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The Role of Fertilization with Nano-Zinc Oxide on the Growth and Yield of Wheat in Calcareous Desert Soil

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The Role of Fertilization with Nano-Zinc Oxide on the Growth and Yield of Wheat in Calcareous Desert Soil

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Abstract. A field experiment was conducted to study the effect of the source and level of addition of nano-zinc oxide on the growth and yield of IPA-99 wheat cultivar grown in desert soil conditions and compare it with regular zinc fertilizers. Fertilizers were sprayed on the soil, the nano-fertilizers included three sources of zinc, nano-metallic zinc oxide (ZnnO), zinc-chelated nano-fertilizer ZnnDTPA, and nano-zinc humate (ZnnHA). The nano-fertilizers were added at levels of 1 and 2 kg ha-1. Whereas the regular zinc fertilizers, ZnO, ZnDTPA, and ZnHA, were added at a level of 4 and 8 kg ha-1 in addition to the control treatment without addition. After harvest, the grain yield, straw yield, and the concentration of zinc, nitrogen, phosphorous, and potassium in the wheat grain were estimated. The results showed that zinc nano fertilizers had a significant effect in increasing the studied plant traits compared to the control treatment, Zinc humate nano fertilizer gave the highest increase in all studied plant traits among the nano-fertilizers, as it achieved an increase in grain yield, straw yield, zinc, nitrogen, phosphorous and potassium concentrations in grains by 45.36%, 57.01%, 409.43%, 42.36%, 98.20%, and 38.56 % respectively over the control treatment. The zinc nano-fertilizers had a significant effect on increasing the yield of grains and the concentration of nitrogen and potassium in the grains compared to the regular zinc fertilizers. While the results showed there was no significant difference in straw yield and the concentration of zinc and phosphorous in the grains between nano and normal zinc fertilizer.

Keywords. Zinc Oxide, Nano, Soil, Desert.

1. Introduction

Nanotechnology has been applied to study nanomaterials with a size of fewer than 100 nanometers and the possibility of exploiting these materials in different areas of life such as agriculture and other fields [1]. The application of nanotechnology in agriculture included fertilizers, pesticides, and other fields of agriculture to sustain land productivity and reduce chemical pollutants in the soil resulting from the use of chemical fertilizers [2]. The lack of micro-nutrients is a widespread problem in many countries of the world whose climate is characterized by arid or semi-arid climate, the nature of its calcareous soils, its reaction tendency to alkaline, and its poverty of organic matter, which causes a decrease in its content of microelements, including zinc [3]. The presence of zinc in the soil at a certain level is necessary for the roots of plants to grow and work well and effectively, and the deficiency of zinc is widespread in many countries of the world and is greater than the rest of the other elements, so it is considered one of the necessary and basic microelements that the plant needs for growth. Zinc plays a vital role in many important enzyme systems in the plant, including carbonic anhydrase, which is responsible for the transfer of CO2 during photosynthesis, and as zinc deficiency leads to a decrease in photosynthesis by 50-70%, depending on the type of plant and the severity of zinc deficiency. And the reason for this decrease may result from a decrease in the concentration of zinc that enters the enzyme synthesis, in addition to other enzymes such as RNA polymerase, which is responsible for protein synthesis, and Ribulose diphosphate carboxylase, which is responsible for the starch formation and other enzymes. It also has an important role in activating enzymes, forming chlorophyll, increasing the rate of production of growth hormones, and forming carbohydrates that the plant stores in wheat grains [4 , 5]. In a study conducted to compare the addition of different levels of nano-Zn and its comparison with similar addition levels of regular zinc fertilizers, [6] observed the superiority of nano-Zn fertilizers in giving the highest rate of absorption of added zinc compared to regular zinc fertilizers. In addition, [7] found that the addition of nano zinc oxide fertilizer to the cucumber plant led to an increase in the amount of zinc absorbed by the plant compared to the regular source of the same fertilizer. [8] found that the nano zinc oxide fertilizer added to the soil was superior to the regular zinc oxide fertilizer in increasing the concentration of zinc and available phosphorus in the soil and the vegetative and root system.

