

Effect of soil covering, foliar spraying with nano-iron, and addition of biofertilizer on soybean yield

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ABSTRACT

During the autumn of 28.05.2025, a field experiment occurred in the Al-Azawiya region of Al-Musayyib district, which is north of Babylon Governorate, using clay loam soil. at the coordinates 32°47'53.9"N, 44°24'32.1"E to study the effect of three factors: The first factor involved soil mulching: no mulch, white polyethylene, and black polyethylene. The second factor was spraying nano-iron fertilizer at concentrations of 0 g L⁻¹, 1.5 g L⁻¹, and 3 g L⁻¹. The third factor involved incorporating the biofertilizer EM1 at concentrations of 0 ml L⁻¹, 2 ml L⁻¹, and 4 ml L⁻¹. The availability of certain soil elements and the growth and yield of Shaymaa soybeans were impacted by these factors. A randomized complete block design (RCBD) was employed for the experiment. The findings were: Using black mulch led to notable variations in yield traits such as pod count, seed weight per pod, 500-seed weight (in grams), and plant yield (in grams). yielding 112.03 pods per plant⁻¹, 2.95 seeds per pod, 64.15 g, and 42.53 g. Results showed that yield characteristics were significantly impacted by the application of the EM1. The results also showed two-way and three-way interactions among the study factors. Black mulch combined with foliar nano-iron fertilizer (3g/L) and EM1 (4ml/L) application significantly improved most plant yield characteristics. The results showed that using the EM1 biofertilizer resulted in significant differences in yield characteristics. Furthermore, the study's factors exhibited two-way and three-way interactions, as indicated by the results. Black mulch + foliar spraying with 3g/L nano-iron fertilizer + 4ml/L biofertilizer application. produced substantial differences in a majority of the analyzed plant yield features. This study's results lead us to conclude that black covering provides superior soybean yield traits. Superior outcomes in pod count, seeds per pod⁻¹, 500-seed weight, and plant yield were observed with the addition of 4 ml L⁻¹ of MS1 alone or alongside 3 g L⁻¹ of nano-iron fertilizer.

Keywords: Mulching; nano-iron; biofertilizer; soybean; seed yield

1. Introduction

The growing global population and diminishing resources are making the sustainability and efficiency of agricultural production a major worldwide concern. According to United Nations data, the global population is projected to more 9 billion by 2050, which will considerably boost the worldwide need for food and Bioenergy (Valavanidis, 2023; Almekh,2025). Mulching is a beneficial and common practice across numerous fields and horticultural studies. Besides acting as a protective layer that shields the soil from various environmental factors. It also results in earlier harvests, better weed management, less water and nutrient runoff, and cleaner fruit. Additionally, it cuts down on the work needed to remove weeds that can harm roots. It also supplies the plant with (CO₂) as this gas builds up beneath the mulch and escapes through the plant's growth holes. (Matković et al., 2015). Mulching is a protective layer and an improved agricultural practice that uses organic or inorganic materials to retain soil moisture, reduce weed growth, maintain soil temperature by covering the surface, reduce evaporation, and conserve soil moisture (Saimon, 2024). Field mulching in many forms greatly enhances the soil holds water and its fertility. This promotes crop growth, allows for more efficient water and nutrient absorption, and improves overall growth and development (Tang, 2024). Foliar spraying is a fertilization method in which a solution containing nutrients is sprayed directly onto the plant's leaves. The leaves absorb these nutrients through the stomata or epidermis, making foliar fertilization an effective and rapid way to correct nutritional deficiencies, especially of micronutrients (Marschner, 2011; Alkarawi and Zotz ,2014).

Mulching is a protective layer and a foliar fertilization is a method of feeding plants by applying liquid fertilizer directly to their leaves. Plants can absorb essential nutrients through their leaves via stomata (Patil, 2018).

