. Foliar nutrition is one of the most important methods for supplying plants with their nutritional needs. Foliar nutrition is coundected by spraying the green parts of plants in diluted solutions and is considered an important and successful method for treating nutrient deficiencies, especially micronutrients (13). Zinc is one of the micronutrients required by plants and is an essential element in enzyme activity and oxidation-reduction processes. It is an essential component of many proteins and increases potato production by increasing photosynthesis in green plants (43). Potato is an important crop in terms of nutrition, ranking fourth after wheat, corn, and rice, and belongs to the Solanaceae family. Potato is considered an important food crop locally, whether for direct consumption or processing (46). Potatoes are It can be grown in more than one season per year, and it can be grown in different climatic conditions. The amount of potato production in Iraq for the year 2023 reached about 4661 Mg per ton annually (1). The current study aims to demonstrate the effect of the interaction between foliar spraying with nano zinc, biofertilizer, and different levels of mineral fertilizers, namely zero, 50, and 100% of the fertilizer recommendation, on the availability of some nutrients in the soil and on the growth of potato plant.

Materials and Methods

Experiment Location

The experiment was conducted during the fall season of 2024/2025 at the Al-Firdaws Agricultural Project location in the Karbala desert, affiliated with Al-Liwaa International Company, one of the formations of the Al-Abbas's (p) Holy Shrine. The location is located at 32° 28' 54" north and 43° 48' 8.3" east, at an elevation of 32 m above sea level.

Soil Preparation

The field soil was prepared by cleaning it of the remains of the previous crop and weeds. It was then harrowed with a hoe to obtain completely clean soil. The soil was then plowed with a rotary plough, plowing crosswise to obtain well-loosened soil and smoothed with harrows. Soil samples were collected randomly from different areas of the field to a depth of (0-30 cm). The samples were thoroughly mixed to ensure homogeneity. A single composite sample was taken and some chemical and physical properties were assessed before cultivation, as shown in Table (1). The experimental land was then leveled and divided into experimental plots measuring (3 x 3 m), leaving 75 cm between units. A drip irrigation network was installed in the field.

Experiment Implementation

Arizona potato seeds (tubers) were planted on September 15, 2024, at a distance of 30 cm between plants. The first irrigation was given on the same day. Two tubers were planted in each hole, and the plants were thinned to one plant after 3 weeks of cultivation. The experimental units were separated from each other by a distance of 1 m.

Experimental Design

The experiment was conducted using a factorial experiment system according to a Randomized Complete Block Design (RCBD). The experimental unit included three replicates, each of which included (27) treatments distributed randomly. The number of experimental units was (81).

Table (1): Some chemical and physical properties of the study soil before cultivation

Traits	Values	Units
EC (1:1) Electrical conductivity	2.95	$DS.m^{-1}$
pH (1:1)	7.33	
CEC (cation exchange capacity)	19.31	Centimole $charge.kg^{-1}$
OM (organic matter)	0.11	$g.kg^{-1}$ Soil
Available nitrogen (NH4++NO3-)	20.4	$mg.kg^{-1}$ Soil

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Available phosphorus (P)		6.4	
Available potassium (K)		115	
Available zinc (Zn)		23	
Bulk density		0.1226	$Mg.m^{-3}$
soil separators	Sand	771	$g.kg^{-1}$ soil
	Silt	99	
	Clay	130	
Texture		LOAMY SAND	

Experimental Factors

1- **The first factor**: Mineral fertilizer (NPK) was added according to the agricultural parameters from the fertilizer recommendations, symbolized by (F). It was added at a rate of 0%, symbolized by (F0), 50%, symbolized by (F1), and 100%, symbolized by (F2).

- Nitrogen fertilizer (urea) (46% N) was added according to the fertilizer recommendations, at a rate of 180 $kg.ha^{-1}$ (in two batches, the first two weeks after cultivation and the second one month after cultivation).

- Phosphate fertilizer (P2O5) was added at a rate of 48%, according to the fertilizer recommendations, at a rate of 100 $kg.ha^{-1}$ (P) when preparing the land for cultivation.

- Potassium was added in the form of potassium sulfate (K2SO4) at a rate of (240 $kg.ha^{-1}$ (42% K) and in different addition quantities of 400 g. $plate^{-1}$ (3). The first batch was added at cultivation, the second batch 30 days after cultivation, and the third batch was added 50 days after cultivation. Chemical fertilizers were added according to the agricultural treatments at 0%, 50%, and 100% of the fertilizer recommendation. Irrigation and weeding continued as needed. Each experimental unit included (30) plants, and the required measurements were taken.

2- The second factor: Adding the biofertilizer EM1 Effective Microorganisms.

The biofertilizer (EM1), symbolized by (E), was generally added to each liter of this solution that was activated with 250 liters of water, to 500 liters of water. The biofertilizer (EM1) was added at three levels (0, 10, and 20). $g.L^{-1}$ (symbol: E0) with a concentration of (0 g of $preparation.L^{-1}$). It is symbolized by (E1) and a concentration of (10 g of $preparation.L^{-1}$) and symbolized by (E2)) and a concentration of (20 g of $preparation.L^{-1}$) locally produced and added by feeding.

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3- The third factor: Spraying nano zinc in the form of nano zinc oxide Zn_2O_3 (80% Zn) with a purity of (90%), purchased from Khazra Nano Chelated Fertilizer Company in Iran (a completely water-soluble powder). The nano zinc element was sprayed at three levels: (symbol: Z0 = 0 $g.L^{-1}$, Z1 = 1 $g.L^{-1}$, Z2 = 2 g.L-1).

