

# Integrated fertilization strategies to improve agronomic parameters of common bean

Ruelas-Islas, Jesús del Rosario<sup>1</sup>; Romero-Félix, Celia S.<sup>1</sup>; Mendoza-Pérez, Candido<sup>2</sup>; Buelna-Tarín, Salomon<sup>1</sup>; Sifuentes-Ibarra, Ernesto<sup>3</sup>; Ruiz-Pérez, Vladimir<sup>1</sup>; Núñez-Ramírez, Fidel<sup>4</sup>

<sup>1</sup> Universidad Autónoma de Sinaloa, Facultad de Agricultura del Valle del Fuerte, Calle 16 y Avenida Japaraquí, Juan José Ríos, Sinaloa, México. C.P 81110.

<sup>2</sup> Colegio de Postgraduados, Departamento de Hidrociencias, Carretera México-Texcoco, Montecillo, México. C.P. 56230.

<sup>3</sup> Campo Experimental Valle del Fuerte-INIFAP. Carretera internacional México-Nogales km 1609, Juan José Ríos, Sinaloa, México. C.P. 81110.

<sup>4</sup> Universidad Autónoma de Baja California, Instituto de Ciencias Agrícolas. Ejido Nuevo León, Mexicali, Baja California, México. C.P. 21705.

\* Correspondence: celiaromero@favf.mx

## ABSTRACT

**Objective:** To investigate the effect of biofertilizers and phosphorus rates on overall growth, biomass production, chlorophyll content and yield of common bean Azufrado Reyna under field conditions.

**Design/methodology/approach:** Split plot in a randomized complete block design with four replicates and four treatments (three phosphorus rates and the control). Growth index, growth components, aboveground biomass and yield were evaluated.

**Results:** The phosphorus rates influenced the growth index, growth components, aboveground biomass and yield with respect to the control; while the combination of biofertilizers positively interact with some of the parameters evaluated.

**Limitations on study/implications:** The study only assessed the evaluation of agronomic parameters; therefore, it is convenient to quantify the performance of biofertilizers in contrasting soil conditions.

**Findings/conclusions:** The application of biofertilizers with lower phosphorus rates had a positive effect on grain yield, thus reducing the amount of chemical fertilizers. Also, the dry weight of grains showed the highest correlation with grain yield.

**Keywords:** microorganisms, fertilization, common bean.

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## INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is a crop well adapted to diverse soil and climatic conditions. Moreover, its nutritional importance is associated with its content of vitamins and minerals, which are essential components of the human diet (Abebe and Mekonnen, 2019). Crop yield is mainly affected by biotic factors, such as diseases, and abiotic factors, including crop management, irrigation, fertilization, drought, temperature variability, and soil fertility status (Obssi *et al.*, 2022). However, the genetic and physiological potential of different varieties may vary in terms of nutrient use efficiency (Shanka *et al.*, 2016). The

application of high rates of phosphorus (P) fertilizers has contributed to P accumulation in forms unavailable for plant growth. In this regard, several studies have shown that the application of  $50 \text{ kg ha}^{-1} \text{ P}_2\text{O}_5$  increased the yield of field crops (Hossain *et al.*, 2011; Shanka *et al.*, 2016). These findings are consistent with those reported by Ruelas-Islas *et al.* (2018), who found that a moderate P fertilizer rate of  $50 \text{ kg ha}^{-1} \text{ P}_2\text{O}_5$  promoted biomass accumulation, as well as growth and yield parameters, in bean cv. Azufrado Higuera in northern Sinaloa, Mexico. Other studies have shown that the application of microorganisms as biofertilizers improves nutrient availability, increases productivity, and reduces the need for P fertilization (Sharma *et al.*, 2020; Pirttilä *et al.*, 2021). Accordingly, González-Marquetti *et al.* (2021) found that inoculation with the combined application of *Trichoderma asperellum* + Azofert® (*Rhizobium leguminosarum* strain CF1) in common bean cv. 'BAT-304' favored growth parameters and increased the expression of defense enzymes. Mora *et al.* (2024) reported that plants treated with *Trichoderma* sp. exhibited a more complex architecture, with thicker stems and greater root volume. Likewise, Mohamed *et al.* (2019) stated that inoculation with *Bacillus subtilis*, *Pseudomonas fluorescens*, and mycorrhizae, either individually or in co-inoculation (*B. subtilis* + AMF and *P. fluorescens* + AMF), increased Fe and P uptake in bean plants compared with non-inoculated plants. Similarly, Hoyos-Carbajal *et al.* (2015) found that strains of *Trichoderma harzianum* and *T. asperelloides* enhanced the concentrations of Ca, Mg, K, Fe, and Cu in the foliar tissues of plants grown in soil with andic properties. Based on the above, the effect of microbial biofertilizers in combination with phosphorus on the growth, yield, and yield components of common bean cv. Azufrado Reyna was evaluated under field conditions.