Iron is a component of many vital enzyme cofactors that perform electron and oxygen transport functions, facilitate chemical transformations, and regulate protein stability; therefore, it is essential for a wide range of biological functions (El-Desouky, 2021). Biofertilizers (EM1), short for effective microorganisms, are mixed cultures of naturally occurring beneficial organisms that can be used as inoculants to increase microbial diversity in soil ecosystems. These organisms mainly consist of photosynthetic bacteria, lactic acid bacteria, yeasts, actinomycetes, and fermenting fungi. Active microorganisms improve soil structure, increase fertility, dramatically enhance biodiversity, suppress soil-borne pathogens, fix nitrogen in the soil, and promote nutrient uptake (Joshi, 2019). Soybeans have played a pivotal role globally in food security and sustainable agriculture. They are an essential protein source for humans and animals and can fix atmospheric pollutants. Soybeans contribute to nitrogen (N₂) uptake through symbiosis with root nodules. The importance of soybeans extends beyond agriculture to the environment, as they improve soil fertility and promote sustainable farming systems (Zhang, 2023). In calcareous soils lacking iron, nano iron and EM1 biofertilizer work together to greatly improve soybean development, physiology, and yield. Nano iron fertilizer enhances plant activity and improves photosynthetic efficiency. EM1 enhances soil quality and nutrient access, resulting in greater plant mass and grain output. The interaction between nano iron and EM1 also positively impacts nutrient availability and absorption. Iron nanoparticles applied as a foliar spray demonstrate greater reactivity and leaf penetration, which boosts iron uptake. EM1's enhancement of microbial activity facilitates nutrient release, especially in high-pH soils. (Alkarawi,2025). This research aims to determine the most effective mulching method, nano-iron fertilizer concentration, and EM1 concentration, and to assess their influence on soybean development and productivity.

2. Materials and methods

2.1. Sampling site

Random soil samples were gathered from the field, from a depth of 0-30 cm, and then thoroughly combined from agricultural areas within Al-Musayyib District, Babil Governorate. Representative samples were transported to the laboratory for preparation, where they were ground, air-dried, and passed through a 4-mm sieve for the biological experiment. Samples intended for laboratory analyses were passed through a 2-mm sieve, stored in plastic containers, and sent to the laboratory for the required analyses and laboratory experiments.

Table 1. Selected chemical and physical properties of the study soils.

Property		value	Unit
EC1:1		3.2	ds m ⁻¹
pH		7.8	—
CaCO ₃		30.48	%
SOM		1.62	
Available N		28.55	mg kg ⁻¹ soil
Available P		8.32	
Available K		133	
Available Fe		2.6	
Soluble cations and anions	Ca ²⁺	19.4	mmol L ⁻¹
	Mg ²⁺	10.2	
	Na ⁺	21.5	
	K ⁺	0.68	
	SO ₄ ²⁻	9.95	
	Cl ⁻	35.5	
	HCO ₃ ⁻	3.65	
	CO ₃ ²⁻	Nil	
CEC		18.73	cmol _c kg ⁻¹ soil
Soil separates	Sand	295.2	g kg ⁻¹ soil
	Silt	379.8	
	Clay	325	
Texture		Clay loam	

2.2. Determination of selected chemical and physical properties of the study soils

The following methods were used to determine selected chemical and physical properties of the study soils, as shown in Table 1.

2.3. Location experiment

From May 25 to November 4, 2025, a farm in Al-Musayyib District's Al-Azawiya area was the site of a field experiment conducted in autumn. Located in northern Babil Governorate, at longitude 32°47'53.9"N and latitude 44°24'32.1"E. Planting was done using "Shayma" soybean seeds.

2.4. Experimental Factors

First Factor: The soil covering, or mulching, involved two materials: white and black polyethylene, categorized as follows: M0 (no mulching), M1 (white polyethylene mulch), and M2 (black polyethylene mulch).

Second Factor: Chelated iron nanoparticles (Fe_2O_3 nanoparticles) were sprayed at 80% concentration and 90% purity, with particle diameters ranging from 40 to 50 nm, applied at 0, 1.5, and 3 g/L.

Third Factor: EM1 as a biofertilizer. The biofertilizer was applied in three concentrations: 0, 2, and 4 mmol/L, labeled E0, E1, and E2.

2.5. Studied traits

1. Average number of pods per plant: The total number of pods was calculated for five plants per experimental unit.
2. Average number of seeds per pod: This was calculated as the ratio of the number of seeds per plant to the number of pods per plant.
3. Average weight of 500 seeds (g): The weight of 500 seeds was calculated as the average for five plants from each treatment and for all replicates using a scale.
4. Average seed yield per plant (g): This was calculated as the number of seeds per pod * the number of pods * the weight of 100 seeds / 100

2.6. Statistical analysis

Data were statistically analyzed using SPSS through analysis of variance (ANOVA) according to the randomized complete block design (RCBD) at the 5% level.

