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Bio-priming Treatment with PGPB Strains in Cowpea Production Increases Grain Yield and Net Income

PGPB Strainleri ile Biyo-priming Uygulaması Börülce Üretiminde Tane Verimi ve Net Kazancı Artırır

Mustafa CERİTOĞLU[1]
Murat ERMAN[2]
Fatih ÇIĞ[1]
Özge UÇAR[1]
Sipan SOYSAL[1]
Zeki ERDEN[1]
Çağdaş Can TOPRAK[1]

[1] Department of Field Crops, Siirt University, Faculty of Agriculture, Siirt, Türkiye
[2] Department of Field Crops, Bursa Uludağ University, Faculty of Agriculture, Bursa, Türkiye

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Corresponding author / Sorumlu Yazar: Mustafa CERİTOĞLU
E-mail: ceritoglu@siirt.edu.tr

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ABSTRACT

In the 21st century, the use of beneficial microorganisms as biological fertilizers has become a notable phenomenon, driven by the ongoing search for sustainable solutions due to environmental issues associated with synthetic fertilizer use. This study aimed to investigate the effect of bio-priming with plant growth-promoting bacteria (PGPB) strains comparing them with synthetic fertilizer and rhizobium inoculation in Siirt ecological conditions. The field experiment was laid out according to a completely randomized design with four replications in the arable land of Siirt University (Siirt, Türkiye) during the 2019 summer season. Three synthetic fertilizer doses as diammonium phosphate (SF1: 100 kg ha^{-1}, SF2: 200 kg ha^{-1}, SF3: 300 kg ha^{-1}) and seven biological fertilizer treatments (B1: TV61C, B2: TV62C, B3: TV126C, B4: TV24C, B5: TV53D, BMIX: TV119E+TV126C, RZB: *Bradyrhizobium* sp.) were compared with control (no fertilization+hydro-priming) in the study. The research results indicated that 300 kg ha^{-1} DAP and PGPB consortia showed the best results on agronomic characteristics. However, particularly when applied in the form of a consortium, PGPB strains exhibited performance very close to synthetic fertilization. Moreover, it was determined that 300 kg ha^{-1} DAP and PGPB consortia increased grain yield over hydro-primed plants by 54.6% and 42.4%, while they provided a net income of $654 and $721.6, respectively. Thus, bio-priming with PGPB increased higher net income compared with synthetic fertilizer due to lower treatment costs. In conclusion, bio-priming with PGPB strains has the potential of useful, sustainable and cost-effective strategy in cowpea production.

Keywords: Biological fertilizer, food security, grain legumes, net gain, sustainable agriculture, *Vigna unguiculata*

ÖZ

21. yüzyılda, sentetik gübre kullanımına ilişkin çevresel sorunlar nedeniyle sürdürülebilir çözümlerin arayışıyla tetiklenen faydalı mikroorganizmaların biyolojik gübre olarak kullanımı dikkate değer bir fenomen haline gelmiştir. Bu çalışma, Siirt ekolojik koşullarında bitki gelişimini teşvik edici bakteri (PGPB) suşları ile biyo-priming uygulamasının etkisini sentetik gübre ve rizobium inokülasyonuna göre karşılaştırmayı amaçlamıştır. Tarla denemesi, 2019 yaz sezonunda Siirt Üniversitesi (Siirt, Türkiye) arazisinde tesadüf blokları deneme desenine göre dört tekerrürlü olarak gerçekleştirilmiştir. Çalışmada diamonyum fosfat olarak üç sentetik gübre dozu (SF1: 100 kg ha^{-1}, SF2: 200 kg ha^{-1}, SF3: 300 kg ha^{-1}) ve yedi biyolojik gübre uygulaması (B1: TV61C, B2: TV62C, B3: TV126C, B4: TV24C, B5: TV53D, BMIX: TV119E+TV126C, RZB: *Bradyrhizobium* sp.) kontrolle (kimyasal gübre yok+hidro-priming) karşılaştırılmıştır. Araştırma sonuçları, 300 kg ha^{-1} DAP ve PGPB konsorsiyumunun tarımsal özellikler üzerinde en iyi sonuçları verdiğini göstermiştir. Ancak özellikle konsorsiyum şeklinde uygulandığında, PGPB suşları sentetik gübreleme ile çok yakın performans göstermiştir. Dahası, 300 kg ha^{-1} DAP ve PGPB konsorsiyumunun hidro-priming uygulanan bitkiler üzerinde %54,6 ve %42,4 artış sağlayarak, sırasıyla $654 ve $721,6 net kazanç sağladığı belirlenmiştir. Dolayısıyla, üstün PGPB suşlarıyla biyo-priming uygulaması, düşük uygulama maliyetine bağlı olarak sentetik gübreye kıyasla daha yüksek net kazanç sağlamıştır. Sonuç olarak, PGPB suşlarıyla biyo-priming uygulaması, börülce üretiminde kullanılabilir, sürdürülebilir ve düşük maliyetli bir strateji potansiyeline sahiptir.

