Journal of Medicinal and Industrial Plant Sciences (2025) 3 (4): 52- 59
P-ISSN: 2959 – 121X
E-ISSN: 3106 – 5406
DOI: https://doi.org/10.32894/MEDIP.25.3.4.5

The impact of foliar application of iron and manganese on growth performance and quality traits of Barley (*Hordeum vulgare* L.)

Shaima Majeed Hamad Aljanabi*, Enas Ismail Mohammed
Field Crops Department, College of Agriculture, Tikrit University, Tikrit, Iraq.
* *Corresponding author: E-mail: sh230040pag@st.tu.edu.iq*

ABSTRACT
A field experiment was conducted during the winter season of 2024–2025 at the Field Crops Research Station (FCRS), Field Crops Department, College of Agriculture, Tikrit University, to estimate the effect of foliar application of manganese (Mn) and iron (Fe) on growth and quality traits of barley, variety Ibaa 99. The study included four concentrations of Mn (0, 1000, 2000, and 3000 ppm) and four concentrations of Fe (0, 1000, 2000, and 3000 ppm). Foliar sprays were applied in two stages: the tillering stage and the booting stage. The experiment was arranged in a factorial split-plot design based on a Randomized Complete Block design (RCBD) with three replications. Five growth and quality traits were measured. The results exhibited that the Mn and Fe concentrations, as well as their interaction, were significant for all studied traits. The highest concentration of Mn (3000 ppm) led to significant increases in chlorophyll content, leaf area, and plant height, in addition to Increase the concentration of Mn in the grain. Similarly, the highest Fe concentration (3000 ppm) significantly enhanced chlorophyll content, leaf area, plant height, Increase the concentration of Fe in the grain. Overall, foliar feeding with Mn and Fe at higher concentrations improved both growth performance and grain quality in barley.

KEYWORDS: Foliar application, iron, manganese, barley, Hordeum vulgare L.

Received: 25/10/2025; **Accepted**: 01/12/2025; **Available online:** 31/12/2025

تأثير الرش الورقي بالحديد والمنغنيز في أداء النمو وصفات الجودة لمحصول الشعير (*Hordeum vulgare* L.)

شيماء ماجد حمد الجنابي*، إيناس إسماعيل محمد
قسم المحاصيل الحقلية، كلية الزراعة، جامعة تكريت، تكريت، العراق.

الملخص
أجريت تجربة حقلية خلال الموسم الشتوي 2024–2025 في محطة أبحاث المحاصيل الحقلية **(FCRS)** التابعة لقسم المحاصيل الحقلية، كلية الزراعة، جامعة تكريت، وذلك لتقدير تأثير الرش الورقي بعنصري المنغنيز **(Mn)** والحديد **(Fe)** في صفات النمو والجودة لمحصول الشعير، صنف إباء 99. شملت الدراسة أربع تراكيز من المنغنيز (0، 1000، 2000، و3000 جزء بالمليون) وأربع تراكيز من الحديد (0، 1000، 2000، و3000 جزء بالمليون). تم تطبيق الرش الورقي على مرحلتين **:**مرحلة التفريع ومرحلة البطان .نُفذت التجربة وفق ترتيب القطع المنشقة العاملية ضمن تصميم القطاعات العشوائية الكاملة **(RCBD)** وبثلاثة مكررات. تم قياس خمس صفات تتعلق بالنمو والجودة. أظهرت النتائج أن تراكيز المنغنيز والحديد، وكذلك التداخل بينهما، كانت ذات تأثير معنوي في جميع الصفات المدروسة. أدى أعلى تركيز من المنغنيز (3000 جزء بالمليون) إلى زيادات معنوية في محتوى الكلوروفيل والمساحة الورقية وارتفاع النبات، بالإضافة إلى زيادة تركيز المنغنيز في الحبوب .وبالمثل، أسهم أعلى تركيز من الحديد (3000 جزء بالمليون) في تحسين معنوي في محتوى الكلوروفيل والمساحة الورقية وارتفاع النبات، مع زيادة تركيز الحديد في الحبوب .وبصورة عامة، أدى التسميد الورقي بالمنغنيز والحديد عند التراكيز العالية إلى تحسين أداء النمو وجودة الحبوب في محصول الشعير.
الكلمات المفتاحية: الرش الورقي، الحديد، المنغنيز، الشعير، ***Hordeum vulgare* L.**