3. Results and discussion

3-1-1 Number of Pods per Plant (Pod per Plant⁻¹)

The results in Table 2 indicate significant differences between the study factors and their interactions in influencing the number of pods per plant. The black mulching treatment (M2) was superior, giving the highest average number of pods per plant, reaching (112.03) pods per plant⁻¹. It outperformed the control treatment (M0), which gave the lowest average number of pods per plant, reaching (87.92) pods per plant. With an average of (99.04) pods per plant, the white mulching treatment (M1) outperformed the control (M0). As for the foliar spraying treatment with nano iron fertilizer, treatment (F2) was significantly superior, giving the highest average (103.61) pods per plant⁻¹. Treatment (F0) showed the lowest average number of pods per plant⁻¹ (96.07), compared to treatment (E2) with the addition of biofertilizer. The results indicated significant differences, with treatment (E2) yielding the highest average number of pods per plant⁻¹ (103.97), significantly surpassing treatment (E0), which yielded

the lowest average (95.35). The results also showed significant differences in the dual interaction between mulching and foliar spraying, with treatment (M2 + F2) yielding the highest average number of pods per plant⁻¹ (115.49), significantly surpassing treatment (M0 + F0), which yielded the lowest average (85.04). Finally, the results showed significant differences in the dual interaction between mulching and biofertilizer, with treatment (M2 + E2) yielding the highest average number of pods per plant (116.24) pods per plant⁻¹ compared to the dual interaction treatment (M0+E0), which gave the lowest average of (84.78) pods per plant⁻¹.

Regarding the dual treatments combining nano-iron and bio-fertilizer, the results indicated a significant impact, specifically with the (E2 + F2) treatment. Achieved the highest average of (107.84) pods per plant⁻¹, compared to the dual interaction treatment (F0 + E0), which gave the lowest average of (92.07) pods per plant⁻¹. As for the triple interaction treatments between covering, nano-iron, and bio-fertilizer, the results indicate significant differences, as the treatment (M2 + F2 + E2) was superior and gave the highest average for the number of pods per plant, which reached (118.53) pods per plant⁻¹, compared to the triple interaction treatment (M0+ F0 + E0), The average number of pods per plant⁻¹ was the lowest, at (83.07).

Table 2. Effect of soil covering, foliar spraying with nano-iron, and the addition of biofertilizer on the number of pods per plant (plant pod⁻¹)

Mulching	Nano Iron	Biofertilizer			Mean
		E0	E1	E2	
M0	F0	83.07	84.60	87.47	85.04
	F1	84.07	87.00	91.33	87.47
	F2	87.20	90.93	95.60	91.24
M1	F0	89.53	94.60	98.60	94.24
	F1	93.27	98.47	104.60	98.78
	F2	97.53	105.40	109.40	104.11
M2	F0	103.60	108.47	114.67	108.91
	F1	108.47	111.07	115.53	111.69
	F2	111.40	116.53	118.53	115.49
LSD0.05		1.553			0.897
Mulching * Biofertilizer					
M0		84.78	87.51	91.47	87.92
M1		93.44	99.49	104.20	99.04
M2		107.82	112.02	116.24	112.03
LSD0.05		0.897			0.518
Nano Iron * Biofertilizer					
F0		92.07	95.89	100.24	96.07
F1		95.27	98.84	103.82	99.31
F2		98.71	104.29	107.84	103.61
LSD0.05		0.897			0.518
Mean of Biofertilizer		95.35	99.67	103.97	
LSD0.05		0.518			

3-1-2 Number of seeds per pod (seed per pod⁻¹)

According to Table 3, the study factors and their interactions have a notable impact on the quantity of seeds within each pod.

The black covering treatment (M2) was superior, giving the highest average number of seeds per pod (2.95) seeds per pod⁻¹, compared to the control treatment (M0), which gave the lowest average (2.74) seeds per pod⁻¹.

Compared to the control (M0), the white covering treatment (M1) showed superiority, yielding an average of (2.86) seeds per pod⁻¹. As for the foliar spray treatment with nano-iron fertilizer, treatment (F2) was significantly superior, giving the highest average number of seeds per pod (2.89) seeds per pod⁻¹ compared to treatment (F0), which gave the lowest average (2.81) seeds per pod⁻¹.

