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The Effect of Inorganic and Microbial Fertilizer Applications on the Grain Yield and Some Agronomic Characters of the bean (*Phaseolus vulgaris* L.)##

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ABSTRACT

Background: In the century we live in, due to the environmental problems caused by the use of synthetic fertilizers, sustainable solutions are being sought. The use of beneficial microorganisms as biological fertilizers, which are directed in line with these searches, is remarkable. has become a phenomenon. This study aimed to investigate the effect of microbial fertilizer comparing them with synthetic fertilizer in Van ecological conditions.

Methods: This research was conducted in summer seasons of 2020 and 2022 to investigate the effects of microbial (Bacillus atrophaeus, Bacillus-GC group and Rhizobium gallicum) and chemical (Control: No fertilizer, NP100: 40 kg N/ ha-1, 60 kg/ ha-1 P2O5 and NP50: 20 kg N / ha-1, 30 kg/ ha-1 P2O5) fertilizer applications on the yield and nutrient content of beans. The experiment was conducted in split plot design and replicated thrice.

Result: Experimental results revealed that the use of microbial fertilizers led to a significant improvement in the morphological characteristics of bean plants in comparison to those treated with inorganic fertilizers. Besides, the utilization of microbial fertilizers, particularly when arranged in a consortium, exhibited performance that was nearly indistinguishable from that of synthetic fertilization. The highest grain yield was obtained with NP100 (40 kg N/ ha-1, 60 kg/ ha-1 P2O5) + NR (Bacillus atrophaeus + Rhizobium gallicum) application. Apart from this effect, other microbial applications also played a positive role in plant growth and production. It was therefore concluded that microbial fertilizers can be employed as a suitable alternative to chemical fertilizers in order to establish a sustainable agricultural system in bean cultivation, to enhance productivity, to safeguard and to improve soil properties.

Key words: Beans, Inorganic fertilizer, Microbial fertilizer, Sustainable agriculture.

INTRODUCTION

The application of inorganic fertilisers is regarded as a prerequisite for enhancing the efficiency of agricultural production. However, the variation in the types and application amounts of inorganic fertilizers applied and the lack of knowledge about fertilization negatively affect the health of living beings and the environment. The overuse of chemical fertilizers hardens the soil, reduces soil fertility, pollutes air, water and soil and lessens important nutrients of soil and minerals, thereby bringing hazards to environment. (Phalvi *et al.,* 2021). Despite high yield and quality in the short term, the use of synthetic fertilizers leads to a decrease in the biodiversity of agricultural soils (Tripathi *et al.,* 2020). It causes the deterioration of soil aggregate structure and carbon sequestration (Gupta *et al.,* 2020). As a result, it reduces soil fertility and contributes to desertification (Huebner, 2023). Therefore, the use of biological fertilizers has become a phenomenon that not only reduces the damage caused by synthetic fertilizers to the soil and the environment, but also provides the nutrients necessary for plant growth (Fasusi *et al.,* 2023). The use of biofertilizers can provide quality products for human consumption by reducing chemical residues and at the same time reduce the risk of environmental pollution. However, the increase in chemical fertilizer prices and the addition of organic fertilizers, especially microbial biofertilizers, to the soil in order to protect the soil ecosystem have made it necessary to minimize the use of chemical fertilizers (Saikia *et al.,* 2018).

Biofertilizers mostly consist of N fixing, P solubilizing and plant growth promoting microorganisms. These bacteria support root development with the N they fix and increase resistance to stress conditions. They promote plant development and growth through plant hormone and

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vitamin synthesis by increasing mineral uptake (Ajaykumar *et al.,* 2022)

Microbial fertilizers containing rhizosphere bacteria that promote plant growth increase plant development and yield by providing plant nutrient uptake to the plant or by increasing the the uptake of plant nutrient elements, producing some plant hormones or by inhibiting pathogen growth (Javorekovα *et al.,* 2015).

Studies have shown that biofertilizers may not completely replace synthetic fertilizers, but are quite effective in facilitating reduced fertilization. Some research findings indicate that biofertiliser strains may potentially yield higher crop yields and improved quality when compared to the use of synthetic fertilisers. In such circumstances, the application of biofertilisers may offer a solution, providing additional benefits. From a broader perspective, biofertilizer strains have many advantages over synthetic fertilizers and significantly overlap with the sustainability vision. The aim of this study was to determine the effects of biofertilizer strains on yield and some agronomic characters of bean by comparing their performance with plants subjected to synthetic fertilizer and rhizobium inoculation in the conditions of Van Province in the Eastern Anatolia Region of Turkey.

