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GROWTH AND PRODUCTIVITY SUSTAINABILITY OF SUNFLOWER BY INFLUENCE OF NITROGEN FERTILIZATION AND BACTERIAL BIOFERTILIZATION

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ABSTRACT

A field experiment was conducted during the spring season of 2024 at the College of Agricultural Engineering Sciences - University of Baghdad, to study cultivation sustainability of sunflower influenced by nitrogen fertilization and bacterial biofertilization. A split-plot arrangement within randomized complete block design with three replications was used. The main plots received 0, 25, 50 and 75% of recommended nitrogen, while the sub-plots were sown with seeds inoculated with *Azotobacter chroococum*, *Azospirillum brasilense*, their mixture and without inoculation, in addition to application of recommended nitrogen fertilization (200 Kg N ha^{-1}) for later comparison with fertilizer combinations. The Findings showed that application 75% of recommended nitrogen fertilizer was significantly superiority in the leaf area (50.21 dm^{2}), fertility rate (71.95%) and seed productivity (5.577 Mg ha^{-1}). Also, there was a significant increase in the vegetative growth when seeds were inoculated with bio-fertilizer mixture, which led to an increase seeds number (1347.6 seeds head^{-1}) and seed productivity (5.406 Mg ha^{-1}). Significant interaction influence noted on most measured parameters. Regarding the comparison of fertilizer combinations with application of 200 kg N h^{-1}, it was observed that the inoculating seeds with bio-fertilizer mixture or alone reduced about 25% of nitrogen fertilizer recommendation.

Key words: Plant nutrition, seeds inoculation, fertility rate, seeds yield.

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INTRODUCTION

Sunflower (Helianthus annuus L.) is one major oil crop in the world (Behnassi et al., 2011). Despite its importance, productivity is still below the required level. This calls for broad social-technological improvements, including crop management and, particularly, nutrition (Elsahookie, 1994). Nitrogen constitutes one major nutritional factor affecting plant productivity (Alaamer et al., 2022). Gaseous nitrogen in the soil constitutes approximately 79% of the atmospheric volume. However, plants can only benefit from this gaseous form after symbiotic or non-symbiotic fixation by microorganisms (Kumer et al., 2022). External mineral application to soil is exposed to volatilization, leaching, or denitrification, while contaminating water sources. Considering this, nitrogenous bacterial biofertilizers become an alternative to reduce mineral fertilizers (Bronson, 2004). Biofertilizers are defined as biological inoculants isolated and prepared from specific microorganisms to improve soil properties and increase its fertility by decomposing the complex substances present in the soil (Haneef et al., 2014). This stimulates plant growth, increases productivity and improves quality.

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They can be defined as fertilizers containing microorganisms. When inoculated with seeds or added to the soil, they colonize the rhizosphere (Inamuddin et al., 2021), or internal parts of the plant, stimulating growth by supplying the plant with the nutrients it needs in a form ready for absorption after decomposing the raw materials and plant residues present in the soil (Sharma, 2002)

Generally, biofertilizers complement mineral fertilizers, as the latter strongly affect early stages of plant growth while the former supply necessary nutrients in addition to the secretion of enzymes, hormones and other compounds. The use of biofertilizers can reduce fertilization costs. *Azotobacter chroococum* is a species belonging to the Azotobactereacea family. It is a free-living, heterotrophic and obligate aerobic (Moorthi et al., 2016). It is one of the most widely used biofertilizers due to its ability to fix atmospheric nitrogen non-symbiotically and convert it to ammonium. It represents the natural nitrogen source in ecosystems and agricultural systems that lack symbiotic nitrogen fixation (Sumbul et al., 2020). In addition, it secretes some growth hormones and vitamins, leading to improved crop growth and productivity. This bacterium fixes about 30 kg N ha^{-1} annually (Aasfar et al., 2021). *Azospirillum brasilense* is a species belonging to the Rhodospirillaceae family. It is the most efficient non-symbiotic nitrogen-fixing bacterium, even in the presence of low oxygen levels. It plays an important role in metabolism of carbon and nitrogen, making them more adaptable to the rhizosphere environment (Zeffa et al., 2019). Due to its role in increasing the availability of nutrients in the soil solution, it plays an important role in improving plant growth and development (Alamri and Mostafa, 2009). It can secrete some growth hormones such as auxins, cytokinins, and gibberellins, which play a major role in encouraging plant growth, and vitamins such as riboflavin, niacin, and thiamin (da Silva et al., 2021). It also enhances the formation of root hairs to provide a good root surface area that helps absorb soil nutrients. This bacterium fixes about 20-40 kg N ha^{-1} annually (Mehdipour-Moghadam et al., 2012). This research aimed to study sustainability of sunflower growth and productivity under the influence of nitrogen fertilizer and bacterial biofertilizer, compensating for nitrogen recommendation.

