Effect of zinc and nano-metal spraying and leaching stages on some vegetative growth characteristics of wheat

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Abstract

This study aimed to evaluate the effects of spraying mineral and nano-zinc fertilizers, and the different application stages, on certain vegetative growth characteristics of wheat. Field experiment 2025-2026, was conducted in a farmer's field in Al-Hashimia. The experimental design was a split-plot RCBD with three replicates. The main panels consisted of four zinc spray treatments : control (without spraying).F0, Metallic Zinc at a concentration of 20 mg L^{-1}.(F1). Nano Zinc Oxide at a concentration of 20 mg L^{-1} (F2), Metallic Zinc at a concentration of 20 mg L^{-1}+ Nano Zinc at a concentration of 20 mg L^{-1} (F3), and the subpanels included four spray stages: Tillering + Elongation stage (D1), Tillering + Booting stage (D2),Elongation + Booting stage (D3), Tillering + Elongation + Booting stage (D4). The treatment with F3 significantly outperformed others (F1,F2 and F0), in all studied parameters. The results showed a PH of 101.75cm , LNWP of 9.17 leave $plant^{-1}$, TN of 478.3 tiller m^{-2},CLI of 54.38 SPAD and FLA of 60.69 cm^{-2}. The application stage of D4 was significantly superior to the stages of D1,D2 and D3 in all studied parameters. The interaction among F3 combining zinc and the D4 spraying stage gave the best results in all studied parameters

Keywords: wheat, nano zinc, metallic zinc, growth stages

Introduction

Wheat is one of the most important strategic grain crops in Iraq and the world, due to its key role in achieving food security and providing a primary source of energy and plant protein for humans (Ahmed et al., 2025). Despite the progress made in agricultural production techniques, the productivity of this crop is still below the required level as a result of its being affected by several environmental and nutritional factors, most notably the lack of micronutrients such as zinc, which is one of the elements necessary for plant growth and development (Hassan et al., 2020). It plays an important role in many vital

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processes within the plant, such as activating enzymes, regulating auxin formation, and contributing to protein formation, as well as its role in improving the efficiency of photosynthesis. (El-Aziz et al., 2022). In modern agriculture, with the adoption of nano-fertilizer technologies, farming has shifted from traditional methods to precision agriculture. NanoZn plays a crucial role in enhancing enzymatic activity, strengthening cell walls, and protecting photosynthetic processes essential for plant growth (Shen et al,2023; Gupta et al.,2024; Sherpa et al.,2024).

Study conducted by Zarea and Karimi (2021) showed that applying added nutrients to crops leads to improved grain quality. On the other hand, Kaleri et al.,(2023) benefited that increases crop yield when combined with other agricultural practices such as tillage and leveling. Rahimi et al.,(2023), it been proven that fertilization reduces the environmental stress that plants experience during their growth period, and it has been confirmed that the fertilizers application is concentrated when the soil is under water stress. Foliar spraying plays a vital role in promoting the growth and corn varieties productivity when used in conjunction with appropriate leveling methods, leads to an increase in vegetative growth indicators. Plant height and chlorophyll ratio. Anwar et al.,(2021); Mueen et al.,(2025), numerous studies have confirmed the synergy between selected variety and modern fertilization processes, opening up prospects for sustainably improving plant productivity by exploiting the characteristics for each variety. Alaamer et al ,(2022); Singh et al.,(2023).

Furthermore, a deficiency of this element causes a decrease in vegetative growth and impaired grain formation, leading to a decline in both the quantity and quality of the yield (Poornima et al., 2019; Al-Ghazali et al.,2023). Due to the limited availability of zinc in many soils, the importance of using foliar spraying as an effective means of directly and rapidly supplying the plant with this element has emerged (Mohammed et al 2022; Alaamer et al.,2026). Nanotechnology is considered one of the promising trends in the agricultural field, as nano-zinc oxide is characterized by unique properties, including small size and increased surface area, which contributes to improving the efficiency of absorption and transfer within the plant compared to

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traditional fertilizers (Al-Sharifi et al., 2023). The use of nanoZn leads to improved vegetative growth and increased productivity, as well as enhancing the plant's ability to withstand various environmental stresses, as a result of its role in activating antioxidant systems and improving nutrient utilization efficiency (EI-Hendawyet al., 2022). Therefore, current study focused on evaluating spraying processes using (Zn) mineral fertilizer and zinc oxide (Zno) nanoparticles on wheat crop and identifying the best treatments that contribute to improving growth characteristics and achieving higher efficiency in the use of nutrients under local environmental conditions.