Anahtar Kelimeler: Biyolojik gübre, gıda güvenliği, yemeklik baklagiller, net kazanç, sürdürülebilir tarım, *Vigna unguiculata*

Introduction

Cowpea (*Vigna unguiculata*), which is an edible grain legume of the family Papilionaceae, shows a high adaptation to warm and adequate-rainfall ecological conditions and mostly cultivated at Southeast Asia, Southern United States, Latin America and Africa. The origin of cowpea is considered as Africa and traditionally cultivated in Mediterranean countries (Domínguez-Perles et al., 2015). Cowpea contributes the food chain for billions of people, mostly in developing countries, with annual production of about 9 million metric tons on 14.5 million hectares area worldwide (FAO, 2023). According to recent estimates, inadequate nutrition is responsible for more than one-third of child deaths worldwide. World Health Organisation (WHO) reported in 2020 that around 45% of child deaths in developing countries are associated with malnutrition, primarily due to the consumption of high-energy but less nutritious cereal-based foods (Okoth et al., 2017). Cowpea contains of 23-32% protein, 50-60% carbohydrates, and approximately 1% fat (Jayathilake et al., 2018). The total protein content is about two to four times higher than that of cereals and tuber crops. Moreover, cowpea protein is a rich source of the essential amino acid lysine when compared to cereal grains (Trehan et al., 2015). Cowpea is also a vital source of antioxidants, beneficial micronutrients, vitamins, and minerals (Owade et al., 2020). Thus, factors restricting cowpea yield and quality such as adverse climatic conditions, disease, pest damage or scarcity of plant nutrients play a critical role on food chain in especially developing countries.

Unfortunately, when it comes to developing countries, the issue is not only limited to nutritional inadequacy; there are also many factors that constrain agricultural production. Production of cowpea in developing countries such as Ethiopia are hindered by lack of modern Technologies, scarcity of advanced cowpea cultivars and accompanying disease and pest management practices, inputs such as fertilizers (Kebede et al., 2020). Another potential disaster scenario arises from the widespread use of uncontrolled synthetic fertilizers, which has become a global issue. Despite achieving high yields and quality in the short term, the use of synthetic fertilizers leads to a decrease in the biological diversity of agricultural soils (Tripathi et al., 2020), results in the deterioration of soil aggregate structure and carbon sequestration (Gupta et al., 2020), ultimately reducing soil fertility (Cai et al., 2019) and contributing to desertification (Huebner, 2023). Therefore, the use of biological fertilizers become a phenomenon to mitigate the damage caused by synthetic fertilizers to soil and the environment, while also providing essential nutrients for plant growth (Fasusi et al., 2023). More importantly, biological fertilizers not only contribute to plant nutrition but also help protect plants against adverse environmental factors and biotic stress conditions (Abdelaziz et al., 2023; Chieb & Gachomo, 2023; Hoque et al., 2023). Researchers have demonstrated that biological fertilizers are applied through various methods, such as foliar application, irrigation water, or seed application, and have shown positive results. Among these methods, the seed priming technique stands out as effective, environmentally friendly, and cost-efficient in providing benefits for plant growth (Akbar et al., 2019).

Seed priming that describes the soaking of seed to low osmotic potential of solution at pre-sowing is used to improve seed germination, seedling growth and also protect plants against biotic and abiotic stresses (Kumar et al., 2020; Singh et al., 2020). Seed priming provides faster and more homogeneous seed germination, boosts seedling development via controlled water uptake, activates starch disruption and enzyme actions, promotes ATP synthesis and antioxidant defense systems, thereby, increasing stress tolerance to negative environmental conditions (Aswathi et al., 2022; Farooq et al., 2017; Imtiaz et al., 2023). Seed priming is a cost-effective, easy-applicable and sustainable strategy for plant nutrition and protection (Sheteiwy et al., 2021). Most common priming techniques are hydro-priming, halo-priming, osmo-priming, nano-priming, bio-priming, solid matrix priming and thermo-priming (Hasanuzzaman & Fotopoulos, 2019). Out of these, bio-priming with plant growth promoting bacteria (PGPB) has a pivotal position due to superior properties including N fixation, P-solubilizing, ACC deaminase activity, indole acetic acid (IAA) and siderophore production, phytohormones secreting.