INTRODUCTION

Barley (Hordeum vulgare L.), commonly known as barley in English, is a major winter cereal crop belonging to the family Poaceae. It is cultivated extensively across diverse agro-ecological regions worldwide and ranks as the third most important cereal crop after wheat and rice. Barley possesses a diploid chromosome number of 2n = 14. Owing to its remarkable adaptability and tolerance to environmental stress, barley is considered one of the earliest domesticated grain crops, originally developed for human consumption and livestock feed (Arsic et al., 2022). Beyond its traditional role as a food and feed grain, barley is recognized as an economically valuable species due to its wide range of applications in medicinal, pharmaceutical, and industrial sectors. This importance is attributed to its rich composition of bioactive compounds and essential micronutrients. Agronomically, barley exhibits several advantageous traits, including high salinity tolerance, drought resistance, low nutrient requirements, and rapid grain development. It is also a key raw material in malt production and is utilized in the manufacture of vinegar and yeast. Globally, barley is cultivated on approximately 66.45 million hectares, producing an estimated 31.144 million metric tons annually (USDA, 2024). Iron (Fe) is an essential micronutrient required for numerous physiological and biochemical processes in plants. It plays a central role in carbon metabolism, contributes to carbohydrate synthesis, and functions as an oxygen carrier during cellular respiration (Dababo et al., 2021). Similarly, manganese (Mn) is a vital trace element involved in multiple metabolic pathways, including carbon assimilation and enzymatic activation. Previous studies have demonstrated that foliar application of Mn enhances grain yield, yield components, and leaf chlorophyll content. As an essential micronutrient, Mn supports critical metabolic functions within various plant tissues and is indispensable for optimal plant growth and development (Alejandro et al., 2020).

MATERIAL AND METHOD

The field experiment was conducted at the Field Crops Research Station (FCRS), Field Crops Department, College of Agriculture, Tikrit University, Tikrit Iraq, which is located at 43°E longitude and 34°N latitude, during the 2024–2025 winter season. The study aimed to evaluate the efficiency of foliar application of iron (Fe) and manganese (Mn) on growth, yield, and quality traits of barley (*Hordeum vulgare* L.). The field was prepared by ploughing with a disc plow, followed by leveling. Nitrogen fertilizer was applied as urea (46% N) at a rate of 320 kg ha^{-1} in two splits: the first at sowing and the second 45 days after planting. Phosphorus fertilizer was applied as triple super phosphate (21% P) at a rate of 200 kg ha^{-1} in a single dose before sowing. The experiment was arranged in a split-plot layout within a randomized complete block design (RCBD) with three replications. Each replication contained 16 experimental units, each measuring 4 m² (2 × 2 m). Each plot consisted of 10 rows spaced 20 cm apart. The barley variety *Ibaa 99* was used.Planting was carried out October 11 using the surface irrigation method.

Micronutrient Treatments

1. Iron (Fe) Treatments

Four concentrations of iron were applied as ferrous sulfate ($FeSO_4 \cdot 7H_2O$):

Code	$FeSO_4$ Amount (g L^{-1})	Concentration (ppm)
Fe0	0.00	0
Fe1	4.96	1000

Fe2	9.92	2000
Fe3	14.88	3000

2. Manganese (Mn) Treatments

Four concentrations of manganese were applied as manganese sulfate ($MnSO_4 \cdot H_2O$):

Code	$MnSO_4$ Amount (g L^{-1})	Concentration (ppm)
Mn0	0.00	0
Mn1	4.06	1000
Mn2	8.12	2000
Mn3	12.80	3000

Foliar Application Protocol

The micronutrient solutions were applied twice; tillering stage and booting stage. Spraying was performed early in the morning using a 16-L knapsack sprayer until leaves were thoroughly wetted without runoff. All standard agronomic practices—including irrigation, manual weeding, thinning, and pest control were carried out uniformly across plots. Harvesting was performed at full maturity on 5 August 2025. Chlorophyll content (SPAD) was measured in the flag leaf at 100% flowering using a portable SPAD chlorophyll meter. Flag leaf area (cm^2) was calculated at full flowering using the formula:

Leaf Area=Maximum Leaf Length (cm)×Maximum Leaf Width (cm)×0.95 . (Thomas, 1975)

Plant height (cm) was measured from the soil surface to the tip of the main spike (excluding awns) at physiological maturity. Samples (0.52 g) were oven-dried, ground, and digested with concentrated nitric acid to measure Grain Iron Concentration (Fe ppm). The mixture was heated at 40–45°C until evaporation occurred, cooled, re-digested with nitric acid, and finally diluted with 15 mL of deionized water. The filtrate was analyzed using an atomic absorption spectrophotometer. (Lindsay & Norvell, 1978) Dried and ground grain samples were digested using concentrated sulfuric acid, and Mn concentration was measured using an atomic absorption spectrophotometer. (Black, 1965) Data were analyzed using ANOVA appropriate for a split-plot RCBD. Means were compared using the Least Significant Difference Duncan test at the 5% level. Statistical analyses were performed using SAS software.

