Bulgarian Journal of Agricultural Science, 32 (No 4) 2026, 888–892

Effect of foliar application dates of nano-Mn concentrations on grain yield and component of maize

Sana Qasim[1], Waleed A. T. El-Fahdawi[2], Farhan Ali Hussein[3], Saddam H. Cheyed[3*] and Noor Ayad Rasheed[3]

[1] *Al-Furat Al-Awsat Technical University, Al Mussaib Technical College, Iraq*
[2] *Department of Field Crop, College of Agriculture, University of Anbar, Iraq*
[3] *Department of Field Crops Sciences College of Agricultural Engineering Sciences, University of Baghdad, Baghdad, Iraq*
[*] *Corresponding author:* saddam.hakeem@coagri.uobaghdad.edu.iq

Abstract

Qasim, S., El-Fahdawi, W. A. T., Hussein, F. A., Cheyed, S. H. & Rasheed, N. A. (2026). Effect of foliar application dates of nano-Mn concentrations on grain yield and component of maize. *Bulg. J. Agric. Sci., 32*(4), 888–892

A field experiment was conducted in the experimental fields of the College of Agricultural Engineering Sciences, University of Baghdad, with the aim of knowing the effect of spraying dates of the vegetative group (beginning of the flowering stage, at 50% flowering, and at completion of female flowering) with nano-manganese (nano-Mn) (0, 10, 20, and 30 mg L^{-1}) on the yield and its components of maize. The experiment was conducted in split-plot arrangement, with the main plots occupied by spraying dates and the secondary plots occupied by nano-Mn concentrations. The results showed a significant effect of spraying dates with nano-manganese on most of the studied traits, as the first date gave the highest average for ear length, N0. of rows in ear, No. of grains in ear, and total grain yield. The results showed a significant effect of spraying with nano-manganese, especially at a concentration of 30 mg L^{-1}, which gave the highest average for ear length, number of rows, No. of grains in row, No. of grains in ear, weight of 1000 grains, and total grain yield. It is concluded from this study that early spraying (beginning of flowering) with nano-Mn, especially at a concentration of 30 mg L^{-1}, improved the characteristics of the crop and its components, which may be mainly due to its direct effect in improving the characteristics of vegetative growth.

Keywords: Zea mays L.; micronutrients; nanoparticles; flowering stage

Introduction

Maize (*Zea mays* L.) is one of the important grain crops, that occupies the first place in terms of cultivated area and production, due to its high nutritional value, as its grains contain carbohydrates, proteins, oil, salts, minerals and vitamins, so it is a good food for humans or animals, in addition to its use in the manufacture of oils, starch and biofuel, and it is also used as a raw material in many other industries (Mutlag et al., 2023). Given the inability to expand the cultivation of this crop with the limited land area and scarcity of available water resources, which requires increasing the efficiency of using available water and various natural resources, and avoiding soil degradation that occurs as a result of the misuse of chemical fertilizers or the adoption of traditional methods in agriculture, researchers have recently turned to producing nano-fertilizers by encapsulating nutrients with nano-materials (Al-Rawi et al., 2023). Nanotechnology is one of the fastest advancing technologies worldwide (Al-Rawi et al., 2024 a), especially in agricultural production, which has shown remarkable development in terms of increasing agricultural production in quantity and quality, and

has also been reflected in reducing environmental pollution by reducing the amounts of added fertilizers. In general, the deficiency of nutrients in the essential plant nutrients leads to disruption of the vital activities of the plant, and the severity of the effect increases as the deficiency of one or more of these nutrients increases. Among the main nutrients for the plant is manganese (Mn), which plays an important role in the plant's metabolic processes such as respiration, photosynthesis, amino acid synthesis, hormone activation, antioxidant enzyme activation, absorption, transport, and increasing the plant's ability to tolerate drought, heat stress, and fungal diseases. Meanwhile, manganese deficiency leads to a negative impact on plant growth indicators, dry matter production, and yield. Symptoms of manganese deficiency appear in the form of pale green or yellow spots on younger leaves (Alloway, 2008; Inani et al., 2015). To rationalize the use of nutrients and increase their efficiency, they were converted into very small particles (less than 100 nanometers), which is known as nanotechnology, which is characterized by increasing their surface area and their penetration and reaching the tissues of the treated plant more quickly, which addresses the problem of poor absorption of nutrients from the soil. Nano-fertilizer technology is one of the fastest advancing technologies worldwide, especially in agricultural sciences through the production and application of environmentally friendly fertilizers, which are more efficient than conventional fertilizers (Al-Rawi et al., 2024 a,b). In general, so far, few researches have been conducted on the function of micronutrients on maize plants (Munirah et al., 2015). Especially in its nano form, however, the effects of manganese on the growth and yield of maize crop have not been precisely defined (Nozulaidi et al., 2016). Also, determining the optimal timing of nutrient addition is an essential and crucial factor to make the plant benefit from these nutrients more effectively to achieve the highest possible benefit and at the lowest costs. Therefore, this study was conducted to determine the response of maize yield to the dates and concentrations of spraying the green group with nano-Mn.