Research indicates that PGPB may not fully replace synthetic fertilizers, however, they have shown to be highly effective in facilitating reduced fertilization. Some research results even suggest that superior PGPB strains can provide higher yield and quality compared to synthetic fertilization. In such cases, adverse environmental conditions (salinity, drought, high temperatures, nutrient deficiencies, etc.) often suppress plant growth, and PGPB applications come into play, offering additional advantages beyond biological fertilization. In a broader perspective, PGPB applications have several advantages over synthetic fertilizers and align significantly with the vision of sustainability. This study aims to investigate the performance of PGPB strains comparing them with plants subjected to synthetic fertilizer and rhizobium inoculation in Siirt ecological conditions. The novelty of this study lies in the originality of the used PGPB strains and the unexplored results of their performance in cowpea cultivation under Siirt conditions.

Methods

Cowpea and Bio-priming Materials

“Karagöz”, which is a cowpea (*Vigna unguiculata*) cultivar, was used in the experiment. Özçelebi and Erman (2021) reported in their study on the adaptation of different cowpea genotypes to Siirt ecological conditions in which the highest grain yield was obtained from the “Karagöz”, therefore the variety was used in this experiment. Rhizobum culture for cowpea seeds was obtained from The Soil, Fertilizer and Water Resources Central Research Institute (Ankara, Türkiye). PGPB strains were isolated from Van Lake Basin within the scope of a TÜBİTAK project (108O147) at 2008 and performance of them were investigated under field conditions (Çakmakçı et al., 2010). The PGPB strains for bio-priming process were selected due to nitrogen fixation and phosphate solubilizing abilities. Taxonomic and isolation informations with superior properties of PGPB strains were given in Table 1.

Experimental Site

The field experiment was laid out from May to September 2019 at the Agricultural areas of Siirt University, Siirt, Turkiye. The experiment area was located at 37° 57’ N and 41°51’ E, an altitude of 585 m above sea level.

Climatic Characterization of Experimental Area

Mean temperatures (MT) of experimental year were lower than long years average (LYA) during march and april while they were higher compared with LYA during other months. Monthly total precipitaion (MTP) was significantly higher at experimental season compared with LYA data. The lowest and highest MT of experimental season were 8.3 °C and 32.0 °C, respectively. Climatic characterization of experimental season and its alteration as LYA was schematized in Figure 1.

Soil Characteristic of Experimental Area

The soil sample was obtained by mixing samples taken from different points of the A horizon. According to the analyses conducted on the sample, the soil in the experimental area has a clay-loam texture, a slightly alkaline, and calcareous structure. It is characterized as having a low content of organic matter and available phosphorus, while being sufficient in terms of available potassium (Table 2).

Table 1.
Taxonomic and isolation informations with superior properties of PGPB strains

Abb	Code	Taxonomy	Location	N fixation	P solubilizing
B1	TV61C	*Bacillus megaterium*	Çakırbey Köyü/Van	+	-
B2	TV62C	*Acinetobacter baumanii*	Tendürek/Van	+	-
B3	TV126C	*Pseudoalteromonas tetraodonis*	Ulupamir Köyü/Van	S	L
B4	TV24C	*Pseudomonas agarici*	Ulupamir Köyü/Van	+	L
B5	TV53D	*Brevibacillus choshinensis*	Çakırbey Köyü/Van	S	S
-	TV119E	*Bacillus* sp.	Ulupamir Köyü/Van	L	+
BMIX	TV119E+TV126C				