RESULTS AND DISCUSSION:

Chlorophyll content (SPAD.)

Table (1) for chlorophyll content shows that there were significant differences in chlorophyll levels when plants were sprayed with iron. The high concentration of iron (3000 ppm) recorded the highest mean value of 33.08%, while the lowest mean value was 29.86%. For manganese, the high concentration (3000 ppm) recorded the highest mean value of 32.78%, whereas the control treatment

(0 ppm) recorded the lowest mean value of 30.03% , while the concentration was 0 ppm His lowest average was 30.03% The reason for this may be attributed to the role of iron in the formation of the two compounds laevlinic amino and Protochlorophylic, which are two compounds that are involved in building chlorophyll, in addition to the role of manganese in producing Chlorophyll, although it is included in its composition (Page et al., 1982), and this result agreed with (Farhan & Mahmoud, 2015). The combination of 3000 ppm (iron + Manganese) recorded the highest mean value of 34.61%, while the combination of (Iron + Manganese) recorded the lowest mean value of 29.28%. This result is attributed to The treatment that received zero ppm. The role of iron and manganese in activating the carbon metabolism process and producing compounds that increase chlorophyll content (Abu Dahi & Al-Younis, 1988).

Table 1. Influence of iron and manganese foliar application on chlorophyll content (SPAD) in barley leaves

Mn concentration ppm	**Fe concentration ppm**				**Mn average**
	0	**1000**	**2000**	**3000**	
0	28.29 k	29.64 ij	30.54 h	31.64 f	30.03 d
1000	29.00 J	30.26 hi	31.48 fg	32.46 de	30.90 c
2000	30.40 hi	30.67 gh	32.70 cd	33.62 b	31.85 b
3000	31.37 fg	31.80 ef	33.32 bc	34.61 a	32.78 a
Fe average	29.86 d	30.59 c	32.01 b	**33.08** a	

Flag leaf area (cm^2)

The results of Table (2) are classified into the characteristic: concentration exceeds

The average concentrations and the interaction between them were significant 3000 ppm for iron, recording the highest rate of 17.11 cm^2 While the concentration recorded 0 ppm which gave the lowest average of 11.71 cm^2 for the trait While the four concentrations of manganese exceeded 3000 ppm by recording the highest average for the trait, which amounted to 15.16 cm^2 For the comparison treatment, 0 ppm. ppm Where it differed morally so the reason for this is that these elements have an important role in operations. 2 The lowest rate of characteristic was recorded at 12.89 cm^{-2}. Oxidation, reduction, respiration, building chlorophyll, and many metabolic and storage compounds, all of which are involved in growth. Expanding cells and building new cells increases the leaf area of the plant (Hassan et al., 1990). It is agreed that These results are in addition to what was mentioned (Yadav & Sharma, 2018). The combination was 3000 ppm (iron+ manganese) giving it its highest average of 18.80 cm^{-1} compared to the harmonic treatment of 0 ppm (iron+ manganese), which recorded its lowest rate of 9.73 cm^2 The reason for this is the efficiency of the carbon assimilation process and increasing growth (Hammadi & Al-Khafaji, 1990).

Table 2. Influence of iron and manganese foliar application on flag leaf area (cm^2) in barley.

Mn concentration ppm	Fe concentration ppm				Mn average
	0	1000	2000	3000	
0	9.7**3** J	11.39 i	14.3**2** ef	16.1**2** cd	12.89d
1000	11.84 hi	13.7**0** f	15.72 d	16.59 b-d	14.46 c
2000	12.4**4** gh	14.64 e	16.39 b-d	16.91 bc	15.09 b
3000	12.82 g	15.72 d	17.25 b	18.8**0** a	16.15 a
Fe average	11.71 d	13.86 c	15.92 b	**17.11** a	

Plant height (cm)

