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Article

Effect of Iron and Molybdenum Fertilization on Growth, Yield, and Protein Content of Faba Bean (Vicia faba L.) Grown in Gypsum Soil

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Abstract: A field experiment was conducted during the 2024–2025 growing season in gypsum soil belonging to the College of Agriculture, Tikrit University, to study the effect of iron (Fe) and molybdenum (Mo) on growth, yield, and protein concentration in broad bean plants. Iron was added at 0, 3, 6, and 12 kg ha^{-1}, and molybdenum at 0, 2, 4, and 8 kg ha^{-1}. The results showed that increasing iron levels led to a significant improvement in all studied traits, with plant height increasing from 70.25 cm at 0 kg ha^{-1} to 84.38 cm at 12 kg ha^{-1}, leaf area from 3285 cm^2 $plant^{-1}$ to 5317 cm^2 $plant^{-1}$, plant dry weight from 13.50 g $plant^{-1}$ to 20.50 g $plant^{-1}$, and the number of bacterial nodules from 16 plant $nodules^{-1}$ to 34 plant $nodules^{-1}$. Grain yield increased from 3141 kg ha^{-1} to 3929 kg ha^{-1}, and pod yield from 8057 kg ha^{-1} to 10620 kg ha^{-1}, while the protein concentration in the grains increased from 17.6% to 23.1%. Regarding the effect of molybdenum, the average levels (4 kg ha^{-1}) showed the highest significant improvement in all traits, with plant height reaching 83.90 cm, leaf area 4787 cm^2 $plant^{-1}$, dry weight 18.64 g $plant^{-1}$, number of nodes 31 $plant^{-1}$, grain yield 3764 kg ha^{-1}, pod yield 10174 kg ha^{-1}, and protein concentration 21.4%. The interaction between the two elements showed a clear and significant effect, with the treatment (Fe 12 kg ha^{-1} × Mo 4 kg ha^{-1}) giving the highest values for all traits: plant height 92.10 cm, leaf area 6218 cm^2 $plant^{-1}$, dry weight 22.95 g $plant^{-1}$, number of nodes 38 $plant^{-1}$, grain yield 4187 kg ha^{-1}, pod yield 11725 kg ha^{-1}, and protein concentration 24.5%.

Keywords: Broad Beans, Iron, Molybdenum, Gypsum Soil, Protein Concentration.

Introduction

Broad beans (*Vicia faba* L.) are among the most important legume crops in Iraq due to their high protein content and their active role in fixing atmospheric nitrogen through symbiotic root nodules. They represent an important source of plant protein and contribute to improving soil fertility within crop rotations [1]. The efficiency of this biological fixation depends directly on the availability of micronutrients involved in the synthesis of enzymes responsible for nitrogen reduction, particularly iron and molybdenum. Iron is involved in the synthesis of cytochromes and ferridexins and plays a fundamental role in electron transport, chlorophyll formation, and the activation of enzymes involved in nitrogen metabolism. It also affects the efficiency of photosynthesis, plant growth, and productivity [2]. Therefore, its deficiency negatively impacts vegetative growth, yield, and the protein content of grains.

Molybdenum is a key component in the synthesis of the nitrogenase enzyme, which is responsible for fixing atmospheric nitrogen, and the nitrate reductase enzyme. This makes it a limiting factor in the number and efficiency of bacterial nodules and the protein content of grains [3,4]. Although molybdenum is usually present in sufficient total quantities in most soils, its availability to plants does not depend solely on its total concentration but is also affected by ionic interactions in the soil solution. In the gypsum soils common in large areas of Salah al-Din Governorate, the concentrations of sulfates (SO_4^{2-}) are high due to the presence of gypsum. Ionic competition occurs between molybdates (MoO_4^{2-}) and sulfates for uptake sites in the roots, as they are two anions with similar structure and charge. This can lead to reduced molybdenum uptake and the appearance of deficiency symptoms despite its availability in the soil [5,6]. Physiological studies have confirmed that increased sulfate content in the root medium reduces molybdate uptake due to their shared role in the same transport systems across cell membranes [7].