MATERIALS AND METHODS

Field Experiment

A field experiment was conducted from 1st March to 1st July, 2024, at the College of Agricultural Engineering Sciences - University of Baghdad, Iraq, 33° 27´ N and 44° 38´ E. Soil samples was taken at 0-30 cm and analyzed in the Advisory Office - College of Agricultural Engineering Sciences - University of Baghdad, Iraq, are shown in Table (1).

A split-plot arrangement within RCBD was used with three replications. The main plots include application of 0, 25, 50 and 75% of recommended N-fertilizer (200 Kg N ha^{-1}) were symbols $N_{0\%}$, $N_{25\%}$, $N_{50\%}$, and $N_{75\%}$ respectively. The sub-plots include the inoculation of seeds with *Azotobacter chroococum*, *Azospirillum brasilense*, their mixture and without inoculation were symbols B_0, B_{Ac}, B_{Ab}, and B_{Ac+Ab} respectively, which prepared by the Ministry of Higher Education and Scientific Research, Scientific Research Commission, Agricultural Research Center. A final treatment included the recommended nitrogen alone (200 Kg N ha^{-1}: $N_{100\%}$).

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Table 1. Soil physical, chemical and biological properties

Trait	Value	Unit
Sand	432	
Loam	317	g Kg^{-1} Soil
Clay	251	
$Ec_{1:1}$	2.20	dsmole m^{-1}
CEC	21.14	dsmole Kg^{-1} Soil
pH	7.15	-----
Organic matter	5.7	g Kg^{-1} Soil
CO_3^{2-}	non	-----
$CaCO_3$	23.72	
Ca^{+2}	18.49	
K^{+}	1.13	
Mg^{+2}	11.54	Meq g^{-1} Soil
Na^{+}	8.66	
Cl^{-}	22.90	
HCO_3^{-}	5.59	
SO_4^{-2}	8.84	
Available N	16.00	
Available P	4.31	mg Kg^{-1} Soil
Available K	112.19	
A. chroococum	log 4.2 g^{-1} Soil	
A. brasilense	log 3 g^{-1} Soil	

Soil management operations were implemented. Then the experimental area was split into 51 experimental units of 4 m^2 (2 m × 2 m) each. Distance between plots was 1 m, between lines was 50 cm, and between planting holes, 25 cm. Each plot had 45 plants. Nitrogen was applied as at two equal doses of urea (46% N) according to the treatments, at four true leaves stage, and flower buds. Phosphate was applied at 48 Kg P ha^{-1} as triple super phosphate (21% P) at one dose before planting, and potassium was applied as potassium sulfate (41% K), 83 Kg K ha^{-1} in one dose before planting (Ali et l., 2014). Flamy cv. sunflower seeds were sown on 1st March 1, 2024, at a depth of 5 cm with three seeds per hole. After emergence, plants were thinned to one plant per hole. Plants were harvested on July 1, 2024.

Preparation of *A. chroococum* and *A. brasilense* for seeds inoculation

Three sterilized flasks were prepared with 200 ml of liquid nutrient medium (N. B). Then, the three flasks were placed in an incubator at 28 °C for 72 h. The seeds were sterilized for 2 min with sodium hypochlorite (1%), washed with distilled water three times and dried. Afterwards, arabic gum (20%) was applied for 30 min according to inoculation treatments. Then, the seeds were dried for 20 min. After that, the sunflower seeds were inoculated and sown in the experimental units.