Materials and Methods

An area test turned into accomplished in the experimental discipline of the College of Agriculture – University of Baghdad (Abu-Ghraib web site) during the years 2021 – 2022, with the goal of knowing the effect of spraying the inexperienced institution with nano-Mn on the yield and its additives of maize. A factorial test was accomplished with an entire randomized block layout with three replicates and within the association of break up panels. The essential panels occupied the spraying dates: the beginning of the flowering stage (T1) and at 50% flowering (T2) and at the completion of female flowering (T3), and the secondary panels represented the concentrations of nano-Mn (0, 10, 20 and 30 mg L^{-1}). Maize seeds (Bohuth 106 variety) were planted in experimental units with an area of (2m× 3m), with an isolation distance of 1m between the experimental units and 2m between the replicates. The irrigation channels were made with a distance of 0.75m between them, and the seeds were planted in holes with a distance of 0.25m between them with a plant density of 53333 plant ha^{-1}, as the No. of treatments was 12 treatments distributed randomly within the replicates so that the total No. of experimental units was 36. Nano-Mn was prepared at the required concentrations of 10, 20 and 30 ml L^{-1}, and distilled water was used as a comparison treatment. The studied traits: Ten plants were randomly selected from the central lines and the following traits were measured: ear length, No. of rows in the cob, No. of grains in the row, number of grains in the cob, and weight of 1000 grains (g). The total grain yield (µg ha^{-1}) was calculated by multiplying the individual plant yield × number of plants/hectare and adjusting the weight based on 15.5% moisture (Elsahookie, 1990). The results were analyzed according to the analysis of variance for the randomized complete block design with the arrangement of the split experiments, and the means were compared using the Least Significant Difference (LSD) at the probability level (%5), and the analysis was done using the statistical analysis program GenStat (Kadem and Abed, 2018).

Results and Discussion

Ear length (cm)

It is noted that the early spraying of the vegetative group (beginning of flowering) with nano-Mn was significantly superior by giving the highest average ear length of 16.27 cm, which gradually decreased until it reached the lowest ear length (15.09 cm) at the late spraying date (when flowering was complete) (Table 1). Spraying early on can really give plants a boost, helping them grow better and producing longer ears. This echoes the findings of Al-Rawi et al. (2023 and 2024 b), who observed a significant increase in ear length when nutrients were applied right at the beginning of the ear formation stage. Interestingly, their findings revealed that upping the concentration of nano-Mn to 20 mg L^{-1} yielded the longest ears, measuring in at an impressive 17.95 cm. However, it's quite curious that when the green group was treated with 30 mg L^{-1} of nano-Mn, the ear length actually dropped compared to that 20 mg L^{-1} treatment, even though it still outperformed the other concentrations. Such intricate dynamics in nutrient levels and plant responses truly highlight the complexity of agricultural science.

Table 1. Effect of dates and concentrations of nano-Mn spraying on ear length and No. of ear rows

Data (T)	Ear length (cm)					No. of rows in the ear (row ear^{-1})				
	Mn (mg L^{-1})				Mean (T)	Mn (mg L^{-1})				Mean (T)
	0	10	20	30		0	10	20	30	
T1	13.08	15.83	18.65	17.52	16.27	16.75	17.417	16.333	13.25	15.94
T2	13.32	14.82	17.94	16.94	15.76	16.083	16.583	16.4	13.25	15.58
T3	12.75	14.17	17.25	16.19	15.09	15.833	16.193	15.193	13.417	15.16
Mean (Mn)	13.05	14.94	17.95	16.88		13.42	15.98	16.73	16.22	
LSD 0.05	T	Mn	Mn × T			T	Mn	Mn × T		
	0.66	0.49	N.S			N.S	0.44	N.S		

Source: Authors' own elaboration

As for the interaction between the dates and concentrations of nano-Mn spraying, no significant effect was shown for the trait (Table 1).