Studies traits:

Chemical and physical analyses of the soil before cultivation

1) Electrical conductivity: (EC) was measured using Conductivity Bridge device in a 1:1 soil:water suspension according to the method in (29).

2) Soil reaction degree: (pH) was measured using a pH meter in a (1:1) soil:water suspension according to the method in (29).

3) Cation exchange capacity: (CEC) was estimated using 1 M ammonium acetate as stated in (9).

4) Available nitrogen: Available nitrogen was estimated by extraction with 2 M potassium chloride solution using a microkjeldahl device according to the Bremmer method in (29).

5) Available phosphorus: Estimated using the Olsen method by extracting it with 0.5 M sodium bicarbonate ($NaHCO_3$) and color-grading it with ammonium molybdate and ascorbic acid. The estimation was then carried out using a spectrophotometer at a wavelength of 882 nm as stated in (29).

6) Available potassium: Extracted using Ammonium acetate was estimated using a flame device according to the method mentioned in (29).

7) Available zinc: Zinc was extracted using a diethylenetriaminepentaacetic acid (DTPA) and triethanolamine (TEA) solution. 20 ml of DTPA and TEA solutions were added and shaken on a mechanical shaker. The extract was then filtered and zinc was measured using an atomic absorption spectrometer (24).

8) Organic matter: Estimated according to the Walkley and Black method mentioned in (29).

9) Bulk density: Estimated using the cylindrical ring sample method according to (8).

10) Soil texture: Estimated using the hydrometer method mentioned in (8).

Estimation of Nutrient Elements in Leaves

The fourth leaf was taken from the growing tip of the main stem of five randomly selected plants from each experimental unit. The leaves were washed to remove dirt and dust and dried in an electric oven with a vacuum at 65°C until the weight was constant. They were then ground and placed in tightly sealed paper bags and stored in a dry place. Wet digestion was then carried out, where 0.2 g of the plant sample was taken and digested using sulfuric and perchloric acid in a ratio of 3:5, according to the method proposed by [10]. After the digestion process was completed, the following elements were estimated:

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1) Estimation of Nitrogen in Leaves: Nitrogen was estimated by evaporation and distillation using a micro-Kjeldahl apparatus, according to the method described in (29).

2) Estimation of Phosphorus in Leaves: It was estimated using a spectrophotometer at a wavelength of 882 nm, as described in (29).

3) Estimation of potassium in leaves: Estimated in the vegetative part of the leaves using a flame device, according to the method mentioned in (29).

4) Estimation of zinc concentration in leaves: The zinc concentration in plant leaves was estimated using an atomic absorption spectrophotometer, according to what was mentioned in (20).

Statistical Analysis

The data were analyzed statistically according to the randomized complete block design (RCBD) using the Genstat program. The least significant difference (LSD) test was used to distinguish statistically different means at a 5% significance level for each source of variance.

Results and Discussion

Effect of nano-zinc spraying and adding biofertilizer and mineral fertilizer on soil element availability

Available nitrogen in soil (mg kg^{-1} soil)

The results of Table (2) indicate significant differences between the levels of the study factors in their effect on the available nitrogen content in soil. The nano-zinc spraying treatment, at a level of 2 g L-1significantly excelled the control treatment, gave the highest average of 35.91 mg kg^{-1} soil, compared to the treatment without nano-zinc spraying (the control treatment), which gave the lowest average of 27.32 mg kg^{-1} soil. As for the biofertilizer addition factor, the 20 g L^{-1} level significantly excelled on the control treatment, gave the highest average of 34.37 mg kg^{-1} soil, compared to the treatment without fertilizer, which gave the lowest average of 28.18 mg kg^{-1} soil. The mineral fertilizer factor excelled on the control treatment. 50% significantly and gave the highest average of 32.05 mg kg^{-1} soil, while the treatment without adding mineral fertilizer gave the lowest average of 28.68 mg kg^{-1} soil. As for bi- treatments, the treatment (2 g L^{-1} nano zinc + 20 g L^{-1} biofertilizer) was significantly excelled and gave the highest average of 38.68 mg kg-1 soil compared to the treatment (without adding nano zinc and without adding biofertilizer), which gave the lowest average of 22.42 mg kg^{-1} soil. As for bi- interaction between nano zinc and mineral fertilizer, the treatment (2 g L^{-1} + 50% recommendation mineral fertilizer) was significantly excelled and gave the highest average of 38.78 mg kg^{-1} soil compared to the treatment (without adding nano zinc and without adding mineral fertilizer) and gave the lowest average of 24.99 mg kg-1 soil. The results of bi- interaction between adding

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biofertilizer and mineral fertilizer showed that the treatment (20 g L^{-1} biofertilizer + mineral fertilizer with 50% recommendation) was significantly excelled. The highest average was 37.43 mg kg-1 soil, compared to the treatment without fertilizer and without mineral fertilizer, which gave the lowest average of 26.24 mg kg^{-1} soil.

