

Effect of foliar spraying with nano-iron and the addition of biofertilizer on soybean growth

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Abstract. A field experiment was conducted to determine the effect of foliar spraying with chelated nano-iron and the addition of the biofertilizer EMI on the growth of soybean plants. The experiment was carried out in the Al-Azawiya area of Al-Musayyib district, north of Babylon Governorate, at a longitude of 32°47'53.9"N, and a latitude of 44°24'32.1"E. During the autumn growing season of 2025, a randomized block design (RCBD) with three replications was used. The experiment included three concentrations of nano-iron fertilizer (0, 1.5 g/L, and 3 g/L) and three levels of the biofertilizer EMI (0, 2 ml L⁻¹, and 4 ml L⁻¹). The results showed that the third concentration of nano-iron fertilizer (3 g L⁻¹) was superior to the control treatment in terms of plant height, number of branches, number of leaves, leaf chlorophyll content, and leaf area. The results also showed that the third level of EMI biofertilizer outperformed the control treatment in plant height, branch number, leaf number, leaf chlorophyll content, and leaf area. The interaction between nano-fertilization and EMI biofertilizer was significant in growth characteristics. The interaction between the third concentration of nano-iron fertilizer (3 g L⁻¹) and the third level of biofertilizer (4 ml L⁻¹) resulted in the highest average vegetative growth indicators for plant height, number of branches, number of leaves, leaf chlorophyll content, and leaf area, surpassing the control treatment. We conclude that the use of nano-iron at a concentration of (3 g L⁻¹) alone or with the dual interaction treatment (between spraying nano-iron fertilizer and the EMI biofertilizer) has a significant effect on all vegetative growth indicators for the studied traits and outperformed the growth indicators of the control treatment.

Keywords: Soybeans, nano-iron, EMI biofertilizer, chlorophyll..

1. INTRODUCTION

Foliar spraying is a fertilization method in which a nutrient solution is sprayed directly onto the plant's leaves. The leaves absorb these nutrients through stomata or the epidermis, making foliar fertilization an effective and rapid means of correcting nutritional deficiencies,

particularly micronutrient deficiencies [1]. Iron is an essential element involved in the synthesis of enzymes that participate in or act as cofactors in metabolism and nitrogen fixation. It is vital for the growth and development of all plants and cannot be replaced by any other element. Some plants absorb iron in relatively large quantities compared to other micronutrients. Iron plays a crucial role in plant life. Foliar feeding is one of the most important methods of supplying plants with their nutrient requirements. This involves spraying the foliage with diluted solutions of these nutrients several times. It is considered a successful and important method for addressing nutrient deficiencies, especially micronutrient deficiencies [2,3]. The use of biofertilizers in agriculture encourages organisms to establish symbiotic relationships with plants, thus increasing growth and yield. It also helps reduce the use of mineral fertilizers by up to 40-50%. Biofertilizers play an important role in preserving the environment, as their effects are evident on the plant and soil, increasing the plant's ability to absorb water and nutrients [4,5,6]. The biofertilizer Effective Microorganisms (EM1) is a product containing a group of beneficial microorganisms, primarily used in organic farming to improve soil fertility, promote plant growth, and enhance crop quality. This biofertilizer was developed by Teruo Higa in Japan during the 1980s [5]. These microorganisms work together to stimulate vital processes in the soil and plants, leading to improved soil biological quality. Soybeans (*Glycine max* (L.) Merr.) are an important food and industrial crop globally, belonging to the legume family. They are distinguished from other legumes by containing all the essential amino acids necessary for the human body to produce protein. Soybeans are cultivated for their oil, which constitutes 14-24% of the yield, and for their protein content, which ranges from 30-50% [7]. Soybean production is sensitive to environmental conditions and the availability of nutrients in the soil. In Iraqi soils, the pH tends to be high, which reduces the availability of most macro- and micronutrients, including nitrogen, potassium, iron, and zinc. These nutrients are affected by leaching and volatilization [8]. The current research aims to reduce the use of mineral fertilizers by using nano-iron fertilizer and EM1 biofertilizer, and to determine the effect of their interaction on growth indicators in soybeans.