Abb: Abbreviation, +: Positive, S: Strong, L: Low, -: Negative

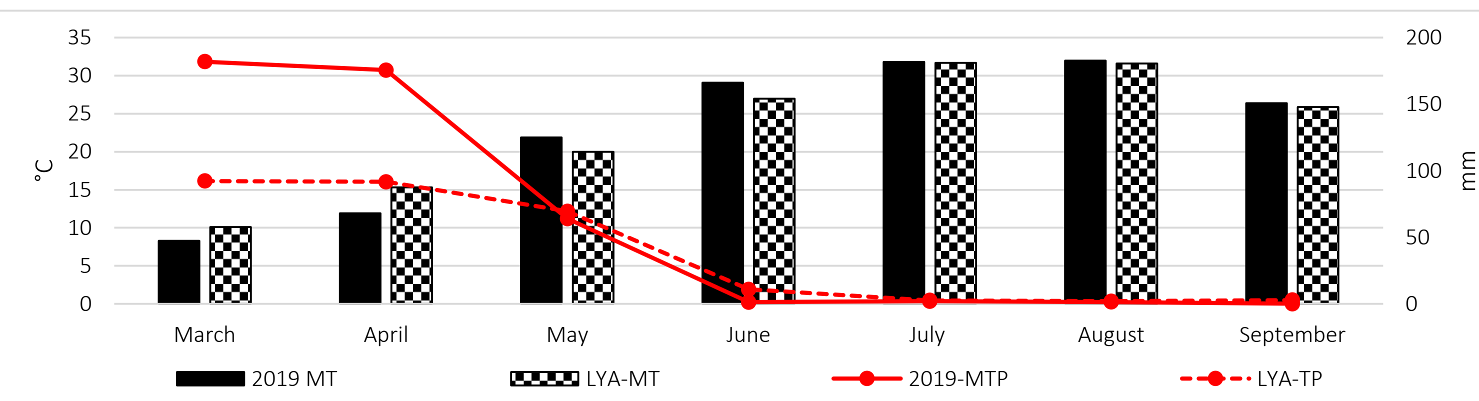

Figure 1.
Climatik properties of experimental area
MT: Mean temperature, LYA: Long years average, MTP: Monthly total precipitaion, TP: Total precipitation

Table 2.
Chemical composition of experimental soil

Sand (%)	Silt (%)	Clay (%)	Texture	pH	EC (S/cm)	Lime (%)	OM (%)	P (kg/da)	K (kg/da)
39.1	11.4	49.5	CL	7.78	685	10.1	1.2	2.02	147

CL: Clay-loam, OM: Organic matter

Laying out of bio-priming process

The process of preparing suspensions of strains preserved at -86 °C involved the use of solid and then liquid nutrient media. Samples obtained with the help of a loop from bacterial strains preserved for 72 hours on Nutrient Agar (NA) were inoculated into 100 ml of Nutrient Broth (NB) and incubated horizontally at 30 °C with constant shaking at 150 rpm overnight. The concentration of the obtained bacterial suspensions was adjusted to approximately ~108 CFU ml- using a turbidimeter by diluting them with sterile distilled water (Sonkurt & Çığ, 2019). Seeds to be used in the research were first weighed and subjected to surface sterilization by immersing them in 70% ethanol for 1 minute, followed by a 5-minute immersion in 10% NaOCl. After sterilization, they were washed three times with distilled water, placed on a sterile filter paper, and dried at room temperature. The prepared bacterial suspensions were added to autoclaved capped flasks at a seed:suspension ratio of 1:5 g/ml and sterilized at 121 °C for 20 minutes in an autoclave (HIRAYAMA, HV-110L, Japan) (Ceritoglu & Erman, 2021). Seeds were placed in the flasks for each bacterial suspension. The capped flasks were placed on a shaker (WiseShake, SHR-2D, Germany) and incubated at 120 rpm and room temperature for 2 hours. Hydro-primed seeds underwent hydro-priming, and distilled water was used as the priming solution. Hydro-priming was conducted as described in bio-priming, with seeds soaked in the solution for 12 hours (Farooq et al., 2019). After hydro-priming, seeds were air-dried between filter papers for 10-12 hours and stored in a refrigerator at 4 °C until sowing.

Experimental design

The field experiment was laid out according to a completely randomized design with four replications in erable land of Siirt University, Siirt, Türkiye during 2019 summer season. Three synthetic fertilizer doses as diammonium phosphate (SF1: 100 kg/ha, SF2: 200 kg/ha, SF3: 300 kg/ha), six PGPB Strains (B1: TV61C, B2: TV62C, B3: TV126C, B4: TV24C, B5: TV53D, BMIX: TV119E+TV126C) and 1 *Bradyrhizobium* inoculation were compared with hydro-primed plants. All treatment was accepted as a single factor in the experiment, i.e., did not cross each other.