Table (2) Effect of nano-zinc spraying and adding biofertilizer and mineral fertilizer on nitrogen availability in the soil after cultivation (mg kg^{-1} soil)

nano zinc	biofertilizer	% mineral fertilizer			Zn*EM1
		0	50	100	
0	0	20.43	24.13	22.70	22.42
	10	27.30	31.77	28.83	29.30
	20	26.83	32.43	31.03	30.10
1	0	26.67	30.87	29.10	28.88
	10	28.80	34.77	32.03	31.87
	20	31.37	37.47	34.20	34.34
2	0	31.23	34.83	33.27	33.11
	10	32.47	39.10	36.23	35.93
	20	32.60	42.40	41.03	38.68
LSD*0.05*		1.696			0.979
Zn * C					average Zn
0		24.99	29.44	27.52	27.32
1		28.94	34.37	31.78	31.70
2		32.10	38.78	36.84	35.91
LSD*0.05*		0.979			0.565
EM1 * C					average EM1
0		26.24	29.94	28.36	28.18
10		29.52	35.21	32.37	32.37
20		30.27	37.43	35.42	34.37
LSD*0.05*		0.979			0.565
Average		28.68	34.20	32.05	
LSD*0.05*		0.565			

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As for the triple interaction between the factors, the treatment (2 g L^{-1} nano zinc + 20 g L^{-1} biofertilizer + 50% mineral fertilizer recommendation) was significantly excelled and gave the highest average of 42.40 mg kg^{-1} soil compared to the treatment of not adding zinc, biofertilizer, and mineral fertilizer, which gave the lowest average of 20.43 mg kg^{-1} soil.

Available Phosphorus in Soil (mg kg^{-1} soil)

The results of Table (3) indicate significant differences between the levels of the study factors in affecting the property of available phosphorus in the soil. The treatment of nano zinc spraying at a level of 2 g L^{-1} was significantly excelled and gave the highest average of 9.56 mg kg-1 soil compared to the treatment without nano zinc spraying (control treatment), which gave the lowest average of 8.20 mg kg-1 soil. As for the factor of adding biofertilizer, the level of 20 g L-1 was significantly excelled and gave the highest average of 9.99 mg kg^{-1} soil compared to the treatment without adding fertilizer, which gave the lowest average of 8.11 mg kg^{-1} soil. As for the factor of mineral fertilizer, the recommendation 50% was significantly excelled and gave the highest average of 9.66 mg kg^{-1} soil, while it gave The treatment without adding mineral fertilizer had the lowest average of 8.34 mg kg^{-1} of soil.

Table (3) Effect of nano-zinc spraying and adding biofertilizer and mineral fertilizer on phosphorus availability in the soil after cultivation.

nano zinc	biofertilizer	% mineral fertilizer			Zn*EM1
		0	50	100	
0	0	6.47	7.60	7.53	7.20
	10	7.87	8.77	8.37	8.33
	20	8.70	9.50	9.03	9.08
1	0	7.63	9.27	8.47	8.46
	10	8.70	9.67	9.30	9.22
	20	9.30	11.00	10.33	10.21
2	0	8.20	9.17	8.67	8.68
	10	9.33	9.63	9.00	9.32
	20	8.83	12.30	10.93	10.69
LSD*0.05*		0.779			0.450
Zn * C					average Zn

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0	**7.68**	**8.62**	**8.31**	**8.20**
1	**8.54**	**9.98**	**9.37**	**9.30**
2	**8.79**	**10.37**	**9.53**	**9.56**
LSD*0.05*	**0.450**			**0.260**
EM1 * C				**average EM1**
0	**7.43**	**8.68**	**8.22**	**8.11**
10	**8.63**	**9.36**	**8.89**	**8.96**
20	**8.94**	**10.93**	**10.10**	**9.99**
LSD*0.05*	**0.450**			**0.260**
Average	**8.34**	**9.66**	**9.07**	
LSD*0.05*	**0.260**			

As for bi- treatments, the treatment (2 g L^{-1} nano zinc + 20 g L^{-1} biofertilizer) was significantly excelled and gave the highest average of 10.69 mg kg-1 soil compared to the treatment (without adding nano zinc and without adding biofertilizer), which gave the lowest average of 7.20 mg kg^{-1} soil. As for bi-interaction between nano zinc and mineral fertilizer, the treatment (2 g L^{-1} + 50% recommendation mineral fertilizer) was significantly excelled and gave the highest average of 10.37 mg kg^{-1} soil compared to the treatment (without adding nano zinc and without adding mineral fertilizer) and gave the lowest average of 7.68 mg kg^{-1} soil. The results of bi- interaction between adding biofertilizer and mineral fertilizer showed that the treatment (20 g L-1 biofertilizer + mineral fertilizer with 50% recommendation) was significantly excelled. It gave the highest average of 10.93 mg kg-1 soil, compared to the treatment without adding fertilizer and without adding mineral fertilizer, which gave the lowest average of 7.43 mg kg-1 soil. As for triple interaction between the factors, the treatment (2 g L^{-1} nano zinc + 20 g L^{-1} biofertilizer + 50% mineral fertilizer recommendation) was significantly excelled and gave the highest average of 12.30 mg kg-1 soil, compared to the treatment without adding zinc, biofertilizer, and mineral fertilizer, which gave the lowest average of 6.47 mg kg^{-1} soil.