Consequently, the gypsum soil conditions in Salah al-Din Governorate may predispose to molybdenum deficiency, resulting in impaired bacterial nodule formation and reduced nitrogen fixation efficiency, leading to decreased growth, yield, and grain protein content. This study aimed to evaluate the effects of iron and molybdenum fertilization, both individually and in combination, on broad bean plant growth, yield, grain protein content, and the number of bacterial nodules under local environmental conditions. The objective was to determine the potential for improving biological nitrogen fixation efficiency and increasing productivity in gypsum soils.

Materials and Methods

The field experiment was conducted in a field belonging to the College of Agriculture, Tikrit University, during the 2024–2025 growing season, in gypsum soil, to study the effect of iron and molybdenum on the growth and yield of broad beans (*Vicia faba* L.). A randomized complete block design (RCBD) with three replications was adopted, with each experimental unit representing an area of 2 m^2. Seeds of the Spanish Barcelona variety (HISTAL) were sown on 1-11-2024 in rows within the plots, with a spacing of 30 cm between rows and 25 cm between plants, at a rate of three seeds per plant. After germination, the plants were thinned to two plants. Irrigation was carried out using drip irrigation with well water. The experiment included two main factors; Molybdenum was added as a liquid solution after dissolving quaternary ammonium molybdate $Mo_7O_{24}\cdot 4H_2O_6(4NH_4)$ (54% molybdenum) in plastic containers to ensure accuracy in the addition to each experimental unit, at four levels (0, 2, 4, 8 kg ha^{-1}), while iron was added as a liquid solution using DTPA-Fe (11% Fe) after dissolving it in irrigation water in plastic containers and then pouring it onto each experimental unit, at four levels (0, 3, 6, 12 kg ha^{-1}). Fertilizers were added according to the following recommendations: Nitrogen was added as urea (46% N) at a rate of 44 kg ha^{-1} in two applications, the first immediately after germination and the second at the beginning of the flower-setting stage. Phosphorus was added at planting as triple superphosphate at a rate of 120 kg ha^{-1} [8]. Potassium was added as potassium sulfate K_2SO_4 (43% K) at a rate of 75 kg K ha^{-1} in two applications, the first when the plants reached a height of 10–15 cm and the second at the beginning of the flower-setting stage [9]. Molybdenum and iron were added as liquid solutions after dissolving the levels in plastic containers and then pouring them onto each experimental unit to ensure even distribution and better absorption. Data were analyzed using a randomized complete block design (RCBD), with results compared using the least significant difference (LSD) at the 0.05 level. Statistical analysis was performed using Excel and SAS V9 software [10].

Table 1. Some physical and chemical properties of the soil under study.

Trait / Property	Value	Unit
Soil pH	7.54	-
Electrical Conductivity (EC)	2.62	$dS{\cdot}m^{-1}$
Cation Exchange Capacity (CEC)	20.01	$cmol{\cdot}kg^{-1}$ soil
Organic Matter (OM)	0.89	%
Calcium Carbonate ($CaCO_3$)	190.58	$g{\cdot}kg^{-1}$
Gypsum ($CaSO_4$)	90.21	$g{\cdot}kg^{-1}$
Available Nitrogen (N)	20.32	$mg{\cdot}kg^{-1}$
Available Phosphorus (P)	8.11	$mg{\cdot}kg^{-1}$
Available Potassium (K)	113.56	$mg{\cdot}kg^{-1}$
Sand	511	$g{\cdot}kg^{-1}$
Silt	325	$g{\cdot}kg^{-1}$
Clay	164	$g{\cdot}kg^{-1}$
Soil Texture	Sandy loam	-
Available Molybdenum	0.72	ppm
Available Iron	1.09	ppm

Characteristics studied

Field measurements were taken at the end of the experiment after harvest on March 15, 2025. The average of five plants from the midlines of each experimental unit was used, as follows:

- **Plant height (cm):** Measured using a graduated ruler from the soil surface to the growing tip.
- **Leaf area (cm^2 $plant^{-1}$):** Measured gravimetrically as described in source [11].
- **Dry weight of plant (g $plant^{-1}$):** Estimated the dry weight of the vegetative parts (stem and leaves) after drying the plants in an electric oven at 70°C for 72 hours. Weighed several times until a constant weight was achieved using a sensitive balance.
- **Number of nodules (nodules $plant^{-1}$):** Roots were extracted from three flowering plants, cleaned with water, and the root nodules were counted for each plant [12].
- **Seed yield (g $plant^{-1}$):** Weighed the seed yield of three plants and divided by the number of plants to obtain the seed yield per plant.
- **Pod yield (g $plant^{-1}$):** Weighed the pod yield of three plants and divided by the number of plants to obtain the pod yield per plant.