Materials and Methods

Study site

Al-Hashimiyah City, the district center of Babylon Governorate, is situated in the Middle Euphrates region, approximately 130 km south of Baghdad, located at latitude 30.40°N and longitude 44.39°E Known for its fertile agricultural lands. (Fig. 1).

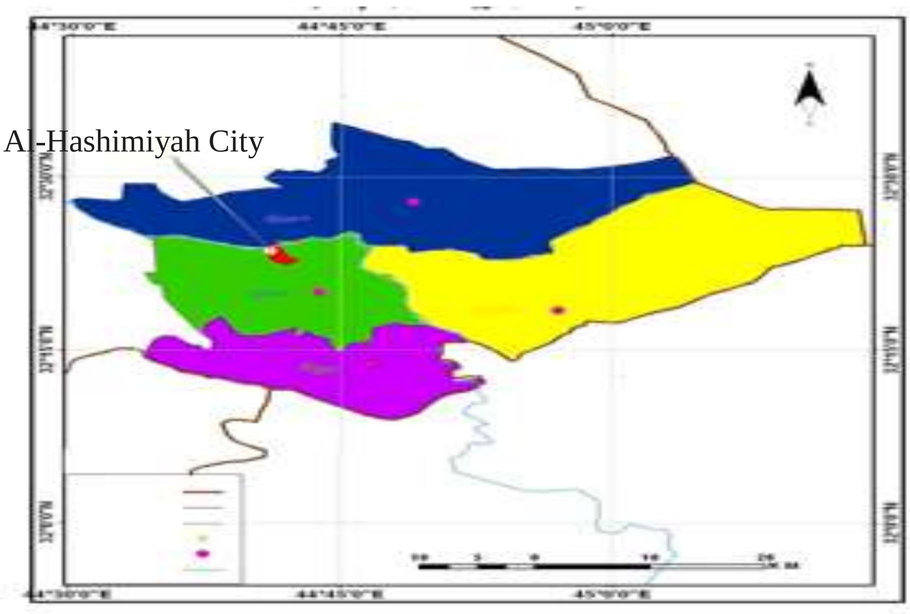

Fig.1. **Study site**

A field experiment was conducted during the 2025-2026 winter season in a farmer's field in Al-Hashimiya district, Babil Governorate. The field soil was plowed, smoothed, and leveled, then divided into three

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replicates, each containing 16 experimental units of 4 m^2 (2m*2m). Phosphate fertilizer (P2O4 45%) was added at a rate of 100 kg ha^{-1} (Al-Fahdawi, 2017: Mueen et al.,2025) mixed with the soil, and planting was carried out in rows with a spacing of 20 cm between rows and a seeding rate of 120 kg ha^{-1} (Ahmed et al., 2016; Alsharifi et al.,2025). Nitrogen fertilizer (urea 46% N) was also added at a rate of 200 kg ha^{-1} (morsy et al.,2021; Alaamer et al.,2026), in four equal installments: the first and second at the beginning of the tillering stage, and the third when 50% of the plants in the experimental unit. Prior to planting, soil samples were collected from nine randomly selected locations (0-10 cm depth) with three replicates each for comprehensive physicochemical analysis. The sampling area was determined based on experimental requirements, with results presented in Table 1 .

Table 1. Analysis of soil physical and chemical characteristics

Depth	**Texture %**			
	Clay	**Silt**	**Sand**	
	64	23	13	Silt Clay loam
	Soil physical properties			
0-10 (cm)	**Pb (Mg m^{-3})**	**TSP (%)**	**SPR (Kpa)**	
	1.30	50.94	1477.08	field capacity %
	1.31	50.56	1466.10	33.14
	1.34	49.43	1544.59	32.61
VA	1.31	50.31	1495.92	
	Soil chemical properties			
0-10	**E.C (ds\cm^3)**	**HP**	True Density (Mg.m-3)	
	2.33	7.01	2.41	
	Soluble cation meq\I			
	Na	**K**	**Ca+Mg**	

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8.24	12.31	56.15	
O.C (%)	CEC Meq\100 g)	CaCo3 (%)	O.M (%)
0.55	31.81	4	0.64

Study Factors

First factor : Zinc Combinations

Control (without spraying) (F0)

Metallic Zinc at a concentration of 20 mg L^{-1} (F1)

Nano Zinc Oxide at a concentration of 20 mg L^{-1} (F2)

Metallic Zinc at a concentration of 20 mg L^{-1}+ Nano Zinc at a concentration of 20 mg L^{-1} (F3).