Zinc deficiency is common in most Iraqi soils due to its high content of lime and its dry climate. Nanotechnology is a necessary technology in modern agriculture that can find the best solutions to agricultural problems. Therefore, the study aimed to know the effect of zinc nano fertilizer in comparison with regular fertilizers on some characteristics and growth characters of wheat grown under desert soil conditions under the sprinkler irrigation system.

2. Materials and Methods

A field experiment was carried out in one of the fields affiliated to Al-Dawar Research Station - Agricultural Research Department of the Ministry of Agriculture (35 km west of Ramadi district). A composite soil sample with a depth of 0-30 cm, representative of the station soil, was obtained, aerobically dried, ground, passed through a 2 mm sieve, some soil chemical properties were estimated as shown in Table 1.

Two types of fertilizer were used in the experiment, the first nano, and includes three fertilizer sources of nano-zinc, nano-metallic zinc oxide, ZnO, nano-chelated zinc, ZnnDTPA, and nano-zinc humate, ZnnHA, the second type is the regular zinc fertilizer and includes three fertilizer sources: ZnO, ZnDTPA, and ZnHA. After preparing the fertilizer sources by adding zinc oxide to the organic compound DTPA and humic acids HA in a ratio of 1:6, that is, 6 DTPA or HA to 1 zinc oxide. The nano-fertilizers were added at levels of 1 and 2 kg ha-1, and the regular fertilizers were added at levels 4 and 8 kg ha-1.

The land was prepared from plowing and smoothing, where the experiment was carried out according to the randomized complete block design according to the order of the factorial experiments with three replications. The first factor is the sources of mineral and nano zinc fertilizers, and the second factor (dose of adding nano and regular fertilizers) is nested within the level fertilizer sources of nano and regular fertilizers. Then the field was divided into blocks, the distance between one block and another was 75 cm, and each block was divided into 18 experimental units with a length of 2 m and a width of 1 m, and the distance between the experimental units was 1 m.

Wheat seeds of IPA-99 variety were sown with a seed quantity of 70 kg ha-1 inside the experimental units on transverse lines, the distance between one line and another was 25 cm, four lines per unit.

The fertilizer levels of zinc were added to the entire soil at planting with the addition of the fertilizer recommendation for nitrogen (200 kg ha^{-1}) in two batches and phosphorous (80 kg ha^{-1}) at planting. At the end of the season, the crop was harvested and the grain yield and straw yield were estimated. Grain samples were taken from all experimental units, crushed, and digested using sulfuric and perchloric acid. The concentration of zinc in the grains was measured using an atomic absorption spectrophotometer, while the total nitrogen concentration was estimated by the Kjeldahl method, as well as the concentration of phosphorous in the grains using a Spectrophotometer by the Barton detector, and potassium was estimated using a flame photometer. The means were compared with the least significant difference (LSD) test at the level (0.05).

Table 1. Chemical properties of soil.

Saturated soil paste (pH)		**7.51**	
Saturated soil paste (EC)		7.56	dS m^{-1}
Organic matter		3.3	gm kg^{-1}
($CaCO_3$)		330	gm kg^{-1}
($CaSO_4.2H_2O$)		5.20	gm kg^{-1}
Cations	(Ca^{+2})	21.7	mmole $^{-1}$
	(Mg^{+2})	5.9	
	(Na^{+})	22.9	
Anions	(Cl^{-})	26.2	
	($SO_4^{=}$)	22.5	
	(HCO_3^{-})	4.6	
	(CO_3^{-})	Nill	
(P)		15.68	mg kg^{-1}
(K)		152.5	
Soil Separators	(Sand)	502	Soil Separators
	(Silt)	178	
	(Clay)	320	
soil texture		Sandy Loam	