Studied traits

1. 100% flowering stage: Five plants were randomly taken from the middle lines of each experimental unit to measure the following**:**

A. Plant height (cm): It was measured from the soil surface to the base of the head.

B. Leaf area (dm^2): It was calculated using the following equation (Hardan and Elsahookie, 2015):

$$\text{Leaf area } (dm^2) = \Sigma wi2 \times 4.31$$

As: 4.31 = constant

$\Sigma wi2$ = sum of squares of leaf width at whorl six

2. Full maturity stage: Five heads were randomly taken from the middle lines of each experimental unit to measure the following:

A. Fertility rate (%): Fifty g of seeds were randomly taken from each experimental unit. Fertility rate was calculated using the following equation:

$$\text{Fertility rate } (\%) = (\text{number of filled seeds/number of total seeds}) \times 100$$

B. Seed number per head, considering five heads.

C. 1000-seeds weight (g): 1000 seeds were weighed. Then, weight was adjusted at 8% moisture.

D. Seed yield (Mg ha-1): Seeds of five heads were collected, weighed and adjusted to 8% moisture. Mean plant yield was multiplied to obtain Total seed yield .

$$\text{Seeds yield } (Mg\ ha^{-1}) = (\text{plant seeds yield} \times \text{number of plants per unit area}) / 10^6$$

The data were statistically analyzed using Genstat program in two phases. In the first phase, experimental design consisted of 4 nitrogen fertilizer doses x 4 biofertilizers x 3 replicates, according to split plot arrangement and randomized complete block design. In the second phase, the data were statistically

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analyzed as one-way ANOVA (in randomized blocks) with 17 treatments [16 fertilizer combinations (4 fertilizer doses × 4 biofertilizers) + recommended nitrogen] with 3 replicates according to a randomized complete block design for comparing the 16 fertilizer combinations with recommended nitrogen ($N_{100\%}$). In both analysis phases, the least significant difference (LSD) test was used to compare the means at a probability level of 0.05 (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Plant height (cm)

Plant height significantly differed among N treatments. The application of 75% of recommended N fertilizer ($N_{75\%}$) achieved the highest average of plant height, 214.3 cm, compared to $N_{50\%}$ and $N_{25\%}$ which achieved 204.1 and 196.3 cm respectively, and control treatment ($N_{0\%}$), 189.3 cm (Table 2). These results indicate significant differences among four-N levels in the plant height. The increases in plant height may be due to the role of N in increasing the size and division of plant cells due to its role in activating the metabolic reactions that occur in the meristematic area as a result of its entry into the formation of multiple compounds (Barker and Pilbeam. 2006, Oyinlola et al., 2010). These results agree with Chantal et al. (2018), who obtained a significant increase in sunflower height when increasing N levels. Seeds inoculation with mixed *A. chroococum* and *A. brasilense* (B_{Ac+Ab}) significantly excelled by producing the highest result, reaching 205.9 cm, compared to control (B_0) which gave the smallest height, 194.4 cm (Table 2). Inoculation of sunflower seeds with *A. chroococum* (B_{Ac}) or *A. brasilense* (B_{Ab}) resulted in 201.6 and 202.0 cm, respectively, with non-significantly different. Taller plants may result from synergistic roles among bacteria and growth-promoting hormones, which may have contributed to cell elongation (Aasfar et al., 2021, Al-Saadi and Al-Hilfy. 2024). Significant interaction noted between two factors and the application of 75% N to inoculated seeds with *A. brasilense* ($N_{75\%}B_{Ab}$) achieved 220.3 cm, without significant difference with $N_{75\%}B_{Ac}$, while control (N_0B_0) achieved 194.4 cm (Table 2). The application of recommended nitrogen fertilizer (200 Kg N ha^{-1} = $N_{100\%}$) was significantly superiority in plant height compared to 13 fertilizer combinations by recording 217.1 cm (Table 2), but non-significantly different with 3 fertilizer combinations only ($N_{150}B_{Ab}$, $N_{150}B_{Ac}$ and $N_{150}B_{Ac+Ab}$). This result indicates that the inoculating of sunflower seeds with mixture or alone of *A. chroococum* and *A. brasilense* played a role in stimulating the division and elongation of internodes cells and thus increasing the plant height by 75% of nitrogen fertilizer recommendation compared to application of full recommendation.