MATERIALS AND METHODS

Location and characterization of experimental area

Van province, where the research was conducted, is located in the Turkey's Eastern Anatolia Region, between 37°-39° north latitude and 43°-45° east longitude and its altitude is 1.726 m. First year of the study (2020) was conducted in Van-Tuşba, within the Field Crops Department at Van Yüzüncü Yıl University's Faculty of Agriculture. The subsequent phase of the study, conducted in 2022, carried out during the summer under irrigated conditions in the farmer's field in Atalan village, located Gevaş district of Van. The 2021 trial was cancelled due to the lack of data due to the negativities experienced. In accordance with the long-term average, precipitation in Van-Tuşba reached a total of 94.3 mm, while Van-Gevaş experienced an average precipitation level of 119.2 mm. Additionally, the average temperature and relative humidity in the area were recorded at a temperature range of 19.2-17.3°C and a humidity range of 45.8-56.5%, respectively. In the first year of the research, average precipitation during the growing season was recorded as 74.7 mm. In the same period, temperature was 19.7°C and the average relative humidity was 46.1%. While the relative humidity and average temperature data for the growing season were higher than the long-term average data, total precipitation remained below the long-term average. In the second year, average temperature and precipitation were below the long-term averages.

Experimental design

Akman 98 bean variety was used as seed material in the study. The experiment was carried out in the split plots in randomized blocks trial design with three replications in a 7 × 3 scheme. The treatments were composed of inoculations and reduced doses of NP during seeding and coverage fertilization. Microbial inoculations (N= inoculation with *B. atrophaeus* (Nitrogen fixing bacterial strain, TV 126C) (2.2-8.8 × 10^6 cfu mL^{-1}); R= inoculation with *R. gallicum* (1 kg bacteria to 100 kg seeds); P= inoculation with *Bacillus-GC group* (Phosphate-solubilizing bacterial strain, TV119E) (2.2-8.8 × 10^6 cfu mL^{-1}); NR= co-inoculation with *B. atrophaeus* + *R. gallicum*; PR= inoculation with Bacillus-GC group + *R. gallicum*; RN= inoculation with Bacillus-GC group + *B. atrophaeus*; NPR= inoculation with *B. atrophaeus* + Bacillus-GC group + *R. gallicum*) and reduced doses of NP (Ammonium sulfate (21%) and triple super phosphate (TSP) (42%) during seeding and coverage fertilization (unfertilized=control; NP_{50}=50% of the recommended dose, 20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5); NP_{100}=100% of the recommended dose of two parts, 40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5).

Installation of field research

The study was conducted for 2 years under irrigated conditions in the 2020 and 2022 growing seasons. Since data could not be obtained in 2021, it was excluded from evaluation. The trial plots were 3 m long, 2.5 m wide and consisted of five rows of plants. The planting density was arranged to be 100 kg seeds per hectare. In the trial, inorganic fertilizers were applied to the main plots, while microbial fertilizer combinations were applied to the subplots. Before planting, all of the P and half of the N from the inorganic fertilizers applied to the trial plots and incorporated with a rake. The remaining half of the nitrogenous fertilizer was applied at 30 days after planting. The field trial, which was repeated for two years, started on May 15, 2020 in the first year and May 20, 2022 in the second year. In the trial, weed control was carried out by hand plucking twice in the first trial year and three times in the second trial year until the flowering period. Thinning was done with the first hoe and throat filling was done with the second hoe. Irrigation was done regularly at certain intervals with the drip irrigation system. Since no disease or pest was detected, chemical control was not needed. Harvesting was done manually in a 3.0 m^2 area in each plot between August 28 and September 03, 2020 for the first trial year and between August 30, 2022 and September 06, 2022 for the second trial year, once the plants turned yellow and the pods began drying.

Statistical analysis

Variance analyses of the data obtained from the study were performed according to the Split Plots in Randomized Blocks Trial Design with three replications. The results of the analysis of variance were evaluated according to the F test and the significant difference were compared and grouped according to the LSD multiple comparison test (IBM SPSS 22.0).