The second factor: Spraying stages

Tillering + Elongation stage (D1)

Tillering + Booting stage (D2)

Elongation + Booting stage (D3)

Tillering + Elongation + Booting stage (D4)

Vegetative growth characteristics

Plant height (PH)

Its was measured using an Invar tape, from the soil surface to the spike end .

Leaves number in plant (leaf plant^{-1})

Tillers number (TN)

The tiller number was determined at the flowering stage, at 100%.with three replicates per experimental unit.

Chlorophyll index in leaves (CIL)

was estimated using a device chlorophyll meter SPAD model 502, for ten randomly selected plants with three replicates for each experimental unit.

Flag leaf area (FLA)

It was calculated according to the method approved by (Al-Sahouki, 2020: Shathar et al.,2024) using Eq1.

$$L_A = FL \times FW \times 0.75 \quad (1)$$

Where:

L_A; Leaf area cm^2, FL; Leaf length cm, FW; Leaf width cm.

Statistical Analysis:

The experimental data were analyzed using GenStat 18th edition (VSN International) with a split-plot arrangement in a randomized complete

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block design (RCBD). Treatment means were compared using Least Significant Difference (LSD) test at α = 0.05 significance level.

Results and discussion

Plant height (cm)

The results of the analysis of variance in Table 2, showed a significant effect of the study factors and their interaction on plant height. A significant advantage was observed with the treatment of spraying Metallic Zinc + nano-zinc at a concentration of 20 mg L^{-1}, resulting in the highest average plant height of 101.75 cm. Compared to the control treatment (without spraying), which yielded the lowest average length of 89.29 cm, this superiority may be attributed to the role of Metallic Zinc + nano-zinc in increasing the rate of nutrient absorption when added to the plant's foliage, as it plays a role in improving photosynthesis, which in turn enhances plant growth. In addition to its positive role in activating enzymes and forming the amino acid tryptophan, which participates in the synthesis of IAA, which is necessary for cell elongation and division, and thus increasing plant height (Alenzy et al., 2022). These results were consistent with what was found by Muhammed and Al-Joboory (2024) .

The results of the same table also showed a significant advantage for the spray treatment in the tillering, elongation and booting stage in plant height, recording the highest average of 97.46 cm, compared to the spray treatment in the tillering stage, which gave the lowest average of 92.70 cm. This superiority may be attributed to the importance of metallic zinc and nano-zinc oxide in increasing vegetative growth in stages close in time to the flowering stage, especially the (tillering + elongation + bud formation) stage, given the importance of this stage in the life of the plant. Providing metallic zinc and nano-zinc oxide at these times through foliar spraying may improve the nutrient absorption process by enhancing the role of the root system in the absorption process, both qualitatively and quantitatively. Likewise, improving vegetative characteristics, in addition to that, foliar spraying at advanced stages of plant life is of great importance in improving the efficiency of sustaining and utilizing nutrients by compensating for their deficiency at sensitive stages of plant life while maintaining water balance within the plant, Malav et al. (2025). These results were somewhat consistent with

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what Al-Rawi (2021) ; Ali et al (2023) .

The results shown in the same table also indicate a significant interaction between the treatment of metallic and nano-zinc spraying and the spraying stages, with the interaction between Metallic Zinc + nano-zinc spraying being the most effective. With a concentration of 20 mg L^{-1} and spraying during the tillering, elongation and booting stage of plant height, it gave the highest average height of 107.30 cm compared to the interaction treatment between the control treatment (without spraying) and spraying during the tillering stage, which gave the lowest average height of 84.72 cm.

Table 2: Effect of zinc combinations and spray stages, and their interaction on plant height.

Transactions	SS				
ZC	D1	D2	D3	D4	V-ZC
F0	84.72	88.79	90.38	93.29	89.29
F1	91.22	89.78	92.12	94.19	91.83
F2	97.44	96.28	92.53	95.07	95.33
F3	97.43	100.45	101.18	107.30	101.75
V-SS	92.70	93.83	94.21	97.46	
ZC=1.45		SS=1.29		ZC*SS=2.56	

Zinc Combinations; ZC, Control (without spraying); F0, Metallic Zinc at a concentration of 20 mg L^{-1} ; F1, Nano Zinc Oxide at a concentration of 20 mg L^{-1} ; F2, Metallic Zinc at a concentration of 20 mg L^{-1}+ Nano Zinc at a concentration of 20 mg L^{-1} ; F3, Spraying stages ; SS, Tillering +

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Elongation stage ;D1,Tillering + Booting stage ;D2,Elongation + Booting stage ;D3,Tillering + Elongation + Booting stage ;D4,

Leaves number in plant (leaf plant^{-1})