Protein concentration in grains (%) :The nitrogen content in the seeds was calculated using a device Kjeldahl Macro, then apply the equation: % Protein = % Nitrogen × 6.25 [13].

Results and Discussion

Plant Height (cm)

The results in Table (2) show significant differences between iron levels. The average plant height at the 0 kg ha^{-1} level was 70.25 cm, increasing to 77.54 cm at the 3 kg ha^{-1} level, then to 83.93 cm at the 6 kg ha^{-1} level. The highest average height was recorded at the 12 kg ha^{-1} level, reaching 84.38 cm, significantly exceeding the control level and lower levels. Regarding molybdenum levels, the 0 kg ha^{-1} level recorded an average height of 73.13 cm, rising to 78.66 cm at the 2 kg ha^{-1} level, and reaching its highest average at 83.90 cm at the 4 kg ha^{-1} level, significantly exceeding the other levels. It decreased slightly at the 8 kg ha^{-1} level to 81.39 cm, but remained significantly higher than the control treatment. Concerning the interaction between iron and molybdenum, the 0 iron × 0 molybdenum treatment resulted in the lowest plant height at 67.23 cm, while the 12 kg iron × 4 kg molybdenum treatment yielded the highest height at 92.10 cm, significantly exceeding most other interaction treatments.

Table 2. Effect of soil application of different levels of iron and molybdenum and their interaction on plant height of faba bean (*Vicia faba* L.) (cm).

Iron level (kg ha^{-1})	Molybdenum level (kg ha^{-1}) 0	2	4	8	Mean of Iron
0	67.23	70.05	72.40	71.30	70.25
3	72.80	77.20	81.00	79.15	77.54
6	78.00	83.40	88.10	86.20	83.93
12	76.50	82.00	92.10	88.90	84.38
Mean of molybdenum	73.13	78.66	83.90	81.39	—
L.S.D $_{0.05}$	Iron	Molybdenum		Iron × Molybdenum	
	3.8	3.0		5.5	

Leaf Area (cm² plant⁻¹)

The results in Table (3) indicate significant differences between iron levels. Leaf area at the 0 kg ha^{-1} level was 3285 cm^2 $plant^{-1}$, rising to 4075 cm^2 $plant^{-1}$ at the 3 kg ha^{-1} level, and then to 4737 cm^2 $plant^{-1}$ at the 6 kg ha^{-1} level. The 12 kg ha^{-1} level recorded the highest average, 5317 cm^2 $plant^{-1}$, significantly exceeding the other levels. As for molybdenum levels, the 0 kg ha^{-1}level recorded an average of 3782 cm^2 $plant^{-1}$, increasing to 4257 cm^2 $plant^{-1}$ at the 2 kg ha^{-1}level, and reaching its highest average at 4 kg/e^1, where it reached 4787 cm^2 $plant^{-1}$, significantly higher than the other levels. It then decreased slightly at the 8 kg ha^{-1} level to 4583 cm^2 $plant^{-1}$, while still remaining significantly higher than the control treatment. Regarding the interaction effect between iron and molybdenum, the treatment (0 iron × 0 molybdenum) recorded the lowest leaf area (3027 cm^2 $plant^{-1}$), while the treatment (12 kg iron × 4 kg molybdenum) achieved the highest value (6218 cm^2 $plant^{-1}$), significantly outperforming all other interaction treatments.

Table 3. Effect of iron and molybdenum soil application and their interaction on leaf area of faba bean (*Vicia faba* L.) (cm^2 $plant^{-1}$).

Iron level (kg ha^{-1})	Molybdenum level (kg ha^{-1}) 0	2	4	8	Mean of Iron
0	3027	3280	3450	3385	3285
3	3650	4020	4380	4250	4075
6	4100	4750	5120	4980	4737
12	4350	4980	6218	5720	5317
Mean of molybdenum	3782	4257	4787	4583	
L.S.D $_{0.05}$	Iron	Molybdenum		Iron × Molybdenum	
	250	230		350	

Dry weight (g plant⁻¹)

Table (4) shows that iron fertilization significantly affected the dry weight of broad beans. The average weight at 0 kg ha^{-1} was 13.50 g $plant^{-1}$, rising to 16.29 g $plant^{-1}$ at 3 kg ha^{-1}, then to 18.69 g $plant^{-1}$ at 6 kg ha^{-1}, reaching a peak average of 20.50 g $plant^{-1}$ at 12 kg ha^{-1}, significantly exceeding the lower averages.