RESULTS AND DISCUSSION

Inorganic and microbial fertilizer applications had an effect on plant height, but this effect was found to be statistically insignificant (P>0.05) in both years. According to inorganic fertilizer averages, the highest plant height value was obtained from NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5) in both years, while the lowest was obtained from control application. In microbial fertilizer averages, the highest values were determined in NR (*B. atrophaeus* + *R. gallicum*) in the first year, PN (*Bacillus-GC group* + *B. atrophaeus*) in the second year and the lowest values were determined in R (*R. gallicum*) application. In both years of the study, the shortest plant height was obtained from the Control + R (*R. gallicum*) fertilizer combinations and the longest plant height was obtained from the first year NP100 (40 kg N/ha-1,60 kg/ha^{-1} P_2O_5)+NR (*B. atrophaeus*+*R. gallicum*) and the second year NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5)+PR (*Bacillus-GC group*+*R. gallicum*) fertilizer combinations (Table 1). Plant height is a hereditary trait, can be affected by the environmental conditions in which it is grows. According to Sözen *et al.* (2021), variation in plant height can can ocur when beans are grown with different applications in the same environmental conditions, leading

Table 1: Plant height, first pod height, number of main branches and number of pods per plant values determined in the study.

SV		Plant height (cm)		First pod height (cm)		Number of main branches (pcs)		Number of pods per plant (pcs)	
IOF	MF	2020	2022	2020	2022	2020	2022	2020	2022
Control	N	43.20	46.47	10.10	9.27e-g	3.70	3.67	19.53b	25.27
	R	36.50	43.27	10.27	8.87f-h	3.30	3.40	13.00i	28.60
	P	39.57	50.80	10.67	9.40c-g	3.50	3.67	16.47e-g	37.80
	NR	40.47	46.80	10.30	10.00b-d	3.53	3.87	15.10h	34.93
	PR	42.97	47.47	9.70	8.40h	3.60	3.87	16.27fg	34.73
	PN	40.60	48.47	10.30	9.47c-f	3.57	4.00	18.63c	39.53
	NPR	42.63	43.50	10.43	9.73b-e	3.83	3.67	15.97g	28.63
NP_{50}	N	41.73	50.80	9.77	10.27b	4.07	3.47	17.00ef	25.80
	R	38.27	45.33	11.43	8.87f-h	3.43	3.40	14.50h	28.13
	P	40.70	49.67	11.53	8.67f-h	3.90	4.00	16.40e-g	38.60
	NR	43.60	45.20	11.00	8.80f-h	3.60	3.87	17.13e	40.07
	PR	39.43	46.90	10.60	10.67a	3.43	3.93	14.37h	31.13
	PN	44.70	52.93	10.63	10.00b-d	3.90	4.20	18.00d	37.33
	NPR	38.83	46.07	11.27	10.27b	3.43	3.03	16.57e-g	26.20
NP_{100}	N	44.63	52.00	10.30	8.80f-h	3.57	3.80	19.60b	42.67
	R	42.03	47.60	11.03	9.33d-g	3.60	3.53	15.10h	36.00
	P	43.27	49.00	10.50	8.47h	3.70	3.93	19.00bc	37.87
	NR	47.67	46.80	10.37	10.07bc	3.90	4.27	21.43a	43.73
	PR	42.93	53.13	10.70	9.13e-h	3.37	4.07	16.40e-g	38.13
	PN	43.33	51.20	10.47	9.33d-g	3.97	3.80	18.47cd	42.20
	NPR	44.00	49.00	11.43	10.87a	3.87	3.80	19.33b	39.93
IOF AVERA.	Control	40.85	46.68	10.25	9.30	3.58	3.70	16.42B	32.79
	NP_{50}	41.04	48.13	10.89	9.65	3.68	3.73	16.28B	32.47
	NP_{100}	43.90	49.80	10.70	9.40	3.70	3.90	18.50A	40.10
MF AVERAGE	N	43.19	49.76	10.06C	9.44B	3.78	3.64	18.71A	31.24B
	R	38.93	45.40	10.91AB	9.02BC	3.50	3.44	14.20D	30.91B
	P	41.18	49.82	10.90AB	8.84C	3.70	3.87	17.29B	38.09AB
	NR	43.91	46.27	10.56A-C	9.62B	3.68	4.00	17.89AB	39.58A
	PR	41.78	49.17	10.33BC	9.46B	3.47	3.96	15.68C	34.67AB
	PN	42.88	50.87	10.47A-C	9.60B	3.81	4.00	18.37A	39.69A
	NPR	41.82	46.19	11.04A	10.29A	3.71	3.50	17.29B	31.59B
LSD (5%)	3.62	4.52	0.45	0.46	0.26	0.43	0.74	5.54	
F values									
MF	ns	ns	**	**	*	*	**	**	
IOF	ns	ns	ns	ns	ns	ns	*	ns	
MF*IOF	ns	ns	ns	**	ns	ns	**	ns	