Available Potassium in Soil (mg kg^{-1} soil)

The results of Table (4) indicate significant differences between the levels of the study factors influencing the property of available potassium in soil. The nano-zinc spray treatment at a level of 2 g L-1 significantly excelled on, gave the highest average of 137.00 mg kg^{-1} soil. Compared to the

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treatment without nano zinc spray (control treatment), which gave the lowest average of 121.37 mg kg^{-1} soil, as for the factor of adding biofertilizer, the level of 20 g L^{-1} was significantly higher and gave the highest average of 133.41 mg kg^{-1} soil compared to the treatment without adding fertilizer, which gave the lowest average of 125.07 mg kg^{-1} soil. As for the factor of mineral fertilizer, the recommendation was significantly higher by 50% and gave the highest average of 132.41 mg kg^{-1} soil, while the treatment without adding mineral fertilizer gave the lowest average of 124.70 mg kg-1 soil. As for bi-treatments, the treatment (2 g L-1 nano zinc + 20 g L^{-1} biofertilizer) was significantly excelled and gave the highest average of 143.22 mg kg^{-1} soil compared to the treatment (without adding nano zinc and without adding biofertilizer), which gave the lowest average of 116.56 mg kg^{-1} soil. As for bi- interaction between nano zinc and mineral fertilizer, the treatment (2 g L-1 + the recommendation of 50% mineral fertilizer) was significantly excelled and gave the highest average of 141.89 mg kg-1 soil compared to the treatment (without adding nano zinc and without adding mineral fertilizer) and gave the lowest average of 119.11 mg kg-1 soil. The results of bi- interaction between adding biofertilizer and mineral fertilizer showed that the treatment (20 g L-1 biofertilizer + mineral fertilizer as recommended) was superior. 50% significantly higher, gave the highest average of 138.11 mg kg^{-1} soil, compared to the treatment without fertilizer and without mineral fertilizer, which gave the lowest average of 122.33 mg kg^{-1} soil. As for triple interaction between the factors, the treatment (2 g L-1 nano zinc + 20 g L^{-1} biofertilizer + 50% recommended mineral fertilizer) gave the highest average of 151.00 mg kg-1 soil, compared to the treatment without zinc, biofertilizer, and mineral fertilizer, which gave the lowest average of 115.00 mg kg^{-1} soil.

Table (4) Effect of spraying nano zinc and adding biofertilizer and mineral fertilizer on potassium availability in the soil after cultivation.

nano zinc	biofertilizer	% mineral fertilizer			Zn*EM1
		0	50	100	
0	0	115.00	118.33	116.33	116.56
	10	118.33	123.33	123.33	121.67
	20	124.00	128.67	125.00	125.89
1	0	124.33	128.33	128.00	126.89
	10	124.33	132.67	128.67	128.56

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	20	127.00	134.67	131.67	131.11
2	0	127.67	135.33	132.33	131.78
	10	131.67	139.33	137.00	136.00
	20	130.00	151.00	148.67	143.22
LSD*0.05*		4.557			2.631
Zn * C					average Zn
0		119.11	123.44	121.56	121.37
1		125.22	131.89	129.44	128.85
2		129.78	141.89	139.33	137.00
LSD*0.05*		2.631			1.519
EM1 * C					average EM1
0		122.33	127.33	125.56	125.07
10		124.78	131.78	129.67	128.74
20		127.00	138.11	135.11	133.41
LSD*0.05*		2.631			1.519
Average		124.70	132.41	130.11	
LSD*0.05*		1.519			

Available Zinc in Soil (mg kg-1 soil)

The results of Table (5) indicate significant differences between the levels of the study factors in affecting the property of available zinc in the soil. The treatment of nano zinc spraying at a level of 2 g L-1 was significantly excelled and gave the highest average of 35.81 mg kg^{-1} soil compared to the treatment without nano zinc spraying (control treatment), which gave the lowest average of 28.07 mg kg^{-1} soil. As for the factor of adding biofertilizer, the level of 20 g L^{-1} was significantly excelled and gave the highest average of 34.24 mg kg^{-1} soil compared to the treatment without adding fertilizer, which gave the lowest average of 28.99 mg kg^{-1} soil. As for the factor of mineral fertilizer, the recommendation 50% was significantly excelled and gave the highest average of 33.84 mg kg^{-1} soil. The treatment without adding mineral fertilizer gave the lowest average of 29.41 mg kg^{-1} of soil.

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Table (5) Effect of nano-zinc spraying and adding biofertilizer and mineral fertilizer on zinc availability in soil after cultivation.

nano zinc	biofertilizer	% mineral fertilizer			Zn*EM1
		0	50	100	
0	0	23.07	25.63	25.67	24.79
	10	26.93	30.47	28.37	28.59
	20	28.40	33.27	30.87	30.84
1	0	27.43	30.20	28.40	28.68
	10	28.63	33.70	31.73	31.36
	20	31.50	35.60	33.40	33.50
2	0	30.83	36.73	32.90	33.49
	10	32.70	38.07	35.93	35.57
	20	35.20	40.93	39.00	38.38
LSD*0.05*		1.042			0.602
Zn * C					average Zn
0		26.13	29.79	28.30	28.07
1		29.19	33.17	31.18	31.18
2		32.91	38.58	35.94	35.81
LSD*0.05*		0.602			0.347
EM1 * C					average EM1
0		27.11	30.86	28.99	28.99
10		29.42	34.08	32.01	31.84
20		31.70	36.60	34.42	34.24
LSD*0.05*		0.602			0.347
Average		29.41	33.84	31.81	
LSD*0.05*		0.347			

As for bi- treatments, the treatment (2 g L-1 nano zinc + 20 g L-1 biofertilizer) was significantly excelled and gave the highest average of 38.38 mg kg^{-1} soil compared to the treatment (without adding nano zinc and without adding biofertilizer), which gave the lowest average of 24.79 mg kg^{-1} soil. As for bi- interaction between nano zinc and mineral fertilizer, the treatment (2 g L^{-1} + 50% recommendation mineral fertilizer) was significantly excelled and gave the highest average of 38.58 mg kg-1 soil compared to