The molybdenum treatments showed a significant advantage for the 4 kg ha^{-1} level, which achieved the highest average weight (18.64 g $plant^{-1}$), followed by the 8 kg ha^{-1} level with an average of (17.75 g $plant^{-1}$), and then the 2 kg ha^{-1} level with an average of (16.84 g $plant^{-1}$). The control level (0 kg ha^{-1}) recorded the lowest average weight (15.25 g $plant^{-1}$).When analyzing the interaction between the two factors, the treatment (12 kg iron × 4 kg molybdenum) yielded the highest dry weight (22.95 g $plant^{-1}$), significantly outperforming the other interaction treatments. This was followed by the treatment (12 kg iron × 8 kg molybdenum), which recorded a weight of (21.50 g plant^{-1}). In contrast, the (0 iron × 0 molybdenum) treatment recorded the lowest value (12.89 g plant^{-1}).

Table 4. Effect of iron and molybdenum soil application and their interaction on dry weight of faba bean (*Vicia faba* L.) (g plant^{-1}).

Iron level (kg ha^{-1})	**Molybdenum level (kg ha^{-1}) 0**	**2**	**4**	**8**	**Mean of Iron**
0	12.89	13.45	13.95	13.70	13.50
3	14.80	15.95	16.90	16.50	16.29
6	17.20	18.50	19.75	19.30	18.69
12	18.10	19.45	22.95	21.50	20.50
Mean of molybdenum	15.25	16.84	18.64	17.75	—
L.S.D $_{0.05}$	Iron	Molybdenum		Iron × Molybdenum	
	1.209	1.122		1.875	

The results in Tables 2, 3, and 4 indicate that increasing iron levels led to a significant improvement in plant height, leaf area, and dry weight. This is attributed to the vital role of iron in chlorophyll formation and its inclusion in the structure of cytochromes and iron-sulfur proteins responsible for electron transport in photosynthesis and respiration. This, in turn, leads to increased dry matter formation and improved vegetative growth. These results are consistent with what [14] indicated, namely that improving iron availability increases photosynthetic efficiency and plant biomass. [15] also confirmed that iron availability is a crucial element in regulating absorption, transport, and metabolism within the plant, which directly impacts growth indicators**.**

Regarding molybdenum, the moderate level resulted in the highest values for the studied growth characteristics. This is attributed to its role in the formation of the nitrate reductase and nitrogenase enzymes, which improve nitrogen assimilation and protein synthesis within the plant, thus increasing leaf area and dry weight. These results are consistent with what [16] stated about the regulatory role of molybdenum in nitrogen metabolism and its relationship to iron. [17] also showed that adding molybdenum at appropriate levels improves vegetative growth in legumes by increasing nitrogen fixation efficiency**.**

The significant superiority of the interaction treatment between high iron and moderate molybdenum levels reflects the functional complementarity between the two elements. Iron contributes to enhancing photosynthesis and carbohydrate formation, while molybdenum promotes nitrogen assimilation, leading to increased cell division and dry matter accumulation.

Number of Bacterial Nodules (nodule plant $^{-1}$)

Table (5) data indicates that increased soil iron levels led to a significant increase in the number of root nodules in broad beans, with the highest nodule count observed at an iron level of 12 kg ha^{-1} compared to the control treatment. This can be scientifically explained by the fact that iron is a crucial element in the synthesis of the leuhemoglobin protein and oxygen regulation within root nodules, thus maintaining a suitable environment for the activity of the nitrogenase enzyme responsible for atmospheric nitrogen fixation [18]. Recent studies have confirmed that iron deficiency reduces nitrogen fixation efficiency and negatively affects nodule formation in legumes, while its availability promotes the functional health of root nodules.

As for molybdenum, a level of 4 kg ha^{-1} showed a significant increase in the number of nodules compared to the control treatment, which is attributed to its role as a cofactor for the nitrogenase enzyme.

Table 5. Effect of iron and molybdenum soil application and their interaction on the number of nodules per faba bean plant (nodules plant^{-1}).