The results of the analysis of variance showed a significant effect of the study factors on the number of plant leaves trait. A significant advantage was observed with the treatment of spraying Metallic Zinc + nano zinc at a concentration of 20 mg L^{-1}, recording the highest average of 9.17 leaf plant^{-1}, compared to the control treatment (without spraying), which gave the lowest average of 6.96 leaf plant^{-1}. This superiority may be attributed to the role of metallic Zinc + nano-zinc in improving the chances of vegetative growth by increasing the leaf area to intercept as much light as possible and increasing the efficiency of the products of the photosynthesis process, which was reflected in a decrease in the state of respiration within the plant and led to an increase in the number of leaves. Bachai and Jamil (2025) found these results to be consistent with what Adrees et al. (2021); Askar. (2024).

The results of the same table also showed a significant advantage for the spray treatment in the tillering, elongation and booting stage of the leaves number in plant, recording the highest average of 9.04 leaf plant^{-1}, compared to the spray treatment in the tillering stage, which gave the lowest average of 6.84 leaf plant^{-1}. This led to an increase in the activity of vital processes in the plant, such as an increase in chlorophyll content, which affects carbon metabolism and was reflected positively in growth indicators such as an increase in the number of leaves (Ghanem et al., 2025). These results were somewhat consistent with what was indicated by Irmes et al. (2023); Mued et al. (2025).

The results shown in the same table also indicate no significant interaction between the application of metallic and nano-zinc and the application stages.

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Table3: Effect of zinc combinations and spray stages, and interaction between them on the number of leaves plant.

Transactions	SS				
ZC	D1	D2	D3	D4	V-ZC
F0	5.97	6.47	7.48	7.94	6.96
F1	6.39	7.19	8.04	8.29	7.48
F2	7.05	7.84	8.83	9.70	8.35
F3	7.97	8.46	10.00	10.24	9.17
V-SS	6.84	7.49	8.59	9.04	
ZC=0.54		SS=.30		ZC*SS=N.S	

Tillering number (tiller m^{-2})

The results of the analysis of variance showed a significant effect of the study factors on the tillering number. Specifically, the treatment of spraying Metallic Zinc + nano-zinc at a concentration of 20 mg L^{-1} showed a significant advantage in this trait, recording the highest average of 478.3 tiller m^{-2}, compared to the control treatment (no spraying). The lowest average yield was 343.6 tiller m^{-2}. This superiority may be attributed to the role of Metallic Zinc nano-zinc in balancing auxins and cytokines, reducing apical dominance, and increasing the plant's tiller formation capacity. Furthermore, the effectiveness of nano-zinc in enhancing photosynthetic efficiency and dry matter accumulation stimulated the plant to increase lateral growth rates, particularly the number of tillers. The results of Jassim et al. (2023) were consistent with those of Hussain et al. (2022) and Singh et al. (2023).

The results of the same table also showed a significant advantage for the spray treatment in the tillering,

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elongation and booting stage in the number of plant tiller, recording the highest average of 455.8 tiller m^{-2}, compared to the spray treatment in the tillering stage only, which gave the lowest average of 353.6 tiller m^{-2}. This superiority may be attributed to nano-zinc controlling growth hormones or improving their performance, creating a balance between longitudinal and transverse growth, maintaining the vitality of a greater number of tillers and their reaching the flowering stage as productive tillers, while helping to improve the compensation mechanism within the wheat crop by controlling the movement of nutrients. This is consistent with what Hossain et al. (2025), Ali et al. (2023); Sallume et al. (2023).

The results shown in the same table also indicate that there is no significant overlap between the spraying treatments of metallic and nano zinc and the spraying stages.

Table 4: Effect of zinc combinations and spray stages, and their interaction on the tillering number.

Transactions	SS				
ZC	D1	D2	D3	D4	V-ZC
F0	297.0	306.05	361.2	409.7	343.6
F1	310.0	394.5	413.4	417.2	383.8
F2	397.0	414.5	442.8	452.5	426.7
F3	410.5	468.2	490.9	543.7	478.3
V-SS	353.6	395.9	427.1	455.8	
ZC=16.61		SS=20.49		ZC*SS=N.S	

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Flag leaf area (cm^2)

The results of the analysis of variance showed a significant effect of the study factors on the flag leaf area characteristic. A significant advantage was observed with the treatment of spraying Metallic Zinc + nano-zinc at a concentration of 20 mg L^{-1}, recording the highest average of 54.38 cm^2, compared to the control treatment (without spraying), which gave the lowest average of 46.06 cm^2. This superiority may be attributed to the role of Metallic Zinc + nano-zinc, whose unique properties have led to the formation of numerous functions within the crop, including chlorophyll formation and activation of photosynthesis and respiration, thus leading to higher CO_2 uptake rates that maintain the crop's health. The structural and morphological composition of chloroplasts in RNA production through carbohydrate regulation and protein synthesis leads to an increase in flag leaf area (Jassim et al., 2023). These results were consistent with those found by Chen et al. (2025); Debnath et al. (2025).