2. MATERIALS AND METHODS

2.1. MATERIALS

2.1.1. Experimental site: It was carried out during the summer season of 2025 on a farm in the Al-Azawiya area of Al-Musayyib district, located north of Babylon Governorate, which is located at longitude (32°47'53.9"N) and latitude (44°24'32.1"E) by planting seeds of the Sheema variety of soybean plant.

2.1.2. Soil Preparation: The field soil was prepared by removing weeds and plant debris from the previous crop. It was then harrowed with a forklift and plowed perpendicularly twice to achieve well-loosened soil. Finally, it was smoothed with a disc harrow. The soil was leveled and divided into experimental units measuring 2.5 x 2.25 meters. Each experimental unit was further divided into three rows, spaced 75 cm apart. The experimental area was

fertilized with nitrogen fertilizer in the form of urea (46% nitrogen) at a rate of 80 kg/ha (half the recommended application rate) in two equal applications: the first during land preparation and the second at the flowering stage. Triple superphosphate fertilizer (46%P₂O₅) was added at a rate of 40 kg/ha (half the fertilizer recommendation) before planting and 20 kg/ha K₂O (half the fertilizer recommendation) [9]. Crop service operations of irrigation and weeding were carried out as required, and the plant was harvested on 11.04.2025. Soil samples were collected from random areas of the experimental ground to a depth of (0-30) cm, air-dried, ground with a hammer, and passed through a sieve with openings of 2 mm. Some physical and chemical properties were measured as shown in Table No. (1).

Table 1. Some physical and chemical properties in the soil field.

| Capacity | Value | Measurement Unit |
|--------------------------------|-------|---------------------------------|
| Soil (pH) | 7.71 | |
| Electrical Conductivity (EC) | 3.2 | dS m ⁻¹ |
| Cation Exchange Capacity (CEC) | 18.73 | Centimole kg ⁻¹ soil |
| Ca ²⁺ | 19.4 | m mol.L ⁻¹ |
| Mg ²⁺ | 10.02 | |
| Na ⁺ | 21.1 | |
| Cl ⁻ | 35.5 | |
| SO ₄ ²⁻ | 9.94 | |
| CO ₃ ²⁻ | Nil | |
| HCO ₃ ⁻ | 3.65 | |
| Bulk density | 1.32 | Mg.m ⁻³ |
| Soil organic matter (S.O.M.) | 2.68 | g kg ⁻¹ soil |
| Iron | 2.06 | mg kg Soil ⁻¹ |
| Available nitrogen | 28.05 | mg kg Soil ⁻¹ |
| Available phosphorus | 8.41 | |
| Available Potassium | 122.1 | |
| Sand | 295 | g kg ⁻¹ soil |
| Silt | 325 | |
| Clay | 380 | |
| Soil texture | | Clay Loam |

2.1.3. Field Experiment: Soybean seeds were sown on May 28, 2025, with a spacing of 40 cm between plants. Two to three seeds were planted per plant, and thinning to one plant per plant occurred two weeks after sowing. The experimental unit consisted of 18 plants. The experimental factors included:

The first factor was nano-iron fertilizer (Fe₂O₃), designated F₀, F₁, and F₂, applied at three concentrations (0, 1.5, and 3 g/L) in water-soluble form, with three applications spaced 30 days apart.

The second factor was biofertilizer EM1, designated E₀, E₁, and E₂ applied at three levels (0, 2, and 4 ml/L) at a rate of 20 liters per hectare, 20 days after seedling emergence. Timing and Method of Application: Three foliar sprays of nano-iron fertilizer were applied, one month apart, according to the recommended concentrations. The control treatment was sprayed with distilled water using a 10-liter sprayer. Five milliliters of laundry detergent (such as bleach) were added to reduce leaf surface tension. The plants were watered the day before spraying to facilitate absorption of the nano-fertilizer through the leaf stomata. Spraying should be done in the early morning or evening when the stomata are open. The biofertilizer (EM1) was added to the plants by injection. An incision was made next to the plant, and the fertilizer was applied near the root zone. Injection was carried out 20 days after seedling emergence [10].

2.1.4. Plant Characteristics Under Study

Five plants were selected from the midline of each experimental unit, and the following vegetative growth characteristics of soybean plants were measured:

2.1.5. Average Plant Height (cm) The heights of the five randomly selected plants were measured at the end of the experiment, and their averages were calculated for each experimental unit [11].

2.1.6. Average Number of Branches (Treatment per plant) The number of branches was counted for the five randomly selected plants from the midline of the experimental unit.