Iron level (kg ha^{-1})	Molybdenum level (kg ha^{-1}) 0	2	4	8	Mean of Iron
0	18.25	20.50	21.90	21.15	20.45
3	22.10	24.05	26.75	25.90	24.70
6	26.35	29.05	32.15	30.25	29.45
12	29.10	33.05	36.25	34.40	33.20
Mean of molybdenum	23.45	26.16	29.26	27.42	—
L.S.D 0.05	Iron	Molybdenum		Iron × Molybdenum	
	1.75	1.50		2.80	

Total Grain Yield (kg ha^{-1})

The results in Table (6) show a clear and significant effect of iron and molybdenum levels, and their interaction, on the pod yield (kg ha^{-1}) of broad beans. Yield increased with increasing iron levels from 0 to 12 kg ha^{-1}, with the average yield at the control level being (3141 kg ha^{-1}). This gradually increased to (3566 kg ha^{-1}) at the 3 kg ha^{-1} level, then to (3823 kg ha^{-1}) at the 6 kg ha^{-1} level, reaching its highest average at 12 kg ha^{-1} at (3929 kg ha^{-1}). Molybdenum levels also showed a significant effect, with the yield at 0 kg ha^{-1} (3358 kg ha^{-1}) rising to its highest average at 4 kg ha^{-1} (3764 kg ha^{-1}), then decreasing slightly at 8 kg ha^{-1} (3666 kg ha^{-1}). Regarding the interaction between iron and molybdenum, the treatment (12 kg iron × 4 kg molybdenum) showed the highest horn yield (4187 kg ha^{-1}), significantly outperforming the other interactions, while the control treatment (0 iron × 0 molybdenum) recorded the lowest yield (2959 kg ha^{-1}).

Table 6. Effect of iron and molybdenum soil application and their interaction on seed yield total of (pod yield) of faba bean (*Vicia faba* L.) (kg ha^{-1}).

Iron level (kg ha^{-1})	Molybdenum level (kg ha^{-1}) 0	2	4	8	Mean of Iron
0	2959	3185	3323	3095	3141
3	3388	3656	3493	3725	3566
6	3476	3816	4052	3948	3823
12	3605	4029	4187	3896	3929
Mean of molybdenum	3358	3671	3764	3666	—
L.S.D 0.05	Iron	Molybdenum		Iron × Molybdenum	
	118	102		186	

Total pod yield (kg ha^{-1})

The results in Table (7) indicate that adding iron to the soil led to a significant increase in pod yield for broad beans compared to the no-add treatment. The average yield at the 12 kg ha^{-1} level was (10620 kg ha^{-1}), significantly higher than the 6 kg ha^{-1} level (10318 kg ha^{-1}) and the 3 kg ha^{-1} level (9403 kg ha^{-1}). The no-add treatment recorded the lowest average yield at (8057 kg ha^{-1}). Regarding molybdenum, the results showed a significant variation in molybdenum levels in pod yield. The highest average yield was recorded at the 4 kg ha^{-1} level (10174 kg/ha), followed by the 8 kg ha^{-1} level (9898 kg/ha), and the 2 kg ha^{-1} level (9693 kg/ha). The lowest average yield was recorded at the no-added level (8634 kg/ha). The interaction between iron and molybdenum levels also showed a significant effect on pod yield. The treatment combining 12 kg ha^{-1} of iron with 4 kg ha^{-1} of molybdenum yielded the highest value (11,725 kg ha^{-1}), while the treatment without added iron and molybdenum recorded the lowest value (7,214 kg ha^{-1}).

Table 7. Effect of iron and molybdenum soil application and their interaction on pod yield of faba bean (*Vicia faba* L.) (kg ha⁻¹).

Iron level (kg ha^{-1})	Molybdenum level (kg ha^{-1}) 0	2	4	8	Mean of Iron
0	7214	8045	8650	8320	8057
3	8840	9565	9180	10025	9403
6	9025	10320	11140	10785	10318
12	9455	10840	11725	10460	10620
Mean of molybdenum	8634	9693	10174	9898	—
L.S.D $_{0.05}$	Iron	Molybdenum		Iron × Molybdenum	
	365	310		540	

The results indicate that increasing soil iron levels led to a significant increase in grain and pod yield in broad beans. This is attributed to the vital role of iron in plant physiological processes. Iron is an essential element in the synthesis of enzymes involved in cellular respiration and photosynthesis. It is also important in chlorophyll formation and electron transport during the photosynthesis chain, thus promoting energy production necessary for plant growth and the accumulation of organic matter in producing organs such as pods and seeds [20].