The results of Table (3) for the plant height trait show that there are significant differences in the trait when sprayed with iron. It was recorded High concentration of iron: 3000 ppm Its highest average was 101.63 cm with a significant difference from treatment The comparison amounted to 96.73 cm while the high concentration of manganese was 3000 ppm higher Its average was 101.11 cm with a significant difference from the comparison, which recorded an average of 95.69 cm. This is due to the reasonThis is due to the role of iron in the formation of compounds such as cytochromes and ferredoxin, which are of great importance in the process Carbon assimilation, which leads to an increase in carbon assimilation rates and thus an increase in dry matter manufacturing It leads to increased growth, and manganese plays an important role in oxidation and reduction processes within plant cells It is clearly reflected in an increase in plant height (Awad, 1987) and (Al-Nuaimi, 2000) and these results agreed with (Mahmood et al., 2018) As for the effect of the interaction between iron and manganese, the combination gave 3000 ppm (iron + manganese) Its highest average was 105.33 cm, while the combination recorded 0 ppm (Iron + Manganese) is the lowest average It reached 86.93 cm. The reason for this is attributed to the role of these elements combined in the elongation of cells and their role in Carbon assimilation process. Which reflected positively on plant height (Abu Dahi & Al-Younis, 2009). These results agreed with what was reported by (Zain et al., 2015).

Table 3. Influence of iron and manganese foliar application on plant height (cm) in barley.

Mn concentration ppm	Fe concentration ppm				Mn average
	0	1000	2000	3000	
0	93.8**6 K**	94.30 **jk**	95.60 **i-k**	99.00 **e-g**	**95.69 c**
1000	96.00 **g-i**	98.00 **e-g**	97.03 **gh**	100.00 **cd**	**97.75 bc**
2000	97.40 **g-i**	97.83 **e-h**	99.56 **c-e**	102.200 **b**	**99.25 b**
3000	99.66 **c-e**	99.13 **c-f**	100.33 **c**	105.33 **a**	.101**11 a**
Fe average	96.73 c	97.31 bc	98.13 b	101.63 a	

Percentage of iron in grains (%).

The results of Table (4) include the average concentrations and the interaction between them in the character of the percentage of iron in the grains The high concentration of iron, ppm3000, had a maximum average of 3.71% compared to the concentration of 0 ppm which recorded the lowest average of 3.43%, while the concentration was 3000 ppm Manganese has the highest average Its lowest average was 3.29 %, and the reason for this was It reached 3.78 %, while the comparison treatment recorded 0 ppm To increase the concentration of iron added to the spray solution, which led to an increase in the amount absorbed into the seeds With an increase The plant did not get enough soil, which led to it absorbing the largest amount of sprayed iron Its concentration in the spray solution was confirmed by (Al-Alusi, 2002) and this result agrees with (Al-Khalifawi, 2022).

The effect of the interaction between the average concentrations was significant on the trait, as the combination recorded 3000 ppm (Iron + Manganese) The highest average was 3.92%, while the comparison treatment recorded 0 ppm (iron+ manganese) Its lowest average was 3.15%. The reason for this is attributed to the role of these elements in improving growth indicators as a result. It affects many vital activities within the plant and increases division.

Table 4. Influence of iron and manganese foliar application on iron percentage (%) in barley.

Mn concentration ppm	Fe concentration ppm				Mn average
	0	1000	2000	3000	
0	3.**15** b	3.22 ba	3.27 ba	3.52 ba	3.29 b
1000	3.34 ba	3.41 ba	3.56 ba	3.67 ba	3.49 ab
2000	3.61 ba	3.61 ba	3.64 ba	3.75 ba	3.65 a
3000	3.63 ba	3.65 ba	3.91 a	3.92 a	3.78 a
Fe average	3.43 a	3.47 a	3.60 a	3.71a	

Percentage of manganese in grains (%).

The results of Table (Al-Alusi, 2002) show the average concentrations and the interaction between them regarding the percentage of manganese in grains High concentration of manganese 3000 ppm Its highest average was 1.89% compared to the concentration of 0 ppm The lowest average was 1.24%, while the concentration was 3000 ppm Iron is higher Its lowest average was 1.49%, which was attributed to Its average was 1.93%, while the comparison treatment recorded 0 ppm This is due to an increase in the concentration of manganese in the spray solution, which leads to increased absorption by the plant when Spray it on the foliage of the plant, as it possesses properties that enable it to increase the enzymatic activity and process The interaction between the average concentrations is significant in carbon assimilation. This is what was mentioned by (Al-Alusi, 2002). It was an effect Characteristic, as the combination recorded 3000 ppm (Iron + Manganese) had the highest average of 2.14% recorded Comparison treatment 0 ppm (Iron + Manganese) The lowest average was 1.25%, and the reason for this is attributed to the role of this elements combined improve growth indicators as a result of their influence on many vital activities within the plant.

Table 5. Influence of iron and manganese foliar application on manganese percentage (%) in barley.