The means with the same letter within variable are not significantly different (Duncan's multiple range test p<0.05).

* and ** significant at 0.05 and 0.01 levels, respectively. ns: no significant.

SV: Sources of variation, IOF: Inorganic fertilizers, MF: Microbial fertilizers.

to differences plant heights across plant subjected to different fertilizer combinations.

Researchers who obtained similar results with the study, Doğan and Çığ (2023), reported that plants achieved greater heights with microbial, inorganic and organic fertilizers, while the shortest plant height was detected in control application and that fertilizers had a positive effect on plant height. Soysal and Erman (2020) and Yolci and Tunçtürk (2022) reported that the effect of microbiological fertilizer applications was significant. Özsoy Altunkaynak and Ceyhan (2018) reported that different N and bacteria applications led to increased plant height compared to the control and a certain increase was obtained whwn N was combined with bacterial application. Additionally, Çağlar *et al.* (2024) reported that the highest plant height was obtained from chemical fertilizer applications with P-solubilizing and N-fixing bacteria and the lowest from control application.

In microbial fertilizer applications, the highest first pod height was obtained from NPR (*B. atrophaeus+Bacillus-GC group+R. gallicum*) in both years, the lowest from N (*B. atrophaeus*) in the first year and P (*Bacillus-GC group*) in the second year. In inorganic fertilizer applications, the highest first pod height was obtained from NP_{50} (20 kg N/ha^{-1}, 30 kg/ha^{-1} P_2O_5) in both years and the lowest from control applications (Table 1). First pod height is especially important under conditions where harvesting will be done by machine. Therefore, harvest losses in beans are suitable for mechanized harvesting and where the first pods form at high altitudes are expected to be minimal (Elkoca and Çınar, 2015). Similar to the study, there are researchers who stated that the difference between bacterial applications is statistically significant in terms of first pod height (Bulut, 2013; Özaktan *et al.,* 2020; Soysal and Erman 2020), while other researchers found no significant effect (Akman, 2017). As seen in Table 1, statistically significant (P≥0.01) differences were found between microbial and inorganic fertilizer applications in the second year. The highest first pod height value (10.87 cm) was obtained with the NP_{100} (40 kg N/ha^{-1}, 60 kg/ha^{-1} P_2O_5)+NPR (*B.atrophaeus+Bacillus-GC group+R. gallicum*) application, while the lowest (8.40 cm) was obtained in the control+PR (*Bacillus-GC group+R. gallicum*) application (Fig 1a).

According to microbial fertilizer averages, the lowest number of main branches in 2020 was observed with PR (*Bacillus-GC group+R.gallicum*) application and in 2022 it was with R (*R. gallicum*) applications and in inorganic fertilizer averages, the lowest was in control and the highest was in NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5) applications in both years of the study. According to the application combinations, the lowest number of main branch were determined in control+R in the first year, the highest in the NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5)+N (*B.atrophaeus*); the lowest in the NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5)+NPR (*B.atrophaeus + Bacillus-GC group+R. gallicum*) and the highest in the NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5)+PR (*Bacillus-GC group + R.gallicum*) applications in the second year (Table 1). Bulut (2013) and other researchers (Akman, 2017; Gautam *et al.,* 2024) reported that bacteria application had a significant effect on the number of branches in plants.