Table 2. Influence of N fertilizer, bacterial biofertilizer and their interaction on the plant height (cm) of sunflower

N Ferti.	Bio-fertilizer				Average
	B_0	B_{Ac}	B_{Ab}	B_{Ac+Ab}	
N_0	182.2	187.6	190.8	196.6	189.3
N_{50}	190.8	197.6	194.5	202.1	196.3
N_{100}	197.8	204.7	202.3	211.4	204.1
N_{150}	206.9	216.4	220.3	213.6	214.3
Lsd .05	5.8				3.1
Avrage	194.4	201.6	202.0	205.9	
Lsd .05	2.9				
N200	217.1				
Lsd .05	5.5				

Leaf area (dm^2)

Leaf area significantly differed among the four N levels. The $N_{75\%}$ treatment resulted in the largest leaf area, 50.21 dm^2, compared to $N_{50\%}$ and $N_{25\%}$ which gave 47.92 and 45.44 dm^2 respectively, and control with, 42.62 dm^2, (Table 3). The increases in leaf area when the application of 75% of N fertilizer recommendation could be attributed to increased leaf content of N and P and their

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positive effect in increasing leaf cell size by stimulating their ability to elongate and expand (Ali et al., 2013, Salih, 2013). This result was consistent with Kandil et al. (2017), who observed a significant increase in sunflower leaf area when fertilized with N. Leaf area significantly differed among the four inoculation treatments. Seeds inoculation with B_{Ac+Ab} achieved the largest leaf area, 48.65 dm^2, compared to B_{Ac} or B_{Ab} and control which achieved 47.48, 46.09 and 43.97 $dm^{2,}$ respectively (Table 3). The increases of N percentage in the plant leaves growing from inoculated seeds with the bio-mixture and the creation of a balance between nutrients within the leaf tissues to activate the vital processes may explain the increase of leaf area (Zeng et al., 2014). Otherwise, the poor vegetative growth of plants grown from seeds that are non-inoculated with biofertilizer could be attributed to the low physical, chemical and biological properties of the soil (Table 1). Significant interaction noted between two factors (Table 3), as $N_{75\%}B_{Ac+Ab}$ achieved the highest value, 52.58 dm^2, whilst N_0B_0 achieved 38.47 dm^2. The full recommendation of nitrogen fertilizer ($N_{100\%}$) significantly excelled in the leaf area compared to 14 fertilizer combinations by giving 51.73 dm^2, but non-significantly different with 2 fertilizer combinations only ($N_{150}B_{Ac}$ and $N_{150}B_{Ac+Ab}$) combinations (Table 3). This result shows the positive role of seeds inoculation with *A. chroococum* and *A. brasilense* mixture or *A. chroococum* only in reducing applied N as well as stimulating leaf elongation and expansion.

Table 3. Influence of N fertilizer, bacterial biofertilizer and their interaction on the leaf area (dm^2) of sunflower

N Ferti.	Bio-fertilizer				Average
	B_0	B_{Ac}	B_{Ab}	B_{Ac+Ab}	
N_0	38.47	44.64	41.41	45.96	42.62
N_{50}	42.83	45.49	46.19	47.23	45.44
N_{100}	46.23	49.35	47.27	48.82	47.92
N_{150}	48.33	50.44	49.49	52.58	50.21
Lsd .05			2.05		1.13
Avrage	43.97	47.48	46.09	48.65	
Lsd .05			1.03		
N200			51.73		
Lsd .05			2.16		

Fertility rate (%)