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the treatment (without adding nano zinc and without adding mineral fertilizer) and gave the lowest average of 26.13 mg kg^{-1} soil. The results of bi- interaction between adding biofertilizer and mineral fertilizer showed that the treatment (20 g L^{-1} biofertilizer + mineral fertilizer with 50% recommendation) was significantly excelled. It gave the highest average of 36.60 mg kg-1 soil, compared to the treatment without adding fertilizer and without adding mineral fertilizer, which gave the lowest average of 27.11 mg kg^{-1} soil. As for triple interaction between the factors, the treatment (2 g L^{-1} nano zinc + 20 g L^{-1} biofertilizer + 50% mineral fertilizer recommendation) was significantly excelled, gave the highest average of 40.93 mg kg^{-1} soil, compared to the treatment without adding zinc, biofertilizer, and mineral fertilizer, which gave the lowest average of 23.07 mg kg^{-1} soil.

The effect of nano-zinc spraying and adding biofertilizer and mineral fertilizer on leaf nutrient content

Nitrogen concentration in leaves (%)

The results of Table (8) indicate significant differences between the levels of the study factors in their effect on leaf nitrogen content. The nano-zinc spraying treatment, at a level of 2 g.L-1significantly excelled the control treatment, gave the highest average of 2.27%, compared to the treatment without nano-zinc spraying (the control treatment), which gave the lowest average of 1.95%. As for the biofertilizer addition factor, the 20 g.L^{-1} level significantly excelled on the control treatment, gave the highest average of 2.23%, compared to the treatment without adding fertilizer, which gave the lowest average of 2.00%. The mineral fertilizer factor, the 50% recommendation, gave the highest average of 2.19%, while the treatment without adding mineral fertilizer gave the lowest average of 2.04%. As for bi- treatments, the treatment (2 g L-1 nano zinc + 20 g L-1 biofertilizer) was significantly excelled and gave the highest average of 2.44% compared to the treatment (without adding nano zinc and without adding biofertilizer), which gave the lowest average of 1.78%. As for bi- interaction between nano zinc and mineral fertilizer, the treatment (2 g L^{-1} + the recommendation of 50% mineral fertilizer) was significantly excelled and gave the highest average of 2.37% compared to the treatment (not adding nano zinc and not adding mineral fertilizer) and gave the lowest average of 1.90%. The results of bi-interaction between adding biofertilizer and mineral fertilizer showed that the treatment (20 g L^{-1} biofertilizer + mineral fertilizer with a recommendation of 50%) was significantly excelled and gave the highest average of 2.36% compared to the treatment of not adding fertilizer and not adding mineral fertilizer, which gave the lowest The average was 1.96%. As for triple interaction between

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the factors, the treatment (2 g L^{-1} nano zinc + 20 g L^{-1} biofertilizer + 50% recommended mineral fertilizer) was significantly excelled, gave the highest average of 2.60%, compared to the treatment without adding zinc, biofertilizer, and mineral fertilizer, which gave the lowest average of 1.77%.

Table (8) Effect of spraying nano zinc and adding biofertilizer and mineral fertilizer on the percentage of nitrogen in leaves.

nano zinc	biofertilizer	% mineral fertilizer			Zn*EM1
		0	50	100	
0	0	1.77	1.78	1.78	1.78
	10	1.92	2.07	2.03	2.00
	20	2.00	2.11	2.07	2.06
1	0	2.06	2.15	2.09	2.10
	10	2.02	2.15	2.10	2.09
	20	2.08	2.38	2.15	2.20
2	0	2.07	2.19	2.12	2.13
	10	2.15	2.32	2.25	2.24
	20	2.28	2.60	2.45	2.44
LSD*0.05*		0.038			0.022
Zn * C					average Zn
0		1.90	1.98	1.96	1.95
1		2.05	2.23	2.11	2.13
2		2.17	2.37	2.27	2.27
LSD*0.05*		0.022			0.013
EM1 * C					average EM1
0		1.96	2.04	2.00	2.00
10		2.03	2.18	2.12	2.11
20		2.12	2.36	2.22	2.23
LSD*0.05*		0.022			0.013
Average		2.04	2.19	2.11	
LSD*0.05*		0.013			

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Phosphorus concentration in leaves %

The results of Table (9) indicate significant differences between the levels of the study factors influencing leaf phosphorus content. The nanozinc spray treatment, at a level of 2 $g.L^{-1}$significantly excelled the control treatment, gave the highest average of 0.51%, compared to the treatment without nanozinc spray (the control treatment), which gave the lowest average of 0.37%. As for the biofertilizer addition factor, the 20 $g.L^{-1}$ level significantly excelled on the control treatment, gave the highest average of 0.47%, compared to the treatment without fertilizer, which gave the lowest average of 0.41%. The mineral fertilizer factor, the 50% recommendation, gave the highest average of 0.47%, while the treatment without mineral fertilizer gave the lowest average of 0.42%.