Adding a biofertilizer resulted in significant differences, with treatment (E2) yielding the highest average number of seeds per pod (2.87) seeds per pod⁻¹, significantly surpassing treatment (E0), which yielded the lowest average (2.83) seeds per pod⁻¹. Similarly, the results of the dual interaction between mulching and foliar spraying showed significant differences, with treatment (M2 + F2) yielding the highest average number of seeds per pod (2.98) seeds per pod⁻¹, significantly surpassing the dual interaction treatment (M0 + F0), which yielded the lowest average (2.69) seeds per pod⁻¹. Finally, the results of the dual interaction between mulching and biofertilizer also showed significant differences, with treatment (M2 + E2) yielding the highest average number of seeds per pod (2.97) seeds per pod⁻¹, compared to the dual interaction treatment (M0 + E0), which yielded the lowest average. (2.72) pod⁻¹ seeds. As for the binary interaction coefficients between nano-iron and bio-fertilizer, the results showed a significant effect, as the treatment (E2 + F2) gave the highest average for the number of seeds in the pods, which reached (2.90) pod⁻¹ seeds, compared to the binary interaction treatment (F0 + E0), which gave the lowest average, which reached (2.80) pod⁻¹ seeds. As for the ternary interaction coefficients between the coating, nano-iron, and bio-fertilizer, the results indicate significant differences, as the treatment (M2 + F2 + E2) was superior and gave the highest average for the number of seeds in the pods, which reached (2.99) pod⁻¹ seeds, compared to the ternary interaction treatment (M0 + F0 + E0), which gave the lowest average for the number of seeds in the pods, which reached (2.67) pod⁻¹ seeds.

Table 3. Effect of soil covering, spraying with foliar nano-iron and adding biofertilizer on the number of seeds in pods (seed pod⁻¹)

Mulching	Nano Iron	Biofertilizer			Mean
		E0	E1	E2	
M0	F0	2.67	2.69	2.71	2.69
	F1	2.71	2.74	2.76	2.74
	F2	2.76	2.78	2.80	2.78
M1	F0	2.80	2.82	2.84	2.82
	F1	2.84	2.86	2.88	2.86
	F2	2.88	2.90	2.91	2.89
M2	F0	2.91	2.93	2.94	2.93
	F1	2.94	2.95	2.97	2.96
	F2	2.97	2.98	2.99	2.98
LSD0.05		0.003			0.002
Mulching * Biofertilizer					
M0		2.72	2.74	2.76	2.74
M1		2.84	2.86	2.87	2.86
M2		2.94	2.95	2.97	2.95
LSD0.05		0.002			0.001

Nano Iron * Biofertilizer				
F0	2.80	2.81	2.83	2.81
F1	2.83	2.85	2.87	2.85
F2	2.87	2.89	2.90	2.89
LSD0.05	0.002			0.001
Mean of Biofertilizer	2.83	2.85	2.87	
LSD0.05	0.001			

3-1-3 500-seed weight (grams)

The results in Table 4 indicate significant differences in the effects of the study factors and their interactions on the 500-seed weight trait. The black covering treatment (M2) was superior, giving the highest average 500-seed weight trait at (64.15) g, surpassing the control treatment (M0), which gave the lowest average 500-seed weight trait at (57.19) g. The white covering treatment (M1) was superior to the control treatment (M0), giving an average 500-seed weight trait of (60.51) g. As for the foliar spraying treatment with nano-iron fertilizer, treatment (F2) was significantly superior, yielding the highest average 500-seed weight (61.73) g, compared to treatment (F0), which yielded the lowest average (59.42) g. Regarding the biofertilizer addition treatment, the results indicated the presence of Significant differences, with treatment (E2) giving the highest average for the 500-seed weight trait, which reached (61.52) g, and significantly surpassing treatment (E0), which gave the lowest average, which reached (59.85) g. As for the dual interaction treatments between covering and foliar spraying, the results indicated significant differences, with treatment (M2 + F2) giving the highest average for the 500-seed weight trait, which reached (65.69) g, and significantly surpassing the dual interaction treatment (M0 + F0), which gave the lowest average for the 500-seed weight trait, which reached (56.71) g. As for the dual interaction treatments between covering and biofertilizer, the results indicated significant differences, with treatment (M2 + E2) giving the highest average for the 500-seed weight trait, which reached (65.22) g, compared to the dual interaction treatment (M0+E0), which gave the lowest average, which reached (56.54) g. The results of the two-way interaction between nano-iron and biofertilizer showed a significant effect, with the (E2 + F2) treatment yielding the highest average 500-seed weight (62.83) g compared to the two-way interaction (F0 + E0) treatment, which yielded the lowest average (58.84) g. However, the results of the three-way interaction between soil mulching, nano-iron, and biofertilizer also indicated significant differences, with the (M2 + F2 + E2) treatment yielding the highest average 500-seed weight (67.20) g compared to the three-way interaction (M0 + F0 + E0) treatment, which yielded the lowest average 500-seed weight (56.20 g).