The effect of molybdenum is due to its vital role in fixing atmospheric nitrogen within the root nodules of legumes. Molybdenum is an active component of the nitrogenase enzyme, which catalyzes the conversion of atmospheric nitrogen into ammonia usable by plants, thus increasing protein and biomass accumulation in grains and pods [21]. Therefore, we observe that the highest average yield of pods and grains was at a molybdenum level of 4 kg ha^{-1}, while a higher level (8 kg ha^{-1}) resulted in a slight decrease, possibly due to nutrient saturation or the effect of high fertilization on the balance of other plant elements [22].

The interaction between iron and molybdenum showed a significant effect on grain and pod yields, with the combination of high iron levels (12 kg ha^{-1}) and a moderate molybdenum level (4 kg ha^{-1}) yielding the highest productivity. This can be explained by the fact that iron enhances the efficiency of photosynthesis and energy production, while molybdenum supports nitrogen fixation and its conversion into essential nitrogen compounds, leading to enhanced plant growth and the formation of more grains and pods. This positive interaction between nutrients highlights the importance of a balanced fertilization program that considers the integration of primary and secondary nutrients to improve legume productivity.

Protein Concentration in Grains*(%)*

The results in Table (8) indicate that adding iron to the soil significantly increased the protein content in broad bean grains, with the average rising from 17.6% when iron was not added to 23.1% at a level of 12 kg ha^{-1}, with a gradual increase at levels of 3 and 6 kg ha^{-1}. This is attributed to the fact that iron is an essential element in the formation of enzymes involved in photosynthesis and electron transport. It also contributes to protein and chlorophyll synthesis, thus increasing the efficiency of nitrogen utilization and its conversion into protein in grains [23].Regarding the effect of molybdenum, the results showed an increase in protein content with increasing molybdenum levels up to 4 kg ha^{-1} (21.4%), followed by a slight decrease at 8 kg ha^{-1} (20.9%). This is attributed to the vital role of molybdenum in the nitrogenase enzyme, which catalyzes atmospheric nitrogen fixation and its conversion into nitrogenous forms usable by the plant, thus promoting protein accumulation in grains [24]. Very high concentrations may also affect the plant's nutrient balance, which explains the slight decrease at the highest level.

The interaction between iron and molybdenum also showed a significant effect on protein content. The treatment combining an iron level of 12 kg ha^{-1} with a molybdenum level of 4 kg ha^{-1}

resulted in the highest protein value (24.5%), while the treatment without the addition of iron and molybdenum recorded the lowest value (16.5%). This indicates that the complementary application of nutrients enhances photosynthesis and enzymatic activity in the plant, thereby improving nitrogen conversion to protein in cereals.

Table 8. Effect of iron and molybdenum soil application and their interaction on seed protein content of faba bean (*Vicia faba* L.) (%).

Iron level (kg ha^{-1})	**Molybdenum level (kg ha^{-1})** 0	2	4	8	**Mean of Iron**
0	16.5	17.8	18.2	18.0	17.6
3	18.5	19.6	20.2	19.8	19.5
6	20.1	21.8	22.6	22.0	21.6
12	21.0	23.0	24.5	23.8	23.1
Mean of molybdenum	19.0	20.5	21.4	20.9	—
L.S.D $_{0.05}$	Iron 1.12	Molybdenum 0.98		Iron × Molybdenum 1.85	

Conclusion

- Iron fertilization improved all growth characteristics, yield, and protein concentration in broad beans.
- Moderate levels of molybdenum (4 kg ha^{-1}) significantly improved growth characteristics, yield, and protein concentration.
- The interaction between Fe (12 kg ha^{-1}) and Mo (4 kg ha^{-1}) resulted in the highest growth rate.

Recommendations:

- Use 12 kg ha^{-1} of Fe with 4 kg ha^{-1} of Mo to achieve maximum broad bean yield in gypsum soil.
- Maintain a balance of micronutrients to avoid nutrient saturation or the negative effects of over-fertilization.
- This study can be replicated with other legume species.

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