Each plot was formed with 6 rows which was determined with 60 cm of inter-row distance (Çulha & Bozoğlu, 2017) and 5 m length, i.e., plot size was 15 m2. Seeds were sown with 10 cm intervals on rows. Before and after flowering, weed control has been carried out twice with hoeing. Throughout the study, due to high temperatures and lack of rainfall, to prevent drought stress in plants during the necessary periods, a total of 4 times irrigation has been applied through the drip irrigation system. No signs of diseases or harmful agents have been observed in the experimental area. After throwing one row each from the edges of each plot and 50 cm from the beginnings of the plots as edge effects, the remaining plants were harvested. Harvesting was done manually, and after drying the plants in the open field, the threshing process was performed.

Experimental observations

In the study, flowering period and pod-setting period were determined for the examination of phenological characteristics. For the determination of both characteristics, the periods when 50% of the plants in the plot flowered and 50% set pods were considered. Prior to harvest, on randomly selected 10 plant samples from each plot, plant fresh weight, plant dry weight, seedling length, node count, first pod height, pod length, seed count in the pod, and pod count on the plant were determined. For determining the dry weight of seedlings, plant samples were preserved in an oven set at 68 °C for 72 hours, then removed, and their weights were immediately determined. After the threshing process, the per-hectare grain yield was determined based on the obtained grains.

Economic Analysis

The cost of variable inputs and total income from grain yield was taken into consideration to calculate the economic analysis of treatments. Net income and benefit-cost ratio were calculated by the formulae of CIMMYT (1988).

Statistical analysis

The data obtained within the scope of the research were subjected to analysis of variance using a randomized complete block design. Tukey's Honestly Significant Difference (HSD) test was employed for grouping the means. Statistical calculations were performed using the JMP program.

Results

In the conducted research investigating the effects of different fertilizer methods on cowpea cultivation, it has been observed that, in almost all examined characteristics, the lowest values were obtained from hydro-priming. Additionally, it has been noted that increasing doses of synthetic fertilizers parallelly led to an increase in plant growth and yield components, with different reactions emerging depending on the species in the application of PGPB. While Rhizobium inoculation showed positive results compared to the hydro-priming, it was determined to be a less satisfactory solution compared to synthetic fertilizer. In the case of bio-priming application, competitive results with synthetic fertilizer were obtained in the group where a consortium was applied compared to individual PGPB applications.

Analysis of variance for the data indicated that there was no statistically significant difference in flowering time and plant fresh weight. However, it was recorded that statistically significant differences ($p < .01$) occurred in all other parameters depending on the fertilization systems. When examining the coefficients of variation for the characteristics, all parameters, except for plant dry weight (%24.3), were found to be below 20% (Table 3).

Table 3.

Analysis of variance on investigated characteristics

Trait	DF	VC	Mean of square	F prob.
Flowering time		4.36	7.660	nsd
Plant fresh weight		5.87	15426.500	nsd
Plant dry weight		24.3	105.800	**
Plant height		5.47	956.700	**
Number of nods	10	10.9	319.000	**
Pod length		13.3	22.600	**
Number of seeds per pod		7.36	15.790	**
Number of pods per plant		14.7	8.999	**
Grain yield		2.18	2187.200	**

DF: Degree of freedom, VC: Variation of coefficiency, nsd: No significant difference, **: $p < .01$