2.1.7. Average Number of Leaves (Leaf per plant) The number of leaves was counted for the five randomly selected plants, and the total was divided by the number of leaves to calculate the averages.

2.1.8. Average Leaf Area (dm²): Leaf area was measured using a planimeter after cloning the leaf. The total leaf area of the plant was then estimated by multiplying the area of one leaf by the number of leaves.

2.1.9. Average Leaf Chlorophyll Index (SPAD): The chlorophyll index of the five randomly selected plants was measured using a Japanese-made SPAD meter.

2.1.10. Statistical Analysis: The experiment was designed as a factorial experiment using a Randomized Complete Block Design (RCBD) with three replicates of 27 experimental units each, randomly distributed, for a total of 81 experimental units. The means were compared using the Least Significant Difference (LSD) test at a significance level of 0.05. Microsoft Excel was used for the analysis [12].

3. RESULTS AND DISCUSSION

3.1. RESULTS

3.1.1. Effect of Foliar Spraying with Nano Iron and Adding Biofertilizer on Plant Height (cm)

Table 2 shows significant differences in the individual factors and their interactions at a probability level of 0.05. The third concentration of nano iron fertilizer (3 g L⁻¹) resulted in the highest average plant height, reaching 67.51 cm, compared to the control treatment, which resulted in the lowest average plant height of 60.58 cm. This may be attributed to the fact that iron (Fe) is one of the most important elements involved in many physiological and metabolic

processes, such as photosynthesis, respiration, electron transport, nitrogen fixation, and nitrate reduction [13,14,15]. This, in turn, affects the growth and elongation of plant parts. This is consistent with [7] in an experiment on soybean plants, where plants sprayed foliar with nano-iron gave the highest average plant lengths compared to control plants.

The third-level biofertilizer treatment (4 ml L⁻¹) resulted in the highest average plant height of 65.27 cm compared to the control treatment, which yielded the lowest average plant height of 62.51 cm. This is attributed to the increased plant productivity of the active microorganisms present in the biofertilizer (EM), in addition to increased antioxidant activity in the treated varieties, higher polyphenol and carotenoid content, and increased nitrogen and phosphorus concentrations in the soil compared to the control sample [16, 17]. This aligns with the findings of [18] in their study on the effect of biofertilizers on soybean plants. Their results showed that the use of biofertilizers led to significant differences in plant height, with the application of biofertilizers resulting in the highest average plant heights compared to the control treatment.

Table 2. Effect of foliar spraying with nano-iron and the addition of biofertilizer on plant height (cm)

| Nano Fe | Biofertilizer EM1 | | | Mean |
|----------------|-------------------|----------------|----------------|-----------|
| | E ₀ | E ₁ | E ₂ | |
| F ₀ | 59.53 | 60.60 | 61.60 | 60.58 |
| F ₁ | 62.40 | 63.40 | 64.67 | 63.49 |
| F ₂ | 65.60 | 67.40 | 69.53 | 67.51 |
| Mean | 62.51 | 63.80 | 65.27 | |
| LSD 0.05 | Nano Fe 0.224 | Interactions | 0.388 | EM1 0.224 |

Regarding the interaction between nano-iron fertilizer and biofertilizer, the treatment with the third concentration of nano-iron fertilizer (3 g L⁻¹) and the third level of biofertilizer (4 ml L⁻¹) resulted in the highest average plant height (69.53 cm), compared to the control treatment which yielded the lowest average plant height (59.53 cm). This aligns with [11] study on soybean plants, which generally demonstrates that spraying soybean leaves with nano-iron chelates and injecting Biohealth biofertilizer into the soil improves plant growth and productivity. The vegetative growth stage is the most critical period for soybean foliar application of micronutrients to enhance physiological activity and increase dry matter production.