According to microbial fertilizer averages, the highest number of pods per plant was detected from N (*B. atrophaeus*) in the first year and in the second year from PN (*Bacillus-GC group+B. atrophaeus*); and in inorganic fertilizer averages, the highest number of pods per plant was detected from NP_{100} (40 kg N/ha^{-1}, 60 kg/ha^{-1} P_2O_5) applications in both years (Table 1). In terms of inorganic and microbial fertilizer combinations, the highest number of pods per plant was detected in NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5)+NR (*B. atrophaeus+R. gallicum*) application in both years, while the lowest was in control+R (*R. gallicum*) applications in the first year and in control+N (*B. atrophaeus*) applications in the second year (Table 1). As seen in Table 1, there were significant (Pd≤ 0.01) differences between microbial and inorganic fertilizer applications in 2020. The highest value was obtained in NP_{100} (40 kg N/ha^{-1}, 60 kg/ha^{-1} P_2O_5) + NR (*B. atrophaeus + R. gallicum*) and the lowest in control+N (*B. atrophaeus*) applications (Fig 1b). In bean cultivation, the number of pods per plant is one of the important criteria that always positively affects yield (Sözen *et al.,* 2021). Doğan and Çığ (2023) and other researchers (Soysal and Erman, 2020; Akman, 2017 and Aldemir *et al.,* 2019) reported that microbial and inorganic fertilizer applications significantly effected in the number of pods per plant compared to the control. Sonkarlay *et al.* (2020) reported that when P was applied alone or in combination with organic fertilizer and biofertilizer, the number of pods per plant increased significantly compared to the control. When the application combinations were examined, the minimum number of grains per pod occurred in NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5) +PR (*Bacillus-GC group + R. gallicum*) in 2020, the maximum in NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5)+N (*B. atrophaeus*) and the minimum in NP50 (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5) +NPR *(B. atrophaeus+ Bacillus-GC group + R. gallicum*) and the maximum in control+PR (*Bacillus-GC group+R. gallicum*) applications in 2022. The difference in terms of application averages and combinations was found to be insignificant (Table 2). Researchers who stated that PGPBs increased the number of grains in pods (Galindo *et al.,* 2022; Ma *et al.,* 2019; Bulut, 2013; Akman, 2017) reported that inorganic fertilizers did not significantly increase the number of grains in pods (Şahin, 2018).

According to microbial fertilizer averages, the maximum 100-grain weight was obtained from the N (*B. atrophaeus*) application, while the minimum was from the R (*R. gallicum*) application in the first year of the study. In the second year the maximum 100-grain weight was obtained from the R (*R. gallicum*) and the minimum from the N (*B. atrophaeus*) applications. The difference between microbial applications in the first year was statistically significant (P≤0.01), while in the second year, the difference was insignificant (P≤0.01) both microbial and inorganic applications.

According to the inorganic fertilizer applications average, the 100-grain weight was lowest in control treatment in the first year and in the NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5) second year while it was in the NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5) in the first year and in the NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5) second year (Table 2). In the application combinations, the highest 100-grain weight (25.15 g) was obtained from NP_{100} (40 kg N/ha-1,60 kg/ha^{-1} P_2O_5)+N (*B. atrophaeus*) and the lowest (20.83 g) from control+R (*R. gallicum*) (Fig 1c). The 100-grain weight, a critical factor affecting the yield and market quality in beans, is influenced by the hereditary characteristics of the plant and the environmental conditions under which it grows. In some researchers (Bulut, 2013; Akman, 2017) reported that microbial fertilizers positively impacts 100-grain weight, while Doğan and Çığ (2023) reported that they did not. However, Şahin (2018) reported that inorganic fertilizers increased did not affect 100-grain weight significantly, while Doğan and Çığ (2023)

Table 2: Number of grains per pod, 100-grain weight, grain yield and biological yield values determined in the study.