Table (9) The effect of nano zinc spraying and adding biofertilizer and mineral fertilizer on the percentage of phosphorus in the leaves.

nano zinc	biofertilizer	% mineral fertilizer			Zn*EM1
		0	50	100	
0	0	0.33	0.33	0.33	0.33
	10	0.36	0.42	0.39	0.39
	20	0.39	0.36	0.44	0.40
1	0	0.39	0.46	0.44	0.43
	10	0.40	0.49	0.44	0.44
	20	0.43	0.52	0.48	0.47
2	0	0.45	0.51	0.47	0.48
	10	0.47	0.54	0.51	0.51
	20	0.51	0.60	0.54	0.55
LSD*0.05*		0.016			0.009
Zn * C					average Zn
0		0.36	0.37	0.39	0.37
1		0.41	0.49	0.45	0.45
2		0.48	0.55	0.51	0.51
LSD*0.05*		0.009			0.005
EM1 * C					average EM1
0		0.39	0.43	0.41	0.41
10		0.41	0.48	0.45	0.45

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20	0.44	0.49	0.48	0.47
LSD*0.05*	0.009			0.005
Average	0.42	0.47	0.45	
LSD*0.05*	0.005			

As for bi- treatments, the treatment (2 g L^{-1} nano zinc + 20 g L^{-1} biofertilizer) was significantly excelled and gave the highest average of 0.55% compared to the treatment (without adding nano zinc and without adding biofertilizer), which gave the lowest average of 0.33%. As for bi- interaction between nano zinc and mineral fertilizer, the treatment (2 g L-1 + the recommendation of 50% mineral fertilizer) was significantly excelled and gave the highest average of 0.55% compared to the treatment (not adding nano zinc and not adding mineral fertilizer) and gave the lowest average of 0.36%. The results of bi-interaction between adding biofertilizer and mineral fertilizer showed that the treatment (20 g L^{-1} biofertilizer + mineral fertilizer with a recommendation of 50%) was significantly excelled and gave the highest average of 0.49% compared to the treatment of not adding fertilizer and not adding mineral fertilizer, which gave the lowest The average was 0.39%. As for triple interaction between the factors, the treatment (2 g L^{-1} nano zinc + 20 g L-1 biofertilizer + 50% recommended mineral fertilizer) was significantly excelled, gave the highest average of 0.60%, compared to the treatment without adding zinc, biofertilizer, and mineral fertilizer, which gave the lowest average of 0.33%.

Potassium Concentration in Leaves (%)

The results of Table (10) indicate significant differences between the levels of the study factors influencing the percentage of potassium in leaves. The treatment of nano-zinc spraying at a level of 2 g L-1 significantly excelled on, gave the highest average of 3.37%, compared to the treatment without nano-zinc spraying (the control treatment), which gave the lowest average of 2.46%. As for the factor of adding biofertilizer, the level of 20 g L-1 significantly excelled on, gave the highest average of 3.32%, compared to the treatment without adding fertilizer, which gave the lowest average of 2.70%. As for the factor of mineral fertilizer, the 50% recommendation significantly excelled on, gave the highest average of 3.27%, while the treatment without adding mineral fertilizer gave the lowest average of 2.78%.

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Table (10) The effect of nano zinc spraying and adding biofertilizer and mineral fertilizer on the percentage of potassium in the leaves.

nano zinc	biofertilizer	% mineral fertilizer			Zn*EM1
		0	50	100	
0	0	1.98	1.95	2.01	1.98
	10	2.29	2.82	2.56	2.56
	20	2.56	3.19	2.79	2.85
1	0	2.76	3.19	2.96	2.97
	10	2.96	3.42	3.19	3.19
	20	3.26	3.89	3.56	3.57
2	0	2.86	3.46	3.16	3.16
	10	3.12	3.62	3.46	3.40
	20	3.26	3.89	3.49	3.55
LSD*0.05*		0.139			0.080
Zn * C					average Zn
0		2.28	2.65	2.45	2.46
1		2.99	3.50	3.23	3.24
2		3.08	3.66	3.37	3.37
LSD*0.05*		0.080			0.046
EM1 * C					average EM1
0		2.53	2.87	2.71	2.70
10		2.79	3.29	3.07	3.05
20		3.02	3.66	3.28	3.32
LSD*0.05*		0.080			0.046
Average		2.78	3.27	3.02	
LSD*0.05*		0.046			

As for bi- treatments, the treatment (2 g L-1 nano zinc + 20 g L-1 biofertilizer) was significantly excelled and gave the highest average of 3.55% compared to the treatment (without adding nano zinc and without adding biofertilizer), which gave the lowest average of 1.98%. As for bi- interaction between nano zinc and mineral fertilizer, the treatment (2 g L-1 + the recommendation of 50% mineral fertilizer) was significantly excelled and gave

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the highest average of 3.66% compared to the treatment (not adding nano zinc and not adding mineral fertilizer) and gave the lowest average of 2.28%. The results of bi-interaction between adding biofertilizer and mineral fertilizer showed that the treatment (20 g L-1 biofertilizer + mineral fertilizer with a recommendation of 50%) was significantly excelled and gave the highest average of 3.66% compared to the treatment of not adding fertilizer and not adding mineral fertilizer, which gave the lowest The average was 2.53%. As for the triple interaction between the factors, the treatment (2 g L-1 nano zinc + 20 g L-1 biofertilizer + 50% recommended mineral fertilizer) was significantly excelled, gave the highest average of 3.89% compared to the treatment without adding zinc, biofertilizer, and mineral fertilizer, which gave the lowest average of 1.98%.