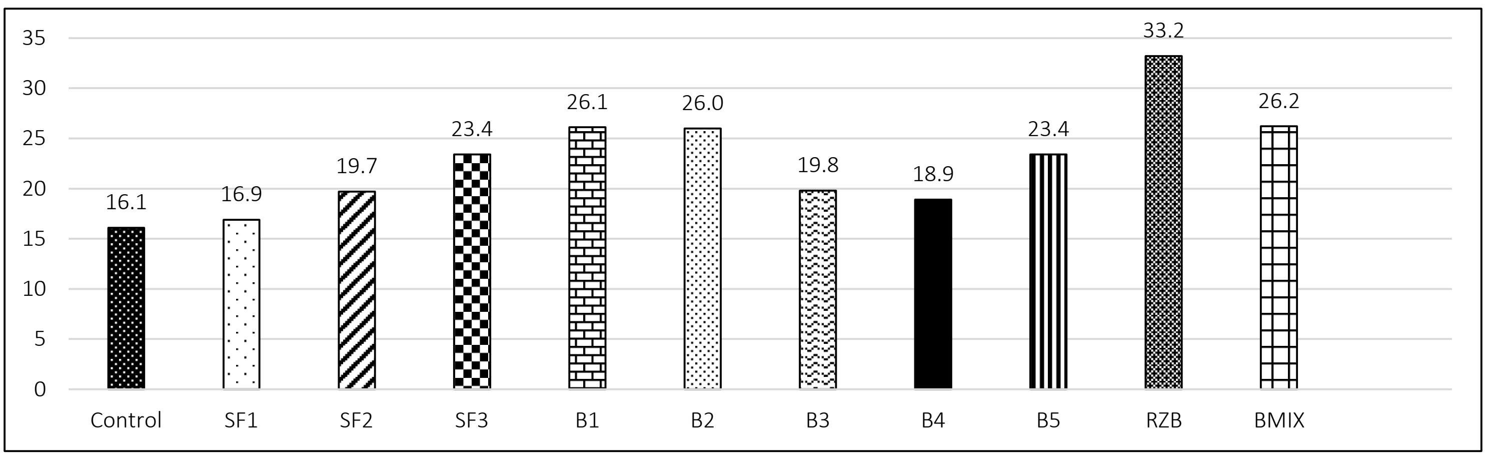

Figure 2.

Dry matter accumulation in cowpea plants depending on treatments

SF1: 100 kg ha^{-1}, SF2: 200 kg ha^{-1}, SF3: 300 kg ha^{-1}, B1: TV61C, B2: TV62C, B3: TV126C, B4: TV24C, B5: TV53D, BMIX: TV119E+TV126C, RZB: Bradyrhizobium sp.

The flowering time and plant fresh weight varied between 55.3-60.0 days and 37.4-67.4 g, respectively, in the study, with no statistically significant differences observed in the averages. The plant dry weight ranged from 16.1 to 33.2 g. The lowest dry matter accumulation was observed in the hydro-priming, while the highest value was detected in plants inoculated with rhizobium (Figure 2). Depending on the treatments, the lowest plant height (42.7 cm) was observed in the hydro-primed plants, while the tallest plant height (88.9 cm) was obtained from the 300 kg/ha DAP application, followed by the group treated with BMIX priming. The lowest and highest number of nodes (9.8-19.3) were observed in the B1 application and the 300 kg/ha DAP fertilization, respectively. Similarly, the shortest pod length (6.32 cm) was observed in the hydro-primed plants, while the longest pod length (13.92 cm) was observed in the 300 kg/ha DAP fertilization. The number of seeds in the pod varied between 3.74 and 10.88, with the lowest and highest values recorded in the B2 application and the 300 kg/ha DAP fertilization, respectively. While the lowest number of pods per plant was determined in the B4 application, the highest values were observed in the same statistical group, including the 300 kg/ha DAP, B5, and BMIX applications. Although the lowest grain yield (1456 kg/ha) was obtained in the hydro-priming, the results obtained from the B4-treated plants (1505 kg/ha) were statistically in the same group. The highest grain yield was obtained from the 300 kg/ha DAP application at 2251 kg/ha, followed by BMIX at 2074 kg/ha (Table 4).

Table 4.
Means of agronomic and yield attributes of cowpea plants under different fertilizations

Treatment	FT (day)	SFW (g)	SDW (g)	PH (cm)	NN	PL (cm)	NSP	NPP	GY (kg/ha)
Control	60.0	48.7	16.1^{b}	42.7^{f}	10.1^{d}	6.32^{e}	5.95^{ef}	3.75^{cd}	1456^{f}
SF1	58.8	37.4	16.9^{b}	50.9^{de}	11.9^{cd}	7.42^{de}	6.88^{c-e}	5.45^{abc}	1749^{de}
SF2	55.3	43.8	19.7^{ab}	59.1^{bc}	14.5^{bc}	8.59^{cde}	7.43^{cd}	6.33^{ab}	1952^{c}
SF3	57.8	49.5	23.4^{ab}	88.9^{a}	19.3^{a}	13.92^{a}	10.88^{a}	7.33^{a}	2251^{a}
B1	57.8	52.0	26.1^{ab}	52.2^{cde}	9.8^{d}	7.89^{cde}	4.61gh	4.60^{bcd}	1734^{de}
B2	57.0	48.4	26.0^{ab}	51.9^{cde}	11.8^{cd}	7.09^{de}	3.74h	4.97^{bc}	1786^{d}
B3	58.3	37.6	19.8^{ab}	44.7^{ef}	11.9^{cd}	7.73^{cde}	7.73^{b-d}	3.95^{cd}	1654^{e}
B4	56.5	39.9	18.9^{b}	53.2^{cd}	11.7^{cd}	9.71^{bcd}	6.53^{d-f}	2.87^{d}	1505^{f}
B5	57.6	64.1	23.4^{ab}	64.5^{b}	13.7^{bc}	10.68^{bc}	7.95^{bc}	7.09^{a}	1891^{c}
RZB	59.0	52.3	33.2^{a}	57.4^{bcd}	12.2^{cd}	8.91^{cde}	5.60^{f}g	4.68^{bcd}	1741^{de}
BMIX	56.0	67.4	26.2^{ab}	87.3^{a}	16.4^{ab}	12.61^{ab}	8.83^{b}	7.07^{a}	2074^{b}
Mean	57.7	49.2	22.7	59.3	13.0	9.17	6.92	5.28	1799