3. Results and Discussion

3.1. Grain Yield

The effect of the source and level of zinc fertilizer on the total grain yield of wheat (kg ha^{-1}) was presented in Table 2. It is noted that all nano-zinc fertilizers for both levels 1 and 2 kg ha^{-1} it achieved a significant increase in grain yield compared to the control treatment. The highest increase in yield was when zinc humate nano fertilizer was added at the addition level of 2 kg ha^{-1} and by 45.36% compared to the control treatment, while zinc oxide at the level of 2 kg ha^{-1} achieved an increase of 26.04% compared to the control treatment. The reason may be due to the important role of zinc inactivating enzymes and forming chlorophyll and carbohydrates that the plant stores in grains, which leads to an increase in their number and weight [4 , 5]. As well as the important role of humic acid in improving the chemical, physical and biological properties of the soil, thus increasing the availability of nutrients and improving the biochemical reactions of the plant and its physiological growth [9]. This is consistent with what was found by [10], and the results of the statistical analysis confirm that the use of nano-fertilizers has achieved a significant increase of 9.98% in grain yield compared to regular fertilizers. This may be because nano-fertilizers, due to their high surface area and solubility, increase their interactions on the surfaces of the soil and plant roots and the ease of their dissemination.

This may be because nano-fertilizers, due to their high surface area and solubility, increase their reactions on the surfaces of the soil and plant roots and the ease of their spread, as the acid works to hold the positively charged nanomaterials with a greater quantity and force on the negatively charged surfaces, it increases the adsorption of zinc and thus increases its availability for a longer period in the soil during all stages of plant growth [11].

Table 2. Effect of source and level of zinc nano and regular fertilizers on the grain yield (kg ha^{-1}).

Source	Mineral (Kg ha^{-1})		Nano (Kg ha^{-1})		Meansource
	4	8	1	2	
ZnO	4572	4803	5037	5613	5006
ZnDTPA	4842	5610	6303	6403	5789
ZnHA	6034	6228	5723	6473	6114
Control		4453			
LSD		298			236
Mean	5348		5925		
LSD		431.9			

3.2. Straw Yield

The results indicate the effect of the source and level of zinc fertilizer on the straw yield of wheat (Table 3). It is noted that all nano-zinc fertilizers for both levels 1 and 2 kg ha-1 achieved a significant increase in straw yield compared to the control treatment, and the highest increase in yield was when adding nano-zinc humate fertilizer at the level of addition of 2 kg ha-1, and it was 57.01% compared to the control treatment, and the lowest percentage was 45.89% when adding nano-zinc oxide at the same level of addition as compared to the control treatment as well. The superiority of nano-zinc humate among the nano-sources may be due to the role of added zinc in increasing and improving plant nutrition, construction, and growth. It participates in the formation of protein materials, enzymes, and carbohydrate metabolism through its important role in the photosynthesis process. This important role of zinc is reflected positively on the characteristics and indicators of vegetative growth, such as plant height and the number of branches, which increases the characteristic of the straw yield of wheat. This is consistent with what was observed by [12]. The presence of humic acid is important in increasing the activity of the process of cell division and the permeability of the cell membrane, and it facilitates the process of absorption and transmission of the element inside the plant, in addition to its important role in improving the chemical, physical and biological characteristics of the soil when added to the soil. All of this will increase the vital availability of the nutrients necessary for the plant, and their effect will be positively reflected by increasing the indicators of vegetative growth and thus increasing the dry weight of the plant [9, 10]. It is also noted that the increase achieved by the zinc nano sources as a general average did not have a significant effect in increasing the straw yield compared to the regular zinc sources.

Table 3. Effect of source and level of zinc nano and regular fertilizers on the straw yield (kg ha^{-1}).