The results of the same table also showed a significant superiority of the spray treatment in the tillering, elongation and booting stage in the leaf area characteristic, recording the highest average of 53.71 cm2, compared to the spray treatment in the tillering stage, which gave the lowest average of 46.93 cm2. This superiority may be attributed to the significant effect of nano-zinc oxide spraying, particularly during the tillering, elongation, and booting stages. This effect is most pronounced in these stages, as it facilitates the absorption and transport of processed nutrients from the source in different directions, and activates the enzymes responsible for Physiological activities by providing the required nutrients in their sensitive stages and thus increasing the leaf area (Kaleri, 2023). These results were somewhat consistent with what was indicated by Al-Ajili et al. (2023);AL-Salama et al.,(2024). The results shown in the same table also indicate no significant interaction between the application of metallic and nano-zinc and the application stages.

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Table 5: Effect of zinc combinations and spray stages, and interaction between them on flag leaf area..

Transactions	SS				
ZC	D1	D2	D3	D4	V-ZC
F0	41.89	44.56	47.83	49.69	46.06
F1	45.14	50.09	51.15	51.33	49.43
F2	49.25	51.82	54.03	55.94	52.79
F3	51.42	52.75	55.73	57.60	54.38
V-SS	46.93	49.81	52.18	53.71	
ZC=1.10		SS=1.68		ZC*SS=N.S	

Chlorophyll index in leaves (SPAD)

The results of the analysis of variance in Appendix 5 showed a significant effect of the study factors and their interaction on the chlorophyll index in leaves. A significant advantage was observed with the treatment of spraying Metallic Zinc + nano-zinc at a concentration of 20 mg L^{-1}, which recorded the highest average of 60.69 SPAD. Compared to the control treatment (without spraying), which gave the lowest average of 50.12 SPAD, this superiority may be attributed to the role of metallic Zinc +nano-zinc in increasing the activity of photosynthesis and plant hormones such as cytokinins and kinetin, which in turn maintain chlorophyll, prolong leaf greenness, and delay aging. Furthermore, it plays an effective role in reducing oxidation processes, thus increasing the chlorophyll content of leaves (Zarea et al., 2023). These results

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are consistent with those found by Qian et al. (2023);Chen et al. (2025).

he same table also showed a significant advantage for the spray treatment during the tillering, elongation, and booting stages in the total chlorophyll content index of the flag leaf, recording the highest average of 58.38 SPAD, compared to the spray treatment during the tillering stage, which gave the lowest The average of 51.68 SPAD. This superiority may be attributed to the fact that the spraying of zinc oxide nanoparticles at these stages arranges and organizes the stroma sheets in the chloroplasts, leading to an increase in the total chlorophyll content of the flag leaf and improved light absorption efficiency (Qamari,et al.,2023). These results are somewhat consistent with those reported by AL-bakri and Lehmood (2024).

The results shown in the same table also indicated a significant interaction between the treatments of metallic and nano zinc spraying and the spraying stages. The interaction treatment between spraying Metallic Zinc + nano zinc at a concentration of 20 mg L^{-1} and spraying at the tillering, elongation and booting stage was superior in the characteristic of the index of total chlorophyll content of the flag leaf, giving it the highest average of 64.47 SPAD. Compared to the interaction treatmentbetween the control treatment (without spraying) and spraying at the tillering stage, which gave the lowest average of 45.25 SPAD.

Table 6: Effect of zinc combinations and spray stages, and their interaction on chlorophyll index in leaves.

Transactions	Spraying stages				
ZC	D1	D2	D3	D4	V-ZC
F0	45.25	50.48	51.87	52.90	50.12
F1	50.85	51.75	54.00	56.18	53.23
F2	53.39	54.39	55.98	59.98	55.64
F3	57.23	59.48	61.59	64.47	60.69
V-SS	51.68	54.02	55.86	58.38	
ZC=1.64		SS=1.41		ZC*SS=2.78	

Conclusions

The study included zinc combinations : Control (without spraying), Metallic Zinc at a concentration of 20 mg L^{-1} , Nano Zinc Oxide at a concentration of 20 mg L^{-1} ,Metallic Zinc at a concentration of 20 mg L^{-1}+ Nano Zinc at a concentration of 20 mg L^{-1}, under four levels of spraying stages Tillering + Elongation stage, Tillering + Booting stage, Elongation + Booting stage, Tillering + Elongation + Booting stage. The results demonstrated that the D4 significantly outperformed D1, D2and D3 across all measured traits. The F3 zinc combinations also surpassed F1,F2 andF0 in all growth parameters. Optimal results were achieved with the interaction of D4 and F3, highlighting this combination as the most effective for enhancing wheat growth parameters.