3.1.2. Effect of Foliar Spraying with Nano Iron and Adding Biofertilizer on the Number of Branches in Plants.

Table 3 shows significant differences in the individual factors and their interactions. The third concentration of nano iron fertilizer (3 g/L) resulted in the highest average number of branches in plants, with an average of 4.69 branches per plant, compared to the control treatment, which yielded the lowest average number of branches per plant (4.33). This aligns with Alwan and Alkarawi, [3] study on broad bean plants sprayed with chelated iron. The results showed that plants treated with chelated iron exhibited superior growth indicators and branching compared to the control treatment, which showed the lowest growth indicators. The same study also confirmed the superiority of plants treated with foliar iron spraying compared to those treated with soil application of iron. The third-level biofertilizer treatment (4 ml L⁻¹) resulted in the highest average number of plant branches (4.69 plants) compared to the control treatment, which resulted in the lowest average number of plant branches (4.33 plants). This

is attributed to the fact that the biofertilizer, containing microorganisms, provides the plant with essential nutrients and vitamins and secretes various growth regulators that create hormonal balance within the plant and increase its nutrient supply, which is reflected in plant growth and increased yield. [19, 20].

Table (3) Effect of foliar spraying with nano-iron and the addition of biofertilizer on the trait of the number of branches of the plant (plant branch-1)

| Nano Fe | Biofertilizer EM1 | | | Mean |
|----------------|-------------------|--------------------|----------------|-----------|
| | E ₀ | E ₁ | E ₂ | |
| F ₀ | 4.13 | 4.33 | 4.53 | 4.33 |
| F ₁ | 4.33 | 4.53 | 4.73 | 4.53 |
| F ₂ | 4.53 | 4.73 | 4.80 | 4.69 |
| Mean | 4.33 | 4.53 | 4.69 | |
| LSD 0.05 | Nano Fe 0.038 | Interactions 0.067 | | EM1 0.038 |

Regarding the interaction between nano-iron fertilizer and biofertilizer, the treatment (3 g L⁻¹ of nano-iron fertilizer and 4 ml L⁻¹ of biofertilizer) resulted in the highest average number of plant branches (4.80 plants) compared to the control treatment, which resulted in the lowest average number of plant branches (4.13 plants). This aligns with the findings of Al-Olwiad [21] whose study demonstrated that using a combination of chemical and biofertilizers increased plant growth and photosynthetic activity in green beans.

3.1.3. Effect of Foliar Spraying with Nano Iron and Adding Biofertilizer on the Number of Leaves in Plants

Table 4 shows significant differences in the individual factors and their interactions. The third concentration of nano iron fertilizer (3 g L⁻¹) resulted in the highest average number of leaves in plants, reaching 151.04 leaves per plant, compared to the control treatment, which yielded the lowest average number of leaves per plant (129.13). This aligns with Abdulameer's [22] study on beans treated with foliar iron spraying, which showed the highest average number of leaves in the iron-sprayed plants compared to the control treatment, which produced the fewest leaves. The third-level biofertilizer treatment (4 ml L⁻¹) resulted in the highest average number of leaves per plant (144.38 leaves per plant) compared to the control treatment, which yielded the lowest average leaf count (135.69 leaves per plant). This aligns with the findings of Sharma and Bhattacharyya [23], whose study on cowpea plants treated with *Rhizobium* sp. showed a 15% increase in yield across various stages of plant growth, including dry weight, number of leaves, branches, pods, and leaf moisture, compared to the control treatment.

Table (4) Effect of foliar spraying with nano-iron and addition of biofertilizer on the number of plant leaves (1 plant leaf)

| Nano Fe | Biofertilizer EM1 | | | Mean |
|----------------|-------------------|--------------------|----------------|-----------|
| | E ₀ | E ₁ | E ₂ | |
| F ₀ | 124.40 | 130.40 | 132.60 | 129.13 |
| F ₁ | 135.80 | 142.40 | 144.60 | 140.93 |
| F ₂ | 146.87 | 150.33 | 155.93 | 151.04 |
| Mean | 135.69 | 141.04 | 144.38 | |
| LSD 0.05 | Nano Fe 0.916 | Interactions 1.587 | | EM1 0.916 |

Furthermore, the total number of microorganisms and the levels of available potassium and phosphorus in the soil increased significantly after treatment with this microbial inoculant, demonstrating the role of beneficial microorganisms in improving plant nutrient status and soil health.

As for the binary interactions between nano-iron fertilizer and bio-fertilizer, the treatment (the third concentration of nano-iron fertilizer 3g/L and the third level of bio-fertilizer 4ml L⁻¹) gave the highest average for the number of plant leaves, which reached (155.93) plant leaves⁻¹, compared to the control treatment, which gave the lowest average for plant lengths, which reached (124.40) plant leaves⁻¹. This is consistent with [24]. The interaction between iron and binary fertilizers significantly affected all the studied characteristics. The interaction between nano-iron at a concentration of 30 mg/L with *Bacillus subtilis* bacteria gave the highest values of increase in section length and number of leaves, while the interaction with *Trichoderma harzianum* fungus gave the highest averages for section diameter, chlorophyll content, number of branches, leaf area, and dry matter of the vegetative system.