No. of rows in the ear (rowear^{-1})

The nano-Mn spray awareness of 20 mg L^{-1} gave the very best common quantity of rows inside the ear, attaining 17.95 rows in the ear, with none enormous difference with the attention of 30 mg L^{-1} (Table 1). The motive for this may be due to the superiority of the remedy itself inside the duration of the ear, which can also have affected the growth inside the quantity of rows in the ear. The purpose for the increase within the range of rows inside the ear as a result of adding nano-Mn is because of the role it plays in the plant's metabolic tactics, the synthesis of amino acids, the activation of hormones and antioxidant enzymes, absorption and transport (Alloway, 2008), and this supplied an appropriate condition to increase the wide variety of rows within the ear.

The spraying dates and the interaction between it and the nano-Mn spraying concentrations had no significant effect on the number of rows in the ear.

No. of grains in the row (grain row^{-1})

The results of Table 2 display that the early planting date (at the start of flowering) gave the very best variety of grains in the row (33.21 grain row^{-1}), which step by step reduced with the put off of the spraying date to present the lowest common for the trait at the past due spraying date, which reached 32.32 grain row^{-1}. The boom inside the quantity of grains because of early spraying of nano-Mn may be because of the reality that spraying at this date gave us the maximum period of the ear, which become reflected in the growth within the diameter of the delivery vessels within the ear, and thus the increase in the arrival of the dry be counted produced within the plant and nutrients and their arrival to the ovaries placed at the cease or pinnacle of the ear, which might be regularly atrophied and infertile, which become pondered in the growth inside the number of grains within the row. It is referred to from the consequences of Table 2 that the quantity of grains within the row additionally gradually extended with the growth in nano-Mn concentrations. After achieving 27.46 grain row^{-1} inside the comparison remedy, it multiplied until it reached its highest common (34.73 grain row^{-1}), then decreased slightly when spraying with the best attention of nano-Mn to attain 33.47 grain row^{-1}. The growth within the quantity of grains within the row is because of the prevalence of that remedy inside the duration of the ear and the wide variety of rows, which

Table 2. Effect of spraying dates and concentrations of nano-Mn on the number of grains in the row and the No. of grains in the ear

Data (T)	No. of grain in the rows (grain row^{-1})					No. of grains in the ear (grain ear^{-1})				
	Mn (mg L^{-1})				Mean (T)	Mn (mg L^{-1})				Mean (T)
	0	10	20	30		0	10	20	30	
T1	27.25	34.03	36.68	34.89	33.21	361.5	555.6	638.7	584.4	535.0
T2	27.58	33.25	34.26	33.20	32.07	365.2	545.6	568.0	534.1	503.2
T3	27.54	31.06	33.25	32.32	31.04	369.7	471.7	538.4	511.5	472.8
Mean (Mn)	27.46	32.78	34.73	33.47		365.5	524.3	581.7	543.3	
LSD 0.05	T	Mn	Mn × T			T	Mn	Mn × T		
	0.37	0.27	N.S			15.5	22.2	34.9		

Source: Authors' own elaboration

offers a bigger ear length, and that is undoubtedly associated with the quantity of grains and grain yield (Elsahookie et al., 2021), and that is steady with what was reached by using AL-Shumary et al. (2019), who indicated that the addition of nano-fertilizer containing nano-Mn multiplied the variety of grains.

The spraying dates and the interaction between the two look at elements did no longer have any full-size distinction within the trait.

No. of grains in the ear (grain ear^{-1})

Early foliar application at the beginning of flowering gave the highest No. of grains in the ear, reaching 535 grain ear^{-1}, with a significant difference from the two subsequent dates, in which the late date at the completion of flowering showed the lowest average No. of grains in the ear, reaching 472.8 grain ear^{-1}. The superiority of the early spraying date gives the plant the opportunity to benefit more from the added nutrients by improving the vegetative growth characteristics that represent the main part of building dry matter and providing and transferring it to the grains in the stages of its formation.