SF1: 100 kg ha^{-1}, SF2: 200 kg ha^{-1}, SF3: 300 kg ha^{-1}, B1: TV61C, B2: TV62C, B3: TV126C, B4: TV24C, B5: TV53D, RZB: *Bradyrhizobium* sp., BMIX: TV119E+TV126C, FT: Flowering time, PFW: Plant fresh weight, PDW: Plant dry weight, PH: Plant height, NN: Number of nods, PL: Plant length, NSP: Number of seeds per pod, NPP: Number of pods per plant, GY: Grain yield

The effects of different applications on grain yield and the economic returns of these variations are presented in Table 5. According to the table, the applications that most significantly increase grain yield in comparison to hydro-priming are determined as 300 kg ha^{-1} DAP (54.6%), BMIX (42.4%), and 200 kg ha^{-1} DAP (34.1%). Additionally, calculations were conducted by taking into account the additional gain and expenses compared to the hydro-priming, resulting in the determination of the net gain arising from the applications. According to net income data, the highest net gain per ha area over hydro-priming is observed in the following order: BMIX ($721.6), 300 kg ha^{-1} DAP ($654), and B5 ($502). When evaluated in terms of benefit:cost ratio, the highest value of 36.1 was achieved in the BMIX application, while the lowest ones were obtained from synthetic fertilizer applications (2.0-2.5) and B5 (1.9).

Discussion

The gradual increase in all statistically significant features due to the increase in synthetic fertilizer doses is evident. When the soil characteristics of the experimental area are examined, it is observed that the organic matter content and the available phosphorus amount are very low (Table 2). Therefore, due to the already low levels of nitrogen and phosphorus sources in the soil, plants have shown a significant response to chemical fertilization, exhibiting increasing development and productivity up to the highest DAP level. Numerous scientific studies since the Green Revolution have indicated that synthetic fertilization provides a rapid solution for plant development and yield, and these responses are more visibly manifested in deficiency conditions (Ishikawa et al., 2022), however, in terms of long-term effects, it is pointed out that this leads to the deterioration of soil and underground resources, ultimately threatening living health (Tripathi et al., 2020).

Among the characters investigated in the study, the highest results were obtained in the application with the highest DAP level of 300 kg/ha in all features except plant age and dry matter weight. In terms of seedling fresh weight and seedling dry weight, the best results were observed in the RZB and BMIX applications, respectively. Biological nitrogen fixation provides nitrogen support to plants from a few weeks after seed germination until the grain-filling period. However, compared to chemical fertilization, it offers a slower and more sustained nitrogen support. Studies suggest that a portion of the nitrogen applied to the soil through chemical fertilization undergoes leaching, while another part undergoes denitrification due to evaporation (Geng et al., 2022; Zhang et al., 2023). Nitrogen obtained through biological means directly binds to the plant root zone without any losses (Guo et al., 2023). Therefore, plants receiving nitrogen support until the late stages are believed to produce higher biomass in post-harvest plant samples and consequently accumulate more dry matter. Zhu et al. (1988) reported that biological nitrogen fixation led to an increase in dry matter accumulation in annual clover plants. Rodrigues et al. (2013) observed an increase in total biomass and dry matter accumulation in cowpea seeds inoculated with Bradyrhizobium, and when applied in conjunction with PGPB, it showed a synergistic effect, further enhancing the accumulation.