Zinc concentration in leaves (mg kg-1 dry matter)

The results of Table (11) indicate significant differences between the levels of the study factors in their effect on leaf zinc content. The nanozinc spray treatment at a level of 2 g L-1 significantly excelled on the control treatment, gave the highest average of 29.25 mg kg-1 dry matter, compared to the treatment without nanozinc spray (the control treatment), which gave the lowest average of 19.67 mg kg-1 dry matter. As for the biofertilizer addition factor, the 20 g L-1 level significantly excelled on the control treatment, gave the highest average of 25.51 mg kg-1 dry matter, compared to the treatment without fertilizer, which gave the lowest average of 21.43 mg kg-1 dry matter.

Table (11) Effect of nanozinc spray, biofertilizer, and mineral fertilizer on leaf zinc content.

nano zinc	biofertilizer	% mineral fertilizer			Zn*EM1
		0	50	100	
0	0	19.02	19.15	19.07	19.08
	10	19.32	20.15	19.70	19.72
	20	19.73	20.65	20.21	20.20
1	0	19.80	20.41	20.11	20.11
	10	19.99	20.66	20.41	20.35
	20	20.68	25.61	23.00	23.10
2	0	23.52	26.68	25.12	25.11
	10	27.39	32.04	28.77	29.40
	20	30.02	36.49	33.18	33.23

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LSD0.05	0.807			0.466
Zn * C				average Zn
0	19.36	19.98	19.66	19.67
1	20.16	22.23	21.17	21.19
2	26.98	31.74	29.02	29.25
LSD0.05	0.466			0.269
EM1 * C				average EM1
0	20.78	22.08	21.43	21.43
10	22.24	24.28	22.96	23.16
20	23.48	27.58	25.46	25.51
LSD0.05	0.466			0.269
Average	22.16	24.65	23.29	
LSD0.05	0.269			

As for the mineral fertilizer factor, the 50% recommendation was significantly excelled, gave the highest average of 24.65 mg kg-1 dry matter, while the treatment without adding mineral fertilizer gave the lowest average of 22.16 mg kg-1 dry matter. As for the bi-interaction between nano zinc and mineral fertilizer, the treatment (2 g L-1 + 50% recommendation of mineral fertilizer) was significantly excelled and gave the highest average of 31.74 mg kg-1 dry matter compared to the treatment (no addition of nano zinc and no addition of mineral fertilizer) and gave the lowest average of 19.36 mg kg-1 dry matter, while the results of the bi-interaction between adding biofertilizer and mineral fertilizer showed that the treatment (20 g L-1 biofertilizer + mineral fertilizer with 50% recommendation) was significantly excelled and gave the highest average of 27.58 mg kg-1 dry matter compared to the treatment of no addition of fertilizer and no addition of mineral fertilizer, which gave the lowest average of 20.78 mg kg-1 dry matter. As for triple interaction between the factors, the treatment (2 g L-1 nano zinc + 20 g L-1 biofertilizer + 50% mineral fertilizer recommendation) significantly excelled on, gave the highest average of 36.49 mg kg-1 dry matter, compared to the treatment without adding zinc, biofertilizer, and mineral fertilizer, which gave the lowest average of 19.02 mg kg-1 dry matter.

Discussion

Effect of mineral fertilizer, biofertilizers, and nano zinc spraying on soil nutrient availability indicators.

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The results of Tables (2-5) indicated a significant effect of adding 50% of the fertilizer recommendation to mineral fertilizer on soil nutrient availability indicators (nitrogen, phosphorus, potassium, and zinc). This may be due to the role of mineral fertilizer in increasing soil nutrient availability. This is consistent with what was found by (2) and (34). Nanofertilizers provide crops with nutrients delivered in the form of nanoscale particles or emulsions. They may be more effective than traditional polymer-encapsulated fertilizers, which have seen significant improvements in the past ten years (12). Nanofertilizers have been used to fertilize plants to reduce the use of traditional mineral fertilizers added to the soil, reduce soil contamination with fertilizer and pesticide residues, and protect the environment. They are a type of fertilizer made from organic and mineral materials, are compatible with the environment and plants, and play a role in increasing nutrient efficiency and reducing soil toxicity and the indiscriminate use of mineral fertilizers (2). Adding micronutrient fertilizers to the soil may not meet crop growth requirements, especially when the nutrients are in the form of compounds that are difficult to absorb through the roots. This requires adding large quantities of fertilizers to meet the plant's needs in the case of soil fertilization. For example, iron and zinc are difficult to decompose when added to alkaline soils containing a high percentage of calcium carbonate, so it is preferable to spray them on the plant's vegetative system (21). By improving nutrient use efficiency and overcoming chronic problems, nano-fertilizers may be the best alternative (40). The reason for the increased zinc concentration in the vegetative part of the plant may be due to the increased biomass production, which leads to increased nutrient absorption from the soil. Fertilizers encapsulated in nanoparticles will increase nutrient absorption, leading to higher values of nutrient elements (nitrogen, phosphorus, potassium, and zinc) in the soil (44). The effect of adding biofertilizers had a significant effect on the values of (nitrogen, phosphorus, potassium, and zinc) available in the soil. This may be due to the effectiveness of soil microorganisms in activating the conversion of nutrients from their complex state to the state Available for absorption and the availability of elements in a manner suitable for plant growth in the soil, which led to the creation of physiological balance and the activation of vital activities in the plant. This was positively reflected in the increase in the process of carbon metabolism and the accumulation of the manufactured material in plant tissues, which in turn contributed to the increase in cell division and elongation and thus the increase in their area. This is consistent with what was found by (33) and

(16). The results of the above tables showed that adding biofertilizers leads to a significant increase in the characteristics of the availability of nutrients in the soil after harvest (available nitrogen, available phosphorus, available potassium, available zinc). This increase may be due to the role of microorganisms in the secretion of organic and inorganic acids, which leads to a reduction in the values of the degree of soil reaction and thus an increase in the availability of nutrients. (27) (42) Biofertilization includes the use of beneficial soil microorganisms for the purpose of employing them in improving the biological properties of the soil, as they work to maintain the balance of nutrients in agricultural soil and convert them into forms Available to feed the plant) 7) and ((30.