References

Adrees, M., Khan, Z. S., Hafeez, M., Rizwan, M., Hussain, K., Asrar, M., ... & Ali, S. (2021). Foliar exposure of zinc oxide nanoparticles improved the growth of wheat (Triticum aestivum L.) and decreased cadmium concentration in grains under simultaneous Cd and water deficient stress. *Ecotoxicology and Environmental Safety*, *208*, 111627.

Ali, A. M., Ibrahim, S. M., & Omer, A. M .(2023).Foliar Spraying of Nano-Silicate and Nano-Zinc on Wheat (Triticum aestivum L.) Under Salt Stress Conditions Enhances Productivity and Reduces the Optimal Nitrogen Fertilizer Rate. Communications in Soil Science and Plant Analysis, 54(19), 2731–2744.

Ahmed, Hamid, Mohammed Fawzi and Jamal Walid Mahmoud. 2016. The effect of different seeding rates on the qualitative characteristics and seed viability of four bread wheat varieties. College of Agriculture. University of Basra.

Ahmed, O. S., Mohammed, K. A., & Elshamly, A. (2025). Effects of regulated deficit irrigation, boron and zinc applications on peanuts growth and seed yield in arid conditions. *Aswan Journal of Agricultural and Biological Sciences*.

Al-Ajili, Hawraa Dawood Matar Hussein. 2023. Response of three wheat varieties to stages and concentrations of nano-potassium spraying. PhD dissertation. Technical College. Middle Euphrates Technical University.

Alaamer .S, Saldani.S.M, Alsharifi S.K,. (2026). Technical applications of fertilizer combinations in cotton productivity through automated sensor-based subsurface drip irrigation system. Forest Science and Technology2026. doi;10.1080/21580103.2026.2633235

Alaamer S.A, Alsharifi.S.K, .Shtewy.N, Wheat parameters under influence of the depths and cultivation machinery.IOP Conf. Ser. Earth Environ. Sci.2022.1060(1):012131. http://doi:10.1088/1755 1315/1060/1/012131.2022.

Anwar, S.; Khalilzadeh, R.; Khan, S.; Zaib-un-Nisa; Bashir, R.; Pirzad, A.; Malik, A. (2021).Mitigation of drought stress and yield improvement in wheat by zinc foliar spray relates to enhanced water use efficiency and zinc contents. Efficiency and Zinc Contents.

International Journal of Plant Production2021, 15, 377–389. doi:10.1007/s42106-021-00136-6.

Al-bakri, R. A., & Lehmood, A. M. (2024). Effect of Concentrations and Spraying Stages of NPK Nanofertilizer on the Yield and Components of the Oat Crop (Avena sativa L). In IOP Conference Series: Earth and Environmental Science (Vol. 1371, No. 5, p. 052088). IOP Publishing

Alenzy, A. F., & Al-Hadethi, A. A. (2022). The role of fertilization with nano-zinc oxide on the growth and yield of wheat in calcareous desert soil. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1060, No. 1, p. 012027). IOP Publishing

Al-Fahdawi, Hamada Mohsen Matar and Ali Fad'am Abdullah Al-Muhammadi. 2017. The effect of DAP fertilizer on the growth and yield of soft and durum wheat genotypes grown in a desert environment – Anbar Governorate. Iraqi Journal of Desert Studies 7(1)43–49.

Al-Ghazali, Z., & Al-Zubaidy, S. (2023). Response of three wheat cultivars Triticum aestivum L. to chemical and bio-fertilization and nano-NPK on yield traits and its components. Euphrates journal of agricultural science, 15(3), 295-303.

Al-Rawi, Diaa Saleh Alawi. 2021. The Interrelationship of Variety and Foliar Spraying with Nano- and Conventional Potassium and Zinc Fertilizers on Oat Productivity. PhD Thesis. College of Agriculture. University of Anbar.

Al-Sahouki, Medhat and Dawood Abdul-Basit Abdul-Razzaq. (2020). Plant Genomics and Breeding. University of Baghdad. College of Agricultural Engineering Sciences. Iraq. 218 pp.