3.1.4. Effect of Foliar Spraying with Nano Iron and Adding Biofertilizer on the Chlorophyll Index Trait in Plant Leaves (SPAD)

Table (5) shows the chlorophyll content in plant leaves for individual factors and their interactions, revealing significant differences. The third level of nano iron fertilizer (3 g L⁻¹) resulted in the highest average plant height, reaching (35.52) meters, compared to the control treatment, which yielded the lowest average plant height of (34.60) meters. This is attributed to the fact that iron is involved in a variety of physiological processes in plants, including respiration, chlorophyll synthesis, and oxidation-reduction reactions. Chlorophyll is a natural green pigment found in plants and plays a crucial role in photosynthesis [25,26]. The third-level biofertilizer treatment (4 ml L⁻¹) resulted in the highest average plant height (36.14 m) compared to the control treatment, which yielded the lowest average plant height (34.10 m).

Table 5. Effect of foliar spraying with nano-iron, addition of biofertilizer, chlorophyll content in leaves, SPAD

| Nano Fe | Biofertilizer EM1 | | | Mean |
|----------------|-------------------|--------------------|----------------|-----------|
| | E ₀ | E ₁ | E ₂ | |
| F ₀ | 33.56 | 34.85 | 35.39 | 34.60 |
| F ₁ | 34.30 | 35.21 | 36.31 | 35.28 |
| F ₂ | 34.44 | 35.41 | 36.70 | 35.52 |
| Mean | 34.10 | 35.16 | 36.14 | |
| LSD 0.05 | Nano Fe 0.197 | Interactions 0.341 | | EM1 0.197 |

This aligns with Alkarawi, [11] study on the biofertilizer EM1, which found that all plants exhibited positive indicators in plant height, number of branches, number of leaves, dark green leaf color, and stem strength.

Regarding the interaction between nano-iron fertilizer and biofertilizer, the treatment (3 g/L concentration of nano-iron fertilizer and 4 ml L⁻¹ biofertilizer) resulted in the highest average plant height (36.70 m) compared to the control treatment, which yielded the lowest average plant height (33.56 m). This aligns with the findings of [27]. in their study on cowpea plants

treated with biofertilizers and nano-fertilizers, where the results were statistically significant at the 0.05 level for both the number of leaves and the chlorophyll index.

3.1.5. Effect of Foliar Spraying with Nano Iron and Adding Biofertilizer on Leaf Area

Table (6) shows the measurement of leaf area in plants for individual factors and their interactions, revealing significant differences. The third level of nano iron fertilizer (3 g L^{-1}) resulted in the highest average leaf area, reaching $(59.05) \text{ dm}^2$, compared to the control treatment, which resulted in the lowest average leaf area, reaching $(46.25) \text{ dm}^2$. This is consistent with the findings of Odeleye et al.[28]. in a study conducted on soybean plants, where nutrient spraying showed an increase in leaf area compared to the control treatment. The third-level biofertilizer treatment (4 ml L^{-1}) resulted in the highest average leaf area of the plants (56.16 dm^2) compared to the control treatment, which resulted in the lowest average plant height (49.14 dm^2). This is attributed to the direct effect of biofertilizers, which act as fertilizers for plants, providing essential nutrients for plant growth, most importantly nitrogen, carbon, hydrogen, oxygen, phosphorus, and sulfur, thus serving as a food source for the plants [29].