The concentrations of nano-Mn spraying (20 mg L^{-1}) gave the highest No. of ear grains, reaching 581.7 grain ear^{-1}, followed by a concentration of 30 mg L^{-1}, while the comparison treatment gave the lowest number of ear grains, reaching 365.5 grain ear^{-1}. It should be noted that nano-Mn deficiency leads to a reduction in dry matter production and yield by reducing the components of the crop, the most important of which are the weight and number of grains in the plant (Alloway, 2008).

Plants sprayed with a 20 mg nano-Mn L^{-1} at the early date (beginning of flowering) showed the highest value of interaction, reaching 638.7 grainear^{-1}, while the interaction between spraying with distilled water (comparison) at all spraying dates gave the lowest value of interaction without any significant difference between them, which amounted to 361.5, 365.2 and 369.7 grainear^{-1}, respectively.

Weight of A thousand grains (g)

The early date gave the highest weight of 1000 grains, reaching 171.8 g, while the second and third dates showed the traits without any significant difference between them and with an average of 162.7 and 160.4 g for the second and third dates, respectively (Table 3). The purpose for the superiority of early spraying can be due to it being one of the crucial stages of the plant's existence, which results in raising the efficiency of the plant in the carbon metabolism process, which increases the performance of the source in the direction of the estuaries (Mutlag et al., 2023). This result confirms what Jaber and Al-Jebbori (2013) and Al-Rawi et al. (2023 and 2024 a) reached, who indicated that foliar feeding in the flowering and fruiting stages led to an increase in the grain weight in maize ears. The results showed the superiority of the nano-Mn spray treatment at a concentration of 20 mg L^{-1} in the studied trait, reaching 176.9 g, comparison with control treatment, which gave the lowest average for the trait, reaching 147.7 g. The increase in grain weight as a result of increasing nano-Mn concentrations is due to the important role played by this element in stimulating plant metabolic processes such as respiration, photosynthesis, amino acid synthesis, and hormone activation (Inani et al., 2015), and activating the transport process and stress resistance (Lei et al., 2007), which improves the process of dry matter production and its transfer from the source to the outlets (grains).

Total grain yield (µg ha^{-1})

The results of Table 3 show significant differences in planting dates, nano-Mn concentrations and their interaction in this trait.

The flora treated with the early date gave the best grain yield of 5.06 µg ha^{-1}, with a relative distinction of 10.24 and 14.22% over the second and 0.33 dates, respectively, wherein the closing date gave the lowest of this trait (4.43 µg ha^{-1}). The reason for the superiority of the early spraying date (at the beginning of flowering) is that this date offers the biggest

Table 3. Effect of dates and concentrations of nano-Mn spraying on the weight of thousand grains and total grain yield

Data	1000 grain weight (g)					Grain yield (µg ha^{-1})				
	Mn (mg L^{-1})				Mean (T)	Mn (mg L^{-1})				Mean (T)
(T)	0	10	20	30		0	10	20	30	
T1	151.0	168.7	186.3	181.0	171.8	3.19	4.79	6.30	5.95	5.06
T2	147.3	159.7	173.7	170.0	162.7	3.16	4.36	5.69	5.17	4.59
T3	144.7	159.7	170.7	166.7	160.4	3.09	4.24	5.42	4.98	4.43
Mean (Mn)	147.7	162.7	176.9	172.6		3.15	4.46	5.80	5.36	
LSD 0.05	T	Mn	Mn × T			T	Mn	Mn × T		
	3.5	3.2	N.S			0.123	0.124	0.206		

Source: Authors' own elaboration

ear size, as it gave the best ear duration and No. Of rows inside the ear (Table 1), and this is positively associated with the very last grain yield, which turned into showed by means of Elsahookie et al. (2021), who indicated that ear length offers a field indicator of grain yield and early. It is mentioned that the prevalence of the concentration of 20 g L^{-1} keeps inside the additives of the crop, which become contemplated in giving the highest average overall grain yield of five.80 µg ha^{-1}, whilst the lowest grain yield (3.15 µg ha^{-1}) changed into for the evaluation treatment. This superiority of nano-Mn in popular and the awareness of 20 mg L^{-1} is attributed to the superiority of that remedy in the main and secondary components of the crop (Tables 1, 2 and 3), which became pondered in giving it the highest grain yield. This result is regular with Nozulaidi et al. (2016), who indicated that the grain yield expanded due to growing the ear length, ear weight and grain weight as a result of increasing the concentrations of spraying with manganese. As for the interference, it seems that spraying the concentration of 20 mg L^{-1} on the early date gave the highest interference price of 6.30 µg ha^{-1}, even as the evaluation treatment at all spraying ranges gave the bottom interference value of 3.19, 3.16 and 3.09 µg ha^{-1}, respectively.