Al-Sharifi, A., & Al-Zubaidi, A. (2023). Effect of nano-fertilizer on growth traits of potato cultivars grown under water stress. Euphrates journal of agricultural science, 15(2), 408-423.

Al-Sharifi, S. K., Alaamer, A., Saldani, S.M. Wheat crop productivity requirements using modern irrigation technology. CIGR Journal, 2025.27(3), 136 – 149.

Al-Salama, Y., Alghoraibi, I., & Salem, M. A. (2024). The effect of foliar application of ZnO nanoparticles and ZnSO4 on improving the growth and production of durum wheat. Al-Qadis. J. Agri. Sci, 14(1), 1-11.

Askar, Najm Abdul Tarad. 2024 The effect of soaking and spraying potassium sulfate at different growth stages on the growth, yield and quality of wheat seeds. PhD thesis. College of Agriculture. Al-Qasim Green University.

Bachai, H. S., & Jamil, D. A. K. (2025). Effect of Bulk Zinc and Nano Zinc on the Mineral Elements Content of Barley Plant under Salt Stress.

Chen, J., Zhang, M., Sun, J., Liu, X., Yuan, X., Wang, R., ... & Yang, Y. (2025). Zinc Oxide Nanoparticles Enhance Grain Yield and Nutritional Quality in Rice via Improved Photosynthesis and Zinc Bioavailability. *Foods*, *14*(17), 3018.

Debnath, N., Gosavi, A., Jadhav, A., & Jadhav, A. (2025). Exploring the Potential of Foliar Nano Zinc Oxide Application on Wheat Cultivation in Zinc Deficient Inceptisol. *International Journal of Plant & Soil Science*, *37*(9), 68-76.

El-Aziz, G. H. A., Ahmed, S. S., Radwan, K. H., & Fahmy, A. H. (2022). Positive and negative environmental effect of using zinc oxide nanoparticles on wheat under drought stress. *Open Journal of Applied Sciences*, *12*(6), 1026-1044.

El-Hendawy, S.; Alsamin, B.; Mohammed, N.; Al-Suhaibani, N.; Refay, Y.; Alotaibi, M.; Tola, E.; Mattar, M.A. Combining planting patterns with mulching bolsters the soil water content, growth, yield, and water use efficiency of spring wheat under limited water supply in arid regions. Agronomy 2022, 12(6), 1298; https://doi.org/10.3390/agronomy12061298 .

Ghanem, H. E., Hamza, D. A., Zain El-Abdeen, A. A., Elbatrawy, W. S., & El-Habashy, H. M. (2025). Influence of zinc foliar spray on growth, some important physiological processes, yield and yielazd attributes of bread wheat under water stress. *Scientific Reports*, *15*(1), 14943.

Gupta, A.; Bharati, R.; Kubes, J.; Popelkova, D.; Praus, L.; Yang, X.; Severova, L.; Skalicky, M.; Brestic, M. (2024).Zinc oxide nanoparticles application alleviates salinity stress by modulating plant growth, biochemical attributes, and nutrient homeostasis in Phaseolus vulgaris L. Front. Plant Sci., 15, 1432258.

Hassan M.U.; Aamer M.; Umer chattha M.; Haiying T.; Shahzad B.; Barbanti L.; and H. Guoqin. (2020). The critical role of zinc in plants facing the drought stress. Agriculture 10(9):396.

Hossain, M. S., Paul, A. K., Khan, M. A., & Hasan, M. M. (2025). Effect of Foliar Application of Zinc and Boron on the Growth and Yield of Wheat. *International Journal of*

ISSN 2072-3857

Bio-Resource & Stress Management, *16*(4), 1-7.

Hussain, A., Khan, M. A., Ali, S., & Ahmad, R. (2022). Effect of nano-zinc oxide foliar application at different growth stages on tillering and yield components of wheat (Triticum aestivum L.). Journal of Plant Nutrition, 45(18), 2741–2753.

Irmes, K., Kristó, I., Szentpéteri, L., Rácz, A., Vályi-Nagy, M., Kassai, M. K., ... & Tar, M. (2023). The effect of foliar zinc application on the leaf chlorophyll concentrations and grain yields of the winter wheat (Triticum aestivum L.) in the field experiments of two seasons. *Agronomy*, *13*(6), 1640.

Jassim, R. A. H., Barkat, H. N., & Nassir, M. A. (2023). The Effect of the Level and Methods of Adding Nano-Fertilizer on the Absorption of some Elements and the Growth and Yield of Wheat (Triticum Aestivum. L). In *IOP Conference* Series*: Earth and Environmental* Science (Vol. 1158, No. 6, p. 062023). IOP Publishing.