Source	Mineral (Kg ha^{-1})		Nano (Kg ha^{-1})		Meansource
	4	8	1	2	
ZnO	3796	3972	3872	5213	4213
ZnDTPA	4132	5115	5365	5581	5048
ZnHA	5363	5964	5462	5610	5600
Control		3573			
LSD		214			169
Mean	4617		4617		
LSD		N.S			

3.3. Zinc Concentration in Grains

Table 4 shows the effect of the source and level of zinc fertilizer on the concentration of zinc in the grain of wheat, all zinc nano fertilizers, for both levels 1 and 2 kg ha-1, had a significant increase in zinc concentration in wheat grains compared to the control treatment, and the highest percentage of increase in zinc concentration when adding nano-zinc humate fertilizer at the level of adding 2 kg ha-1 was 409.43% compared to the control treatment. While nano-zinc oxide gave the lowest percentage of increase in the concentration of zinc in the grains, which amounted to 296.43% compared to the control treatment. This superiority of zinc humate nano fertilizer may be due to the role of zinc and its importance to the plant as an essential nutrient that participates as a catalyst in the effectiveness of more than one enzyme and increases the plant's content of chlorophyll, carbohydrates, and proteins. The abundance of zinc in the plant stimulates it to grow dramatically and increase root length, mass, and leaf area [13, 26], which increases the ability of the plant to absorb nutrients from the soil, including zinc, and this is consistent with what several researchers have found [14, 15]. The results of the statistical analysis show that there is no significant difference between the sources of nano and regular fertilizers in terms of their importance in increasing the zinc concentration in wheat grains.

Table 4. Effect of source and level of zinc nano and regular fertilizers on the Zinc concentration in grains (mg kg^{-1}).

Source	Mineral (Kg ha^{-1})		Nano (Kg ha^{-1})		Meansource
	4	8	1	2	
ZnO	64.84	69.37	67.81	72.27	68.57
ZnDTPA	68.02	83.05	79.24	91.31	80.40
ZnHA	104.64	108.86	84.32	92.87	97.67
Control	18.23				
LSD	3.32				2.62
Mean	83.13		81.30		
LSD	N.S				

3.4. Nitrogen Concentration in Grains

The effect of both the source and the level of zinc fertilizer on the nitrogen concentration in wheat grains were shown in Table 5. It is noted that each of the fertilizers of nano-zinc humate and nano-chelated zinc at both levels 1 and 2 kg ha-1 achieved, with a significant difference, an increase in the nitrogen concentration in the grains. Where the highest percentage of increase was at the level of adding 2 kg ha-1 by 42.36% when adding zinc in the form of nano-zinc humate and by 35.40% when adding it with the form of nano-chelated zinc compared to the control treatment. While the nano zinc oxide achieved the lowest rate of increase with a non-significant difference compared to the control treatment. The superiority of zinc humate nano fertilizer by increasing the concentration of nitrogen may be due to the importance of zinc's role in increasing the chlorophyll content of the leaves and the photosynthesis process and improving plant growth, which is reflected in an increase in the root's ability to absorb nutrients from the soil, including nitrogen [16, 25]. In addition to the role of nano-fertilizers by preparing zinc in an amount that suits the needs of the plant, which increases the effectiveness role of zinc in improving the absorption of elements from the soil [17]. This is consistent with what was found by [18]. Also, humic acid has an important role in increasing nitrogen availability and thus increasing its concentration in grains as a result of increasing the amount absorbed by the plant, as it is an important storehouse of plant nutrients, foremost of which is nitrogen [19].

Table 5. Effect of source and level of zinc nano and regular fertilizers on the nitrogen concentration in grains (mg kg^{-1}).

Source	Mineral (Kg ha^{-1})		Nano (Kg ha^{-1})		Meansource
	4	8	1	2	
ZnO	24.04	25.65	25.71	25.95	25.33
ZnDTPA	26.66	28.48	29.72	31.32	29.04
ZnHA	27.36	29.51	31.37	32.93	30.29
Control	23.13				
LSD	2.90				2.30
Mean	24.04		25.65		
LSD	1.89				