The reason may also be due to the role of biofertilizer in improving soil properties, which reduces nitrogen loss (23) and (15). The reason for the increase in available potassium may also be due to the role of microorganisms, which help increase potassium availability and protect it from fixation and loss through the secretion of certain enzymes and organic acids (41). These results are consistent with (25), (36), and (39), which stated that the addition of biofertilizers leads to an increase in some nutrients (nitrogen, potassium) because organisms have the ability to release some nutrients when an energy source is available for these organisms. The interaction between adding 50% mineral fertilizer levels with biofertilizer had a significant effect on the studied characteristics, because mineral fertilizers have an effective role in supplying the soil with its need for nutrients, and the reason for this may be due to the availability of basic nutrients in mineral fertilizer, in addition to the role of biofertilizer in producing organic acids that dissolve phosphorus and producing calcium chelating compounds and releasing phosphorus and the role of organic matter in providing phosphorus by improving soil properties, and this is consistent with what was found by (31) and (41). The reason for the increase in the availability of elements in the soil is due to the role of biofertilizers through the ability of the bacterial inoculum to dissolve the precipitated phosphate compounds and release them into the soil solution in a Available form ($H_2PO_4^-$) dihydrogen phosphate ion and (HPO4-2) monohydrogen phosphate ion. Basillus bacteria work to increase the availability of phosphorus by lowering the soil pH (Satyaprakash et al. 2017). This may also be due to the role of adding mineral fertilizer and increasing the activity of microorganisms in the soil, which leads to the element being converted into a form Available for absorption by the plant throughout the growth

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period. This is consistent with what was found by (2) and (34).

The Effect of Mineral Fertilizers, Biofertilizers, and Nano-Zinc Spraying on Potato Leaf Nutrient Indices

The results of Tables (7-11) indicate a significant effect of adding 50% of the recommended nutrient requirement for mineral fertilizer on the nutrient content of potato leaves (nitrogen, phosphorus, potassium, and zinc). This may be due to the fact that the increase in nitrogen, phosphorus, and potassium concentrations, as well as zinc content in the vegetative part (leaves), of the potato plant, is associated with increased levels of N, P, and K. This leads to increased availability of nutrients for the plant, thus increasing their concentrations in the plant leaves and their role in the activity of biological processes, and the growth and branching of the root system in the soil, which increases the efficiency of nutrient absorption. This is consistent with (18), (45), and (35). Zinc nano fertilizer plays a fundamental role in increasing plant growth and nutrient absorption. That is, increasing the nutrient content of the plant's vegetative group according to nanotechnology is due to the role of nano fertilizers in providing a larger surface area for various metabolic reactions in the plant, which increases the rate of carbon assimilation. Zinc also targets the cell wall and increases the effectiveness of biochemical conversion processes (4) and (22). The reason for increasing the concentration of zinc in the vegetative part of the plant leads to increased biomass production and increased nutrient absorption from the soil and fertilizers encapsulated in nanoparticles, which will increase nutrient absorption (44) and (38). (28) also indicated that the reason may be due to the increased concentration of the element in the spray solution. In addition, the element is slow-moving in the plant, so its accumulation in the leaves increases. As for the effect of adding biofertilizers, it had a significant effect on the values of (nitrogen, phosphorus, potassium, and zinc) in the plant leaves. This may be due to the plant's efficiency due to the abundance of nutrients from mineral fertilizer and the increased availability of The elements that lead to the presence of the vital material, which led to an increase in the available nitrogen in the plant, and this is consistent with what was found by (19), (26), and (17), in addition to the help of biofertilization in the secretion of growth regulators, including the hormone (IAA), which stimulates the absorption of nutrients, including potassium, in addition to the role of bacterial organisms in increasing the availability of potassium and preserving it from the processes of fixation and loss through the secretion of some enzymes and organic acids that increase the availability of nutrients, including potassium, and this is

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consistent with what was found by (21) and (32).

- Conclusions

From the results obtained, we conclude the following: - Mineral fertilization (50%) of the fertilizer recommendation achieved superiority in most of the studied traits. The use of biofertilization by inoculation with EM1 biofertilizer led to a significant increase in soil element availability, nutrient content of potato leaves, and most growth traits. Foliar spraying with nano-zinc at a concentration of 2 g.L-1 resulted in a significant increase in most of the studied traits (available soil elements, nutrient content of leaves, growth traits, and yield). The results showed that the dual and triple interventions among the study factors significantly increased most of the studied traits. The dual interaction of biofertilization and nano-zinc spraying gave the highest values compared to the treatment without nano-zinc spraying and without biofertilizer. The triple interaction also gave 50% mineral fertilizer + 2 g.L-1 nano-zinc spray + biofertilizer. EM1 was significantly excelled and gave the highest values for the studied traits compared to the control treatment without mineral fertilizer, zinc spray and biofertilizer.

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