All four N levels significantly differed in fertility rate (Table 4). $N_{75\%}$ recorded the highest fertility rate, 71.95%, compared to $N_{50\%}$ and $N_{25\%}$ which recorded 68.38 and 64.51% respectively, and control with 60.39%. These findings agree with Chantal et al. (2018). All inoculation treatments significantly differed in fertility rate. Seeds inoculation with B_{Ac+Ab} resulted in the highest fertility rate, 69.97%, compared to B_{Ac} and B_{Ab} which gave 68.70 and 65.24% respectively, and control, with 61.31% (Table 4). The increasing fertility rate could be due to the bio-mixture supplying organic acids, enzymes, and growth hormones (1, 7), enhancing dry matter to Primordia conversion, and improving pollen vitality (Jonnagorla et al., 2021). In this regard, Singh and Umesha (2024) stated that fertility rates are affected by multiple factors, including nutrient availability. Significant interaction noted between two factors (Table 4), as $N_{75\%}B_{Ac+Ab}$ combination had 75.73%, with non-significant difference with $N_{75\%}B_{Ac}$, whereas N_0B_0 had 54.21%.Table (4) shows that the $N_{100\%}$ treatment achieved the highest fertility, reaching 71.69%, compared to 11

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combinations, but non-significantly different with $N_{50\%}B_{Ac}$, $N_{50\%}B_{Ac+Ab}$, $N_{75\%}B_{Ac}$ and $N_{75\%}B_{Ab}$. However, $N_{75\%}B_{Ac+Ab}$ achieved the highest average of this parameter, reaching 75.73%, compared to the recommended N fertilization (Table 3). This finding indicates inoculating with the bio-mixture reduced N necessity by about 1/4 N, while raising fertility.

Table 4. Influence of N fertilizer, bacterial biofertilizer and their interaction on the fertility rate (%) of sunflower

N Ferti.	Bio-fertilizer				Average
	B_0	B_{Ac}	B_{Ab}	B_{Ac+Ab}	
N_0	54.21	63.17	58.95	65.25	60.39
N_{50}	61.46	65.65	62.64	68.28	64.51
N_{100}	63.33	71.96	67.59	70.62	68.38
N_{150}	66.27	74.01	71.80	75.73	71.95
Lsd .05			2.38		1.29
Avrage	61.31	68.70	65.24	69.97	
Lsd .05			1.19		
N200			71.69		
Lsd .05			3.03		

Seeds number per head

Seed number per head significantly differed among the four N levels. The $N_{75\%}$ treatment yielded the highest average of seed number, 1398.7 seeds head^{-1}, compared to $N_{50\%}$ and $N_{25\%}$ with 1332.3 and 1258.1 seeds head^{-1}, respectively, and control ($N_{0\%}$) with 1166.3 seeds head^{-1} (Table 5). The increase in seed number for fertilized plants at a 75% of N fertilizer recommendation may be attributed to their higher fertility rate (Table 4). Chantal et al. (2018) obtained similar results.

The B_{Ac+Ab} treatment significantly excelled and recorded the highest average seed number, 1347.6 seeds head^{-1}, with non-significant difference with B_{Ac} treatment (1320.1 seeds head^{-1}), but significantly higher than B_{Ab} with 1271.4 seeds head^{-1} and control (B_0) with 1216.4 seeds head^{-1} (Table 5). This increase in seed number may be explained by the higher fertility rate (Table 4) of plants grown from inoculated seeds, as also seen by Noaema et al. (2024).

Significant interaction noted between two factors (Table 5), as $N_{75\%}B_{Ac+Ab}$ yielded the highest value (1444.6 seed head^{-1}), with non-significantly different with $N_{75\%}B_{Ac}$, while N_0B_0 yielded the lowest number (1048.3 seed head^{-1}).

The full recommended nitrogen fertilizer ($N_{100\%}$) significantly excelled in the seeds number compared to 13 fertilizer combinations by giving 1436.1 seed head^{-1}, but non-significantly different with $N_{75\%}B_{Ac}$, $N_{75\%}B_{Ab}$ and $N_{75\%}B_{Ac+Ab}$, which achieved 1425.1, 1378.7 and 1444.6 seed head^{-1}, respectively (Table 5). This result indicates seeds inoculation provides about 25% of the recommended N, while increasing sink number (seeds) per sunflower head through its role on fertility.