Conclusions

This study has shown that spraying the nano-Mn element in all its concentrations, especially the concentration of 20 mg L^{-1} at the beginning of the flowering stage, is the most closely related to improving the main and secondary components and the yield of maize grains, and this shows the great importance of choosing the appropriate date for spraying nutrients. It is also noted that the higher concentration of nano-Mn (30 mg L^{-1}) gave a decrease in the yield and its components of maize, which may give an indication that increasing the concentration above 20 mg L^{-1} may give a negative or toxic effect due to the features and effects of nano compounds in general and the nano-Mn element in particular.

References

Alloway, B. J. (2008). Micronutrients and Crop Production: An Introduction. In: *Alloway B.J.* (Ed) *Micronutrient Deficiencies in Global Crop Production. Springer,* 1–40.

Al-Rawi, A. S. M., Mohammed, A. A., Al-Taweel, S. K. & Cheyed, S. H. (2024a). The role of nanotechnology in crop-improvement – A review. *SABRAO J. Breed. Genet., 56*(5), 1929–1937. http://doi.org/10.54910/sabrao2024.56.5.16

Al-Rawi, A. S. M., Shachai, N. F. & Cheyed, S. H. (2024b). Effect of spraying dates with concentrations of nano-zinc on some maize growth traits, yield quality traits and field emergence. yield traits. *IOP Conf. Ser.: Earth and Environ. Sci*., *1371*, 052017. doi:10.1088/1755-1315/1371/5/052017

Al-Rawi, A. S. M., Al-Khafaji, M. J. & Cheyed, S. H. (2023). Effect of spraying dates with nano-zinc on some characteristics of quality, viability, and emergence of maize. *Bulg. J. Agric. Sci., 29*(6), 1165–1169.

AL-Shumary, A.M., Ali, H.A. & Alabdulla, S. A. (2019). Effect of spraying concentrations of integrated nano-fertilizer on growth and yield of genotypes of corn (*Zea mays*L.). *Muthanna J. of Agric. Sci, 7*(2), 114–121.

Elsahookie, M. M. (1990). Maize production and breeding. *Mosul press*, Iraq, 400.

Elsahookie, M. M., Cheyed, S. H. & Dawood, A. A. (2021). Estimating maize ear grain yields on farm. *Iraqi Journal of Agricultural Sciences, 52*(5), 1219–1224.

Inani, N., Nozulaidi, M., Khairi, M., Abdulkadir, A. B. & Jahan, M. S. (2015). Glutathione functions on physiological characters of maize plants to enhance Mn-induced maize production. *Pertanika Journal Tropical Agriculture Sciences, 38*(4), 509–581.

Jaber, A. A. Kh. R. & Al-Jebbori, O. (2013). Effect of nitrogen fertilizer and potassium foliar and dates application on some growth characteristics and yield for (*Zea mays* L.).vr.Bohuth 106. *Al-Forat J. of Agric. Sci., 5*(3), 77–91.

Kadem, F. A. & Abed, N. Y. (2018). Application of statistics and analysis of agricultural experiments (practical part). *Ministry of Higher Education and Scientific Research, College of Agricultural, University of Baghdad*, Iraq, 200.

Lei, Y., Korpelainen, H. & Li, C. (2007). Physiological and biochemical responses to high Mn concentrations in two contrasting Populus cathayana populations. *Chemosphere, 68*(4), 686–694.

Munirah, N., Khairi, M., Nozulaidi, M. & Jahan, M. S. (2015) The effects of zinc application on physiology and production of maize plants. *Australian journal of basic and applied sciences, 9*(2), 362–367.

Mutlag, N. A., Al-Rawi, A. S. M., El-Jubouri, M. D. Y. & Cheyed, S. H. (2023). Response of maize grain yieldand components to foliar iron nanoparticle application. *Revista Bionatura, 8*(4), 70. http://dx.doi.org/10.21931/RB/2023.08.04.70

Nozulaidi, M., NurInani, M., Khairi, M. & Jahan, S. M. D. (2016). Production of Maize; Effects of Manganese Application on Plant Parameters. *J. Agri. Res., 1*(2), 000109.

Received: **January, 31, 2025**; *Approved*: **April, 07, 2025**; *Published*: **August, 2026**