Table (6) Effect of foliar spraying with nano-iron and the addition of biofertilizer on leaf area (dm^2)

| Nano Fe | Biofertilizer EM1 | | | Mean |
|----------------|-------------------|----------------|--------------------|-----------|
| | E ₀ | E ₁ | E ₂ | |
| F ₀ | 43.48 | 45.90 | 49.35 | 46.25 |
| F ₁ | 48.10 | 53.50 | 55.61 | 52.40 |
| F ₂ | 55.84 | 57.82 | 63.51 | 59.05 |
| Mean | 49.14 | 52.41 | 56.16 | |
| LSD 0.05 | Nano Fe 1.127 | | Interactions 1.952 | EM1 1.127 |

As for the binary interactions between nano-iron fertilizer and bio-fertilizer, the treatment (the third concentration of nano-iron fertilizer (3 g L^{-1}) and the third level of bio-fertilizer (4 ml L^{-1}) gave the highest average plant length of $(63.51) \text{ dm}^2$ compared to the control treatment, which gave the lowest average plant length of $(43.48) \text{ dm}^2$. This is consistent with [20] in a study he conducted on fenugreek plants. The study showed an increase in vegetative growth indicators, plant length, number of branches, number of leaves, and leaf area when there was a binary interaction between bio-fertilizer and foliar spraying with chelated nano-iron.

4. CONCLUSIONS

This study concludes that the use of nano-iron (3 g/L) significantly impacted all average vegetative growth indicators: plant height, number of branches, number of leaves, chlorophyll content in leaves, and leaf area, respectively, compared to the control plants. The dual treatment (spraying nano-iron fertilizer and the biofertilizer EM1) yielded the highest averages for the studied traits and outperformed the growth indicators of the control treatment.

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DECLARATION OF COMPETING INTEREST

None

REFERENCES

- [1] Marschner, H., 2011. *Marschner's mineral nutrition of higher plants*. Academic press.
- [2] Rout, J. R., Behera, S., Keshari, N., Ram, S. S., Bhar, S., Chakraborty, A., and Sahoo, S. L., 2015. Effect of iron stress on *Withania somnifera* L.: antioxidant enzyme response and nutrient elemental uptake of in vitro grown plants. *Ecotoxicology*, 24(2): 401-413.
- [3] Alwan, W. M., and Alkarawi, H. H., 2024. The Effect of Mineral and Biofertilization and Nano-Iron on the Growth and Yield of Broad Bean. *Journal of University of Babylon for Pure and Applied Sciences*, 32(4):312-327.
- [4] Kumar, M. S., Reddy, G. C., Phogat, M., and Korav, S., 2018. Role of bio-fertilizers towards sustainable agricultural development: A review. *Journal of Pharmacognosy and Phytochemistry*, 7(6), 1915-1921.
- [5] de Araujo Avila, G. M., Gabardo, G., Clock, D. C., and de Lima Junior, O. S., 2021. Use of efficient microorganisms in agriculture. *Research, Society and Development*, 10(8): e40610817515-e40610817515.
- [6] Alkarawi, H. H., Radhi, I. M., and Hamid, M. M., 2024. Impact of bio-fertilizer and nano iron and chelated iron in the growth and production of cayenne pepper. In *AIP Conference Proceedings* (Vol. 3079, No. 1, p. 020004). AIP Publishing LLC.
- [7] Habib, J. Z., Ali, O. N. and Alsajri, F. A., 2023. Response of Soybean Cultivars to Foliar Fertilizers Using Iron and Boron in Gypsum Soil. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1262, No. 5, p. 052011). IOP Publishing.
- [8] Tiwari, S. P., 2017. Emerging trends in soybean industry. *Soybean Research*, 15(1): 1-17.
- [9] El-Ramady, H., Alshaal, T., Yousef, S., Elmahdy, S., Faizy, S. E. D., Amer, M., and Senesi, N., 2018. Soil fertility and its security. In *The Soils of Egypt* (pp. 137-157). Cham: Springer International Publishing.
- [10] Glick, B. R., 2018. *Methods in plant molecular biology and biotechnology*. CRC Press.
- [11] Alkarawi, H. H., 2025. The Effect of Integrating Nano-Formulated Iron and Zinc Chelates and Bio-Fertilizer on Some Vegetative Growth and Yield Characteristics of Soybean (*Glycine max* (L.) Merrill). *Pak. J. Agri. Sci*, 62(4): 717-728.
- [12] Muhammad, K. M. A. R. A., and Allah, K., 1980. Design and analysis of agricultural experiments. *Dar Al-Kutb for printing and publishing./Mosul University*.
- [13] Devadasu, E. R., Madireddi, S. K., Nama, S. and Subramanyam, R., 2016. Iron deficiency cause changes in photochemistry, thylakoid organization, and accumulation of photosystem II proteins in *Chlamydomonas reinhardtii*. *Photosynthesis research*, 130(1): 469-478.
- [14] Merry, R., Dobbels, A. A., Sadok, W., Naeve, S., Stupar, R. M., and Lorenz, A. J., 2022. Iron deficiency in soybean. *Crop Science*, 62(1): 36-52.
- [15] Gao, F., and Dubos, 2021. Transcriptional integration of plant responses to iron availability. *Journal of experimental botany*, 72(6), 2056-2070.
- [16] Naoof, M. A., and Bayerli, R. M. S., 2025. Promotion of Growth and Fruits Quality Parameters of Tomato Plant by Bio-Fertilizers (*Trichoderma Harzianum* and EM1) and IAA. *Tikrit Journal for Agricultural Sciences*, 25(2): 107-119.