SV: IOF	SV: MF	Number of grains in pod (pieces) 2020	2022	100 grain weight (gr) 2020	2022	Grain yield (kg/ha) 2020	2022	Biological yield (kg/ha) 2020	2022
Control	N	4.30	3.77	22.88d-f	23.92	2826.0d	2154.7p	12054.7b	9384.0u
	R	3.80	4.03	20.83h	27.80	1812.0o	3123.3i	6705.3t	12215.0p
	P	4.00	4.47	23.33cd	26.13	2365.3k	2967.7k	8632.0o	13134.7n
	NR	3.63	4.50	23.62c	25.00	2484.7j	2826.0m	8084.7p	14565.3i
	PR	3.77	4.73	22.88de	28.78	2056.7m	3671.0e	7603.3r	15110.7g
	PN	4.27	4.07	24.82a	27.17	2728.7f	3537.7f	10395.3g	14631.7h
	NPR	3.83	4.07	23.45cd	27.92	2458.7j	3063.3j	9112.0l	12861.3o
NP_{50}	N	4.43	3.87	24.13b	26.10	2662.0g	2124.7q	10955.3k	9712.3t
	R	3.23	3.97	21.75g	27.33	2096.7l	2825.7m	7563.3s	13926.7k
	P	3.97	4.30	23.50c	27.90	2450.7j	3385.3g	8850.7m	11197.3s
	NR	4.27	4.53	23.38cd	28.77	3023.3b	3710.0d	11130.0e	17818.7a
	PR	3.53	4.17	21.32h	26.18	1737.3p	2773.3h	6324.0u	15580.3e
	PN	3.83	4.40	22.87d-f	24.72	2576.0h	3338.0h	9816.0j	16333.3d
	NPR	4.03	3.47	22.30f	24.48	2527.3i	2303.3o	8794.0n	12070.3q
NP_{100}	N	3.53	4.00	25.15a	27.33	2966.0c	3073.3j	9299.3k	11892.0r
	R	3.73	4.53	22.58ef	28.53	2527.3i	2843.7l	10060.7h	13830.0l
	P	4.03	4.23	23.05c-e	27.47	2468.7j	3341.3h	9922.0i	13218.7m
	NR	4.37	4.13	24.27b	25.87	3482.0a	4497.3a	12668.7a	17154.0b
	PR	3.80	4.20	21.12h	27.88	1982.0n	3534.3f	7822.0q	15294.0f
	PN	3.97	4.31	23.20cd	25.65	2846.7d	4402.7b	11620.0c	16571.0c
	NPR	4.07	4.27	22.25f	28.10	2766.0e	3877.7c	11192.7d	14547.7j
IOF AVERAG	Control	3.94	4.23	23.10	26.67	2390.3B	3049.3B	8941.0B	13129.0C
	NP_{50}	3.90	4.10	23.75	26.50	2439.0B	2923.8C	9061.9B	13805.6B
	NP_{100}	3.90	4.20	23.12	27.30	2719.0A	3653.0A	10369.0A	14644.0A
MG AVERAGE	N	4.09	3.88	24.06A	25.78	2818.0B	2450.6G	10769.4A	10329.4F
	R	3.59	4.18	21.72C	27.89	2145.3E	2930.9F	8109.8D	13323.9D
	P	4.00	4.33	23.29AB	27.17	2428.2D	3231.4D	9134.9C	12516.9E
	NR	4.09	4.39	23.76A	26.54	2996.7A	3678.4B	10627.8A	16512.7A
	PR	3.70	4.37	21.77C	27.62	1925.3F	3326.2C	7249.8E	15328.3C
	PN	4.02	4.30	23.63A	25.84	2717.1BC	3759.4A	10610.8A	15844.9A
	NPR	3.98	3.93	22.67B	26.83	2584.0C	3081.4E	9699.6B	13159.8D
LSD (5%)	0.37	0.52	0.63	2.65	13.41	8.19	36.02	21.31	
F values									
MF	ns	ns	**	ns	**	**	**		**
IOF	ns	ns	ns	ns	**	**	**		**
MF*IOF	ns	ns	**	ns	**	**	**		**

The means with the same letter within variable are not significantly different (Duncan's multiple range test p<0.05).

* and ** significant at 0.05 and 0.01 levels, respectively. ns: no significant.

SV: Sources of variation;IOF: Inorganic fertilizers; MF: Microbial fertilizers.

reported that they was affect significantly. The researchers' findings support our findings.