Mn concentration ppm	Fe concentration ppm				Mn average
	0	1000	2000	3000	
0	1.25 g	1.39 fg	1.40 gf	1.63 c-e	1.24 c
1000	1.48 ef	1.65 c-e	1.71 cd	1.97 ab	1.70 b
2000	1.56 d-f	1.65 c-e	1.80 bc	1.97 ab	1.74 b
3000	1.67 c-e	1.74 cd	2.03 a	2.14 a	1.89 a
Fe average	1.49 d	1.61 c	1.73 b	1.93 a	

CONCLUSIONS

The concentrations used in the study showed a highly significant effect for all the studied traits if the high concentration (ppm 3000) of iron and manganese exceeds all the characteristics studied.

REFERENCES

Arsic, M. D. P., Persson, J. K., Schjoerring, J. K., Thygesen, L., Lombi, E., Doolette, C. L., & Husted, S. (2022). Foliar-applied manganese and phosphorus in deficient barley: Linking absorption pathways and leaf nutrient status. *Physiologia Plantarum, 10*, 13761.

USDA. (2024). *Foreign Agricultural Service – Global market analysis*. United States Department of Agriculture.

Dababo, M. B., Baghdadi, M., Kilani, S., & Otri, M. M. (2021). Effect of foliar spraying and ground fertilization with chelated iron (Fe-EDDHA) on some physical and chemical properties and productivity of pear trees (*Pyrus communis* L.). *Syrian Journal of Agricultural Research, 8*(6), 66–77.

Alejandro, S., Holler, S., Meier, B., & Peiter, E. (2020). Manganese in plants: From acquisition to subcellular allocation. *Frontiers in Plant Science*.

Thomas, H. (1975). The growth response to weather of simulated vegetative swards of a single genotype of *Lolium perenne*. *Journal of Agricultural Science, 84*(1), 333–343.

Lindsay, W. L., & Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal, 42*, 421–428.

Black, C. A. (1965). *Methods of soil analysis. Part 1: Physical and mineralogical properties*. American Society of Agronomy.

Page, A. L., Miller, R. H., & Keeney, D. R. (1982). *Methods of soil analysis. Part 2: Chemical and microbiological properties* (Agronomy Series No. 9). American Society of Agronomy.

Farhan, H. N., & Mahmoud, A. S. (2015). Effect of foliar feeding with zinc, iron, and copper on growth and barley productivity under center-pivot irrigation system. *Anbar University Journal of Pure Sciences, 9*(1), 1–8.

Abu Dahi, Y. M., & Al-Younis, M. A. (1988). *Plant nutrition*. Ministry of Higher Education and Scientific Research, University of Baghdad.

Hassan, F. A., Al-Dulaimi, H. Y., & Al-Issawi, L. A. (1990). *Soil fertility and fertilizers*. Dar Al-Hekma for Printing and Publishing.

Yadav, N., & Sharma, Y. K. (2018). Enrichment of iron density in barley (*Hordeum vulgare*) grains through foliar iron application. *Journal of Plant Physiology and Pathology, 6*(3).

Hammadi, K. B., & Al-Khafaji, A. A. (1990). Effect of foliar application of iron and zinc on growth and yield of wheat (Aba-99) grown in calcareous soils. *Iraqi Journal of Agricultural Sciences, 30*(1), 1–2.

Awad, K. M. (1987). *Fertilization and soil fertility*. Ministry of Higher Education and Scientific Research, University of Basra.

Al-Nuaimi, S. N. A. (2000). *Principles of plant nutrition*. University of Mosul.

Mahmood, R. S. M., Sohail, A., & Abbas, R. A. (2018). Effect of spraying some micronutrients on growth traits and green yield of hydroponic barley. *Euphrates Journal of Agricultural Science, 10*(1), 115–124.

Abu Dahi, Y. M. R., & Al-Younis, M. A. (2009). Guide to foliar nutrition with iron, zinc, and potassium and its effect on growth and yield of bread wheat. *Iraqi Journal of Agricultural Sciences, 80*(1), 69–81.

Zain, M. I., Khan, R. W. K., Qadri, U., Ashraf, S., Hussain, S., Minhas, S., Siddique, A., Jahangir, M. M., & Bashir, M. (2015). Foliar application of micronutrients enhances wheat growth, yield, and related attributes. *American Journal of Plant Sciences, 6*, 864–869.

Al-Alusi, Y. A. M. (2002). *The effect of spraying iron and manganese on soils varying in potassium availability and on the growth and yield of wheat* (Doctoral dissertation). College of Agriculture, University of Baghdad, Iraq.

Al-Khalifawi, W. B. A. (2022). *Evaluating the harmful effect of poor-quality irrigation water on soil properties and the effect of spraying iron and zinc fertilizers on the growth and yield of barley* (PhD dissertation). Department of Soil and Water Resources, College of Agriculture, University of Anbar, Iraq.