Table 4. Effect of Soil Mulching, Foliar Spraying with Nanoparticle Iron, and Biofertilizer Addition on 500-Seed Weight (g)

Mulching	Nano Iron	Biofertilizer			Mean
		E0	E1	E2	
M0	F0	56.20	56.61	56.82	56.54
	F1	56.71	56.96	57.65	57.11
	F2	57.20	57.68	58.87	57.92
M1	F0	58.25	59.62	60.62	59.50
	F1	59.25	60.53	61.65	60.48
	F2	60.69	61.60	62.42	61.57
M2	F0	62.06	61.77	62.86	62.23

Mulching	Nano Iron	Biofertilizer			Mean
	F1	63.62	64.34	65.61	64.52
	F2	64.64	65.24	67.20	65.69
LSD0.05		0.403			0.233
Mulching * Biofertilizer					
M0		56.71	57.08	57.78	57.19
M1		59.40	60.58	61.56	60.51
M2		63.44	63.78	65.22	64.15
LSD0.05		0.233			0.134
Nano Iron * Biofertilizer					
F0		58.84	59.33	60.10	59.42
F1		59.86	60.61	61.63	60.70
F2		60.84	61.51	62.83	61.73
LSD0.05		0.233			0.134
Mean of Biofertilizer		59.85	60.48	61.52	
LSD0.05		0.134			

3-1-4 Plant Yield (grams) The results in Table (5) indicate significant differences between the study factors and their interactions in influencing plant yield.

The black mulch treatment (M2) was superior, giving the highest average plant yield (42.52) g, surpassing the control treatment (M0), which gave the lowest average plant yield (27.56) g. The white mulch treatment (M1) was superior to the control treatment (M0), giving an average plant yield of (34.32) g. The foliar spraying treatment with nano-iron fertilizer showed that treatment (F2) was significantly superior, giving the highest average plant yield (37.27) g compared to treatment (F0), which gave the lowest average (32.41) g. Finally, the results of the biofertilizer application treatment indicated significant differences, with treatment (E2) giving the highest average plant yield (37.03) g. Significantly, the treatment (E0) gave the lowest average yield of (32.66) g. As for the dual interaction treatments between mulching and foliar spraying, the results indicated significant differences, as the treatment (M2 + F2) was superior and gave the highest average yield of (45.28) g, and it was significantly superior to the dual interaction treatment (M0 + F0), which gave the lowest average yield of (25.91) g. As for the dual interaction treatments between mulching and biofertilizer, the results indicated significant differences, as the treatment (M2 + E2) gave the highest average yield of (44.99) g, compared to the dual interaction treatment (M0+E0), which gave the lowest average yield of (26.13) g. The results of the binary interaction between nano-iron and biofertilizer showed a significant effect, with the (E2 + F2) treatment yielding the highest average plant yield (39.64) g compared to the binary interaction (F0 + E0) treatment, which yielded the lowest average (30.54) g. The results of the ternary interaction between mulching, nano-iron, and biofertilizer also showed significant differences, with the (M2 + F2 + E2) treatment yielding the highest average plant yield (47.66) g compared to the ternary interaction (M0 + F0 + E0) treatment, which yielded the lowest average plant yield (24.98) g.

Table 5. Effect of Soil Mulching, Foliar Spraying with Nanoparticle Iron, and Biofertilizer Addition on plant yield Weight (g)

Mulching ^l	Nano Iron	Biofertilizer			Mean
		E0	E1	E2	
M0	F0	24.98	25.79	26.98	25.91
	F1	25.88	27.11	29.06	27.35