Kaleri, A. A., Khushk, G. M., Jogi, Q., Lund, M. M., Magsi, M. H., Baloch, N., ... & Laghari, R. (2023). Response of wheat crop to various foliar applications of nitrogen, zinc and boron fertilizers. Plant Health, 2(2), 51-55.

.Mohammed Y;,.Atab H.A;, Alsharifi S.K;. Response of corn at different levels of nitrogen fertilizer and cultivation distances. IOP Conf. Ser.: Earth Environ. Sci .2022.1060 (1):012134. doi:10.1088/1755-1315/1060/1/012134.

Morsy, A. S., Awadalla, A., Hussein, M. M., & El-Dek, S. (2021). Impact of preceding crop, sowing methods and nano-fertilizer (amino mineral) on bread wheat production and quality in toshka region, Egypt. Egyptian Journal of Agronomy, 43(1), 133-147.

Mued, M. M., Yadav, A. S., Siddiqui, S., Rao, P. S., Khan, N., & Pratap, D. (2025). Zinc in Wheat Cultivation: Physiological Roles, Agronomic Impact, and Management Strategies—A Comprehensive Review. *International Journal of Plant and Environment*, *11*(03), 428-436.

Muhammed, S. A. H., & Al-Joboory, W. M. (2024). effect of levels and methods of zinc addition on the growth and yield of wheat cultivated in saline soils. Anbar Journal of Agricultural Sciences, 22(1).

Malav, J. K., Rathod, J., & Kumar, S. (2025). Influence of Phosphorus and Zinc Nutrition on Growth and Yield of Wheat. *International*

Journal of Plant & Soil Science, *37*(3), 96-103.

Mueen.A.S, Alaamer, Sh. A. I. & Alsharifi, S. K. A. (2025). Effect of Agaricus mushroom spent residues on maize production under a drip irrigation system. Bulgarian Journal of Agricultural Science, 31 (6) : 1098–1110.

Qamari, P., Shekari, F., Afsahi, K., Tavakoli, A., Samimifard, R., Shekari, K., & Mastinu, A. (2023). Response of wheat cultivars to zinc application for seed yield and quality improvement. *The Journal of Agricultural Science*, *161*(4), 549-562.

Qian, L., Dawar, K., Ullah, I., Irfan, M., Zhang, Z., Mian, I. A., ... & Alarfaj, A. A. (2023). Zinc foliar application mitigates cadmium-induced growth inhibition and enhances wheat growth, chlorophyll contents, and yield. ACS omega, 8(36), 32372-32381.

Poornima R. and Koti R.V. (2019). Effect of Nano zinc oxide on growth, yield and grain zinc content of sorghum (Sorghum bicolor). Journal of Pharmacognosy and Phytochemistry. 8(4): 727-731

Rahimi, A., Mohammadi, H., & Jafari, S. (2023). Foliar zinc nutrition enhances yield and harvest index of bread wheat. Agronomy Journal, 115(4), 1985–1996.

Sallume, M. O., Mahdi, L. E., Alani, A. R., Farhan, K. J., & Al-Dulaim, K. H. (2023). Effect of spraying humic acid and different types of zinc fertilizer on some growth and yield traits of wheat. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1252, No. 1, p. 012073). IOP Publishing.

Shather.A, Shtewy N, Alsharifi SK.Alwan. (2024). Wheat response to the nitrogen fertilizers in productivity. SABRAO J. Breed. Genet..56(6): 1-12. http://doi.org/10.54910/sabrao2024.56.6.

Shen, M.; Liu, S.; Jiang, C.; Zhang, T.; Chen, W. (2023).Recent advances in stimuli-response mechanisms of nano-enabled controlled-release fertilizers and pesticides. Eco-Environ. Health , 2, 161–175

Sherpa, D.; Kumar, S.; Mishra, S. (2024).Response of Different Doses of Zinc Oxide Nanoparticles in Early Growth of Mung Bean Seedlings to Seed Priming under Salinity Stress Condition. Legume Res.-Int. J. 2024, 1, 7.

Singh, S., Kaur, J., Ram, H., Singh, J., & Kaur, S. (2023). Agronomic biofortification of wheat (Triticum aestivum L.) to alleviate zinc deficiency in human beings. Reviews in Environmental Science and Biotechnology, 22(2), 505–526.

Zarea, M. J., & Karimi, N. (2023). Grain yield and quality of wheat are improved through post-flowering foliar application of zinc and 6-benzylaminopurine under water deficit condition. *Frontiers in plant science*, *13*, 1068649.

ISSN 2072-3857