Table 5.
Economic analysis of grain yield depending on fertilization strategies

Fertilizer treatment	Increase in seed yield (%)	Difference over control (kg ha^{-1})	Difference in gain over control ($)	Cost of fertilizer ($)	Net gain over control ($)	Benefit:Cost ratio
Control	-	-		-	-	-
SF1	20.1	293	351.6	100	251.6	2.5
SF2	34.1	496	595.2	200	395.2	2.0
SF3	54.6	795	954.0	300	654.0	2.2
B1	19.1	278	333.6	20	313.6	15.7
B2	22.7	330	396.0	20	376.0	18.8
B3	13.6	198	237.6	20	217.6	10.9
B4	3.4	49	58.8	20	38.8	1.9
B5	29.9	435	522.0	20	502.0	25.1
RZB	19.6	285	342.0	20	322.0	16.1
BMIX	42.4	618	741.6	20	721.6	36.1

SF1: 100 kg ha^{-1}, SF2: 200 kg ha^{-1}, SF3: 300 kg ha^{-1}, B1: TV61C, B2: TV62C, B3: TV126C, B4: TV24C, B5: TV53D, RZB: *Bradyrhizobium* sp., BMIX: TV119E+TV126C, FT: Flowering time, PFW: Plant fresh weight, PDW: Plant dry weight, PH: Plant height, NN: Number of nods, PL: Plant length, NSP: Number of seeds per pod, NPP: Number of pods per plant, GY: Grain yield

Out of PGPB strains, the B5 has exhibited a performance so effective that it falls into the same statistical group as the consortium and synthetic fertilizer in terms of the number of pods in the plant. When the superior characteristics of PGPB strains are examined, the B5 strain (TV53D) shows a higher capability in N-fixation and P-solubilization compared to other isolates (Table 1). Therefore, it is considered more effective due to its ability to meet the plant's N requirements and the dissolution of P sources in the insoluble form in the rhizosphere, which can then be taken up by plant roots (Erman & Ceritoglu, 2022). Furthermore, when the characteristic features of the bacterial strains forming the consortium (TV119E and TV126C) are examined, it is predicted that they are strong in N fixation and P solubilization and exhibit a synergistic effect on each other. The applications that exhibit superior performance in terms of grain yield (300 kg ha^{-1} DAP and BMIX) are noteworthy for significantly improving not only plant development but also factors influencing yield. Ceritoglu & Erman (2020) reported statistically significant differences among agronomic traits symbolizing grain yield, pod number per plant, seed number per pod, and plant development in chickpea. Various researchers have reported that consortia consisting of PGPB strains can yield superior results compared to the individual performances of the strains (Çığ et al., 2021; Timofeeva et al., 2023). Many researchers denoted that PGPB increases grain yield (Galindo et al., 2022; Ma et al., 2019) in cowpea. Thus, the results of the experiment are in agreement with the fundings of previous researchers.

The BMIX application proves to be highly effective, nearly reaching the maximum synthetic fertilizer dosage, thereby influencing grain yield significantly. However, when considering application costs and the potential for extra gains, another advantage of PGPB (Plant Growth-Promoting Bacteria) applications emerges. The results indicate that PGPB applications allow for higher net gains compared to synthetic fertilization due to their lower application costs. Furthermore, it is found that, apart from the consortium used, the B5 application also outperforms synthetic fertilization in terms of economic gains. This finding makes bio-priming applications more attractive for agricultural production and creates a convincing scenario with potential benefits.

Conclusion and Recommendations

In this study, the effects of synthetic and biological fertilizer applications on the growth and yield of cowpea under Siirt ecology and field conditions were investigated. The research results indicate that, in terms of agronomic characteristics, the application of 300 kg ha^{-1} DAP showed the best results. However, particularly when applied in the form of a consortium, Plant Growth-Promoting Bacteria (PGPB) strains exhibited performance very close to synthetic fertilization. However, economic analysis of obtained crop indicated a novel scenerio in which 300 kg ha^{-1} DAP and PGPB consortia increased grain yield over hydro-priming 54.6% and 42.4%), while they provided net gain as $654 and $721.6, respectively. Thus, bio-priming with PGPB increased higher net gain compared with sythetic fertilizer due to lower treatment cost. In conclusion, bio-priming with superior PGPB strains might be a usefull, sustainable and cost-effective strategy in cowpea production.

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