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Table 5. Effect of nitrogen fertilizer, bacterial bio-fertilizer and their interaction on the Seeds number per sunflower head

N Ferti.	Bio-fertilizer				Average
	B_0	B_{Ac}	B_{Ab}	B_{Ac+Ab}	
N_0	1048.2	1203.5	1133.6	1280.1	1166.3
N_{50}	1183.1	1277.1	1256.7	1315.5	1258.1
N_{100}	1287.8	1374.7	1316.6	1350.0	3.1332
N_{150}	1346.3	1425.1	1378.7	1444.6	7.1398
Lsd .05	60.5				35.2
Avrage	1216.4	1320.1	1271.4	1347.6	
Lsd .05	30.2				
N200	1436.1				
Lsd .05	57.8				

Weight of one thousand seeds (g)

Table 6 findings indicate that the application of different levels of recommended nitrogen fertilizer and bacterial biofertilizers didn't significant affect the one thousand seeds. Also, the interaction between studied factors hadn't significant influence on this parameter. The results also indicate that the application of nitrogen fertilizer recommendation ($N_{100\%}$) didn't significantly differ with all fertilizer combinations in this trait.

Table 6. Influence of N fertilizer, bacterial biofertilizer and their interaction on the one thousand seeds (g) of sunflower

N Ferti.	Bio-fertilizer				Average
	B_0	B_{Ac}	B_{Ab}	B_{Ac+Ab}	
N_0	60.20	61.08	60.71	61.37	60.84
N_{50}	63.16	62.15	62.96	61.86	62.53
N_{100}	62.05	61.34	62.52	60.82	61.68
N_{150}	60.33	59.61	60.78	58.56	59.82
Lsd .05	N.S				N.S
Avrage	61.43	61.04	61.74	60.65	
Lsd .05	N.S				
N200	59.08				
Lsd .05	N.S				

Seeds yield (Mg ha^{-1})

Seed yield significantly differed among N levels. The $N_{75\%}$ treatment produced the highest seeds yield, amounting to 5.577 Mg ha^{-1}, compared to $N_{50\%}$ and $N_{25\%}$ with 5.279 and 4.973 Mg ha^{-1}, respectively, and control ($N_{0\%}$) with 4.599 Mg ha^{-1} (Table 7). The superiority of fertilized plants with 75% of N fertilizer recommendation may be due to their superiority in the fertility rate and seed number per head (Tables 4 and 5). These findings agree with Kandil et al. (2017). Inoculation treatment B_{Ac+Ab} recorded significantly distinguished by producing the highest average, reaching 5.406 Mg ha^{-1}, with non-significantly different with B_{Ac}, which produced 5.311 Mg ha^{-1}, compared to B_{Ab} with 5.033 Mg ha^{-1} and control with 4.682 Mg ha^{-1} (Table 7). Increased fertility and seed number (Tables 4 and 5) of inoculated seeds with the bio-mixture explain the increase seed yield. This agrees with Jonnagorla et al. (2021) and Noaema et al. (2024), who noted that the inoculation of sunflower seeds with *A. chroococum* and *A. brasilense* resulted in higher seed yield. Significant interaction noted between two factors (Table 7). The $N_{75\%}B_{Ac}$ had the highest value, 5.779 Mg ha^{-1}, with non-significantly different with $N_{75\%}B_{Ac+Ab}$, whereas N_0B_0 had the lowest (4.027 Mg ha^{-1}).

The full recommended nitrogen fertilizer ($N_{100\%}$) significantly excelled in the seeds yield compared to 11 fertilizer combinations by giving 5.678 Mg ha^{-1} (Table 7), but it non-significantly different with 5 fertilizer combinations only ($N_{100}B_{Ac}$, $N_{100}B_{Ac+Ab}$, $N_{150}B_{Ac}$, $N_{150}B_{Ab}$ and $N_{150}B_{Ac+Ab}$). These results demonstrate the biological efficiency of bacterial biofertilizers, either alone or in a mixture in reducing by 25-50% the amount of needed nitrogen in sunflower, and stimulating reproductive growth and crop productivity.