- [17] Tommonaro, G., Abbamondi, G. R., Nicolaus, B., Poli, A., D'Angelo, C., Iodice, C., and De Prisco, R. ,2021. Productivity and nutritional trait improvements of different tomatoes cultivated with effective microorganisms technology. *Agriculture*, 11(2):112.
- [18] Meena, K., Meena, R. K., Meena, D. S., Meena, B. S., Meena, C. B., Yadav, V. K., and Jadon, C. K. ,2023. Effect of inorganic fertilizers and biofertilizers on growth and nodulation of soybean [*Glycine max (L.) Merrill*]. *The Pharma Innovation Journal*, 12(7): 1752-1755.
- [19] Higa, T. ,1999 . Application of Effective Microorganism for sustainable crop production. *University of the Ryukyus, Okinawa, Japan*.
- [20] AL-Mouhammedi, A. A., and Yaseen, A. L. Y. ,2020. Effect of spraying nano-iron addition, bio-fertilize and phosphorous on the growth and yield of fenugreek plant (*Trigonella foenum-graecum L.*). *J. of Educational and Scientific Studies*, 6(16): 155-174.
- [21] Al-Olwied, A. A. ,2016. Comparative study of synthetic fertilizers and organic manures on some Mung Bean (*Vigna radiata (L.) Wilczek*) genotypes-1, effect on growth parameters and photosynthesis productivity. *American-Eurasian J Agric Environ Sci*, 16(4): 666-76.
- [22] Abdulameer, A. S. ,2011. Effect of time factor, spray feeding of Copper and Iron in the relation between the number of bacterial root nodules and leaves of Bean. *Journal of Biotechnology Research Center*, 5(3): 45-55.
- [23] Sharma, A. K., and Bhattacharyya, P. N. ,2016. Effect of beneficial microorganisms on cowpea productivity and soil health. *J. Adv. Res. Pharm. Biol. Sci*, 2:15-21.
- [24]. Al-Zuhairi, F. F., Al-Aareji, J. M., and Al-Taae, A. K. ,2021. Effect of nano and regular iron spraying and bio-fertilization on growth of local lemon transplants *Citrus limon L.* budded on sour orange. In *IOP Conference Series: Earth and Environmental Science (Vol. 735, No. 1, p. 012045)*. IOP Publishing.
- [25]. Kobayashi, T., and Nishizawa, N. K. ,2012. Iron uptake, translocation, and regulation in higher plants. *Annual review of plant biology*, 63, 131-152.
- [26]. Zargar, S. M., Agrawal, G. K., Rakwal, R., and Fukao, Y. ,2015. Quantitative proteomics reveals role of sugar in decreasing photosynthetic activity due to Fe deficiency. *Frontiers in Plant Science*, 6, 592.
- [27]. Mirsardoo, F., Aien, A., Abad, H. H. S., and Korehpaz, S. ,2023. The effect of biological and nanofertilizers on cowpea (*Vigna unguiculata L.*) yield, quantitative and qualitative traits in the southern iranian climate. *Turkish Journal Of Field Crops*, 28(1), 111-120.
- [28]. Odeleye, F. O., Odeleye, O. M. O., and Animashaun, M. O. ,2007. Effects of nutrient foliar spray on soybean growth and yield (*Glycine max (L.) Merrill*) in south west Nigeria. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 35(2): 22.
- [29] Shaabani, S., and Dehnavi, M. M. ,2017 . Effect of different levels of nitrogen, bio-fertilizers and nano-nitrogen on yield and nitrogen use efficiency of soybean in Darab region (fars).