3.5. Concentration of Phosphorous in Grains

Table 6 shows the effect of the source and level of zinc fertilizer on phosphorous concentration in wheat grains, where it is noted that all nano-zinc fertilizers outperformed with a significant difference in giving the highest concentration of phosphorous in grains and at both levels 1 and 2 kg ha-1 compared to the control treatment. The highest increase in phosphorous was when adding zinc in the form of nano-zinc humate at the level of addition of 2 kg ha-1, which achieved an increase of 98.20%. While the lowest percentage increase was 66.82% when adding the fertilizer in the form of nano-zinc oxide and at the same level of addition. The superiority of zinc humate in giving the highest concentration of phosphorous in grains may be due to the importance of zinc's role in the formation of IAA, which stimulates the growth and elongation of plant cells and increases the penetration of roots into the soil, thus increasing the amount of nutrients absorbed, which transfers the surplus of the plant's need to its storage areas in the grain. This is consistent with what was found by [20]. Also, the role of humic acid is to increase the concentration of phosphorous on breaking the bonds between iron or zinc ions and phosphorous or calcium, which increases the availability of the element [21]. As well as its role in facilitating the movement of the element inside the plant, this is consistent with what was observed [22]. The results of the statistical analysis show that there is no significant difference between the nano and regular fertilization sources in terms of their importance in increasing the phosphorous concentration in the wheat grains.

Table 6. Effect of source and level of zinc nano and regular fertilizers on the phosphorous concentration in grains (mg kg^{-1}).

Source	Mineral (Kg ha^{-1})		Nano (Kg ha^{-1})		Meansource
	4	8	1	2	
ZnO	4.780	5.747	4.707	5.210	5.111
ZnDTPA	4.987	5.883	4.503	5.787	5.290
ZnHA	5.637	6.153	5.027	6.190	5.752
Control	3.123				
LSD	0.487				0.385
Mean	5.53		5.24		
LSD	N.S				

3.6. Concentration of Potassium in Grains

Table 6 shows the effect of the source and level of zinc fertilizer on potassium concentration in wheat grains, it is noted that the nano-zinc fertilizers achieved a significant increase at both levels 1 and 2 kg

ha^{-1} compared to the control treatment in giving the highest concentration of potassium in the grains, and the highest percentage of increase in potassium was when adding the fertilizer in the form of nano zinc humate at the level of 2 kg ha^{-1}, as it achieved an increase of 38.56% compared to the control treatment, while the nano zinc oxide fertilizer achieved the lowest increase of 25.00% at the same level of addition compared to the control treatment. The superiority of nano-zinc humate in giving the highest concentration of potassium may be due to the importance of zinc's role in stimulating plant growth, cell elongation, and increasing the length of the root system of the plant and its penetration into the soil, thus increasing the amount of nutrients absorbed by the plant, which are then transferred to be stored in the grains [20]. In addition to its important role in activating the processes of photosynthesis and respiration through the activation of enzymes whose effect is reflected in the vital plant processes and this is consistent with what was found [3]. Also, the presence of humic acid facilitates the movement of elements within the plant and improves the permeability of cell membranes as well as its role in improving the properties of the soil and liberating potassium from its minerals into the soil solution, and increasing the concentration of its availability and this will increase the amount of potassium absorbed and increase its concentration in grains and this is consistent with what was found by a number of researchers [22, 23]. The results of the statistical analysis show that the sources of nano-zinc were significantly superior in increasing the potassium concentration in the grains by 5.14% compared to the regular zinc sources. This may be due to the important role of nano-fertilizers in increasing the absorption of water and nutrients by encouraging vegetative growth that stimulates the plant to absorb additional quantities of elements to meet the plant's nutritional need and the continuity of the plant's vital activity [24].

Table 7. Effect of source and level of zinc nano and regular fertilizers on the potassium concentration in grains (mg kg^{-1}).

Source	Mineral (Kg ha^{-1})		Nano (Kg ha^{-1})		Meansource
	4	8	1	2	
ZnO	23.85	25.71	24.97	26.35	25.22
ZnDTPA	25.12	26.09	25.94	28.11	26.32
ZnHA	25.52	26.57	26.17	29.21	26.87
Control	21.08				
LSD	1.00				0.79
Mean	25.48		26.79		
LSD	0.916				

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