Table 7. Influence of N fertilizer, bacterial biofertilizer and their interaction on the seeds yield (Mg ha^{-1}) of sunflower

N Ferti.	Bio-fertilizer				Average
	B_0	B_{Ac}	B_{Ab}	B_{Ac+Ab}	
N_0	4.027	4.781	4.508	5.079	599.4
N_{50}	4.491	5.238	4.843	5.318	4.973
N_{100}	4.886	5.445	5.279	5.506	5.279
N_{150}	5.325	5.779	5.503	5.721	5.577
Lsd .05	0.236				0.187
Avrage	4.682	5.311	5.033	5.406	
Lsd .05	0.118				
N200	5.687				
Lsd .05	0.253				

CONCLUSION

We conclude that the fertilization of sunflower with an amount of 150 Kg N ha^{-1} (75% of recommended nitrogen) resulted best for most parameters, including seed yield. Inoculation of sunflower seeds with a mixture of *A. chroococum* and *A. brasilense* improved vegetative growth, positively reflected in fertility and crop productivity. Regarding fertilizer combinations and $N_{100\%}$ (200 Kg N ha^{-1}), the inoculating of seeds with a mixture of bacterial biofertilizer or with *A. chroococum* or *A. brasilense* alone reduced N needs by 25%. These results confirm the positive role of non-symbiotic nitrogen-fixing bacteria, promoting a safe ecosystem consistent with sustainable agriculture trends that aim to increase the crop's productivity and maintain the soil and human health.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DECLARATION OF FUND

The authors declare that they have not received a fund.

AUTHOR/S DECLARATION

We confirm that all Tables in the manuscript are original to us. Additionally, any Figures and images that do not belong to us have been incorporated with the required permissions for re-publication, which are included with the manuscript.

Author/s signature on Ethical Approval Statement.

Ethical Clearance and Animal welfare

Funds: Self-funds

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استدامة نمو وإنتاجية زهرة الشمس بتأثير التسميد النتروجيني والسماد الحيوي البكتيري

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المستخلص

نفذت تجربة حقلية في الموسم الربيعي لعام 2024 في المحطة البحثية C – كلية علوم الهندسة الزراعية – جامعة بغداد لدراسة استدامة نمو وانتاجية زهرة الشمس بالتسميد النتروجيني وتلقيح البذور بالسماد الحيوي البكتيري. استخدم ترتيب الألواح المنشقة وفق تصميم القطاعات الكاملة المعشاة بثلاثة مكررات. مثلت الألواح الرئيسة إضافة 0 و25 و50 و75% من التوصية السمادية للنتروجين, بينما مثلت الألواح الثانوية تلقيح البذور ببكتريا *A. chroococum* و*A. brasilense* وخليط بينهما ومن دون تلقيح البذور, فضلا عن إضافة التوصية السمادية للنتروجين فقط (200 كغم N هـ$^{-1}$) لمقارنتها لاحقا مع التوليفات السمادية. بينت النتائج أن إضافة 75% من التوصية السمادية للنتروجين تفوقت معنويا في أغلب المؤشرات المقاسة المساحة الورقية (50.21 دسم^2) ونسبة الخصب (71.95%) وإنتاجية البذور (5.577 ميكاغم هـ$^{-1}$). كذلك لوحظت زيادة معنوية في النمو الخضري عند تلقيح البذور بخليط التسميد الحيوي البكتيري مما أدى إلى زيادة عدد البذور (1347.6 بذرة قرص$^{-1}$) وإنتاجية البذور (5.406 ميكاغم هـ$^{-1}$). أثر التداخل معنويا في أغلب الصفات المقاسة. فيما يتعلق بمقارنة التوليفات السمادية مع إضافة 200 كغم N هـ$^{-1}$ فقد لوحظ أن تلقيح البذور بخليط السماد الحيوي البكتيري أو بشكل منفرد قلل حوالي 25% من التوصية السمادية للنتروجين.

الكلمات المفتاحية: تغذية النبات, تلقيح البذور, نسبة الخصب, حاصل البذور