Mulching ^l	Nano Iron	Biofertilizer			Mean
	F2	27.53	29.16	31.53	29.41
M1	F0	29.20	31.81	33.92	31.64
	F1	31.38	34.07	37.09	34.18
	F2	34.06	37.60	39.73	37.13
M2	F0	37.46	39.21	42.37	39.68
	F1	40.64	42.23	44.95	42.61
	F2	42.82	45.36	47.66	45.28
LSD 0.05		0.643			0.371
Mulching * Biofertilizer					
M0		26.13	27.35	29.19	27.56
M1		31.54	34.49	36.91	34.32
M2		40.31	42.27	44.99	42.52
LSD 0.05		0.371			0.214
Nano Iron * Biofertilizer					
F0		30.54	32.27	34.42	32.41
F1		32.63	34.47	37.03	34.71
F2		34.80	37.37	39.64	37.27
LSD 0.05		0.371			0.214
Mean of Biofertilizer		32.66	34.71	37.03	
LSD 0.05		0.214			

3-2 Discussion

Tables 2-5 demonstrate that soybean plants mulched with black polyethylene had better yield indicators (number of pods, pod length, yield per plant, 500-grain weight) than those in the control group. Mulching with black polyethylene enhances soil quality by improving water infiltration and retention, decreasing erosion, and fostering a richer biological environment that supports beneficial organisms like earthworms and certain insects (Zhang, 2017). This also encourages roots to grow into deeper soil, which enhances nutrient uptake and plant growth (Ranjan, 2017). Boutagayout et al. (2025) also observed similar results when examining broad beans grown in soil mulched with black polyethylene. The study revealed that their group had more pods and a better yield than the control group, with a 50.84% increase in seed yield.

These findings align with Kim et al. (2008) research on mung bean plants cultivated in soil covered with black polyethylene. According to their study, seed germination reached 98%, plant height was 61 cm, and the number of pods per plant averaged 15.1. When mung beans were grown with mulching black polyethylene film covering. These results were 13%, 9 cm, and 1.8 cm higher, respectively, when the covering was not used. Cultivating mung beans with black polyethylene film also showed a 38% increase in seed yield compared to cultivation without covering. Regarding the effect of spraying with nano-iron fertilizer on soybean yield indicators, plants sprayed with nano-iron fertilizer exhibited superior yield characteristics. This is attributed to the potential of nanotechnology to offer solutions for increasing the value of agricultural products and mitigating environmental problems. By using nanoparticles and Nano powders, we can produce fertilizers with controlled or delayed release. Nanoparticles are characterized by high reactivity due to their increased specific surface area, the density of their reaction zones, or the increased reactivity of these zones on the particle surfaces. These properties facilitate the absorption of fertilizers produced at the nanoscale (Zhu et al., 2008; Kadhim et al. (2026)).

This aligns with the findings of (Alwan and Alkarawi, 2024; Alkarawi and Obaid 2022; Alkarawi and Hamid 2024) in their study on broad beans, where plants treated with nano-iron spraying showed superior yield characteristics compared to the control treatment. The effect of the EM1 biofertilizer on yield indicators in soybean plants: Plants treated with the biofertilizer showed superior yield indicators. This is attributed to the crucial role biofertilizers play in promoting bacterial populations in soil ecosystems, thus contributing to improved soil fertility, plant growth, and sustainability. They contain live microorganisms that enhance plant growth by increasing the availability of essential nutrients. Nitrogen-fixing bacteria, such as *Rhizobium*, *Azospirillum*, and *Frankia*, are commonly used in biofertilizers for legumes. Their interaction with plant roots promotes their populations and the populations of other beneficial microorganisms. A variety of biofertilizers also produce plant hormones, including auxins, gibberellins, and cytokinins, which promote root and plant growth. Furthermore, the production of organic acids and enzymes by microbial communities improves nutrient bioavailability, which in turn promotes microbial growth (Glick 2012, Dzvene 2024, Verma 2024, and Nabati 2025). This aligns with the findings of Alderete (Prieto et al. 2017; Hamid and Kadhim, 2022), whose study on the effect of biofertilizers on soybean growth and yield showed increased soybean growth and yield compared to the control treatment.

4-Conclusion

From the results, we conclude that the black covering showed superiority in all assessed plant yield traits, including pod count, seeds per pod, 500-seed weight, and individual plant yield. All investigated plant yield measures, such as pod number, pod seed, 500-seed weight, and yield per plant, demonstrated superiority with the third nano-iron fertilizer concentration of 3 g L⁻¹. The study's findings indicate that applying 4 ml L⁻¹ of biofertilizer, the third level, resulted in better outcomes for the plant's yield components, including pod count, seeds per pod, 500-seed weight, and overall yield per plant.

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