According to the 2020 microbial fertilizer averages, the highest grain yield (2996.7 kg/ha) was observed in the NR (*B. atrophaeus*+*R. gallicum*) treatment, while the lowest (1925.3 kg/ha) was in the PR (*Bacillus-GC group*+*R. gallicum*) treatment. In the second year, the highest yield (3759.4 kg/ha) was in the PN (*Bacillus-GC group*+*B. atrophaeus*) application and the lowest (2450.6 kg/ha) in the N (*B. atrophaeus*) application. For inorganic fertilizers averages, the highest grain yield in both years (2719.0 and 3653.0 kg/ha, respectively) was obtained from the NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5) and the least (2390.3 kg/ha) was obtained from control in the first year and NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5) (2923.8 kg/ha) application in the second year (Table 2). As seen in Table 2, microbial and inorganic fertilizer interactions were significant in both years. The highest value was obtained from NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5) +NR (*B.atrophaeus +R.gallicum*) (3482 kg/ha in 2020 and 4497 kg/ha in 2022,) while the lowest value (1737.3 kg/ha in 2020) was obtained from NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5) +PR (*Bacillus-GC group +R.gallicum*) and (2124.7 kg/ha in 2022) from NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5)+N (*B.atrophaeus*) (Fig 1d). When Table 2 is analyzed, according to microbial fertilizer averages in 2020, the highest biological yield (10769.4 kg/ha) was determined in N (*B. atrophaeus*) and the lowest (7249.8 kg/ha) in PR (*Bacillus-GC group+R.gallicum*) treatments. In 2022, NR (*B. atrophaeus+R. gallicum*) produced the highest yield (16512.7 kg/ha) and N (*B. atrophaeus*) the lowest (10329.4 kg/ha). In inorganic fertilizer applications, the highest value was obtained in NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5) application in both years, followed by NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5) and control. Microbial and inorganic fertilizer interactions were statistically very significant (Pd≤0.01) in both years. The

Fig 1: Effect of microbial and inorganic fertilizer on (a) first pod height (cm), (b) number of pods per plant (pieces), (c) weight of 100 grains (gr), (d) grain yield (kg/ha), (e) biological yield (kg/ha).

highest value (12668.7 kg/ha) was obtained from the combination of NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5)+NR (*B. atrophaeus+R.gallicum*) in 2020 and (17818.7 kg/ha) from NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5)+NR (B. atrophaeus +R.gallicum) in 2022 (Fig 1e).

The increased availability of plant nutrients with the application of chemical fertilizers and microbial fertilizers has led to an increase in plant growth parameters. The activities of nitrogen fixation and P-solubilizing bacteria support plants starting within a few weeks from seed germination until the grain filling period. However, they provide slower and more continuous support compared to chemical fertilizers. Studies show that some of the N applied to the soil by chemical fertilization is lost by leaching, or denitrificatied due to evaporation processess (Geng *et al.,* 2022; Zhang *et al.,* 2023). In contrast, biologically sourced N is directly fixed in the the root zone of the plant reducing loses and enhancing nutrient availability (Guo *et al.,* 2023). Therefore, it is believed that plants receiving N supple mentation until the late stages have higher biomass and higher yields. Healthy growing plants had a higher number of pods and 100-seed weight, resulting in higher grain and biological yield in beans. Various researchers have reported that a combination of PGPB strains can give superior results compared to the individual performances of the strains (Çığ *et al.,* 2021; Timofeeva *et al.,* 2023; Ceritoğlu *et al.,* 2024). Many researchers have obtained similar results to the findings obtained as a result of our study (Dela *et al.,* 2023; Singh *et al.,* 2023; Doğan and Çığ, 2023; Ahmad *et al.,* 2022). Sonkarlay *et al.* 2020 and some other researchers (Singh *et al.* 2021; Yadav *et al.* 2021; Lanjewar *et al.* 2023; Namdeo and Bhatnagar, 2023) have suggested using these two fertilizer types together, since higher yields were obtained from areas where microbial and inorganic fertilizers were applied together. Sadeghipour (2017), in a study involving the application of vermicompost and chemical fertilizers, reported that the lowest biological productivity was obtained from control plots, followed by NPK fertilizers.

CONCLUSION

The research results revealed that the grain yield and yield components of beans responded differently to microbial and inorganic fertilizer applications. It was determined that NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5) inorganic fertilizer application showed the best results in terms of many agronomic characteristics. However, especially when applied as a consortium, microbial fertilizers showed a very close performance to synthetic fertilization. In almost all combinations, yield components increased compared to control applications. Most of the inoculations applied together with NP_{50} (20 kg N/ha^{-1},30 kg/ha^{-1} P_2O_5) dose caused an increase in bean grain yield. However, the increase was greater in inoculations made together with NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5). The highest grain yield was obtained in NP100 (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5) + NR (*B. atrophaeus+ R. gallicum*) application. Therefore, we recommend that NP_{100} (40 kg N/ha^{-1},60 kg/ha^{-1} P_2O_5) +NR (*B. atrophaeus+ R. gallicum*) applications be applied together in order to increase grain yield and yield components in bean farming.

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Disclaimers

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Conflict of interest

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