## MATERIALS AND METHODS

The experiment was conducted during the 2022-2023 season in a plot belonging to a cooperating grower ( $25^\circ 47' 57.29'' \text{ N}$ ,  $108^\circ 48' 34.99'' \text{ W}$ ). The soil in this region is classified as clay loam, with low organic matter content ( $>1\%$ ) and a bulk density of  $1.15 \text{ g cm}^{-3}$ . The tillage practices employed were those described in the crop production handbook (INIFAP, 2017). Planting was carried out in moist soil using the Azufrado Reyna variety at a density of  $180,000 \text{ plants ha}^{-1}$ . Weed and pest management were effectively maintained throughout the season. Nitrogen and phosphorus fertilizers were applied pre-plant using Urea® and MAP®.

The treatments consisted of three phosphorus rates ( $\text{P}_2\text{O}_5$ ): T1,  $0 \text{ kg ha}^{-1}$ ; T2,  $25 \text{ kg ha}^{-1}$ ; and T3,  $50 \text{ kg ha}^{-1}$ , in addition to the control treatment. Seeds were inoculated at the recommended rate with Bs® (*Bacillus subtilis*), Funqui® (*Trichoderma viride*, Tr), and mycorrhizae (M). The experiment was established as a split-plot arrangement in a randomized complete block design with four replicates. Phosphorus rates were assigned to the main plots ( $40 \text{ m}^2$ ), whereas biofertilizer inoculation was assigned to the subplots (4 rows arranged linearly within each main plot).

## Variables

Measurements were taken from three plants per treatment to estimate the growth index (GI) [ $\text{height} + \text{width (east to west)} + \text{width (north to south)}/3$ ], as proposed by Atland (2003)

and Torres-Bojórquez *et al.* (2017). Additionally, NDVI readings were recorded to relate these values to biomass production as an indirect measure of crop growth. The Trimble<sup>®</sup> sensor was placed approximately 50 cm above the plant canopy, generating readings between  $-1$  and  $+1$ , where green areas exhibit positive values, whereas areas with sparse vegetation display low or negative values (Johansen and Tømmervik, 2014). SPAD values were also recorded as the average of three prior readings taken from the middle section of the plant and the central part of the leaf, excluding the midrib. Dry matter sampling consisted of removing one meter of plants from each plot. The material was weighed, dehydrated at ambient temperature, and subsequently placed in a forced-air oven ( $70\text{ }^{\circ}\text{C}$ ) until constant weight was reached. At the end of the season, yield and its components were determined from the two central rows and adjusted to 14% moisture content.

### Statistical analysis

All data were subjected to a normality test (Shapiro and Wilk, 1965) and to the appropriate analysis of variance. Pearson correlation models were fitted and tested for significance at  $p < 0.05$  (Minitab<sup>®</sup>, 2018).

## RESULTS AND DISCUSSION

### Growth index (GI) and growth components

Overall, P rates positively influenced the growth index (GI) throughout the season, reaching maximum values at 60 DAP (pod development). Likewise, inoculation with biofertilizers exerted a slight influence on this index, with no statistically significant differences among treatments except for the control (Table 1). The interaction effect showed no significant differences in GI in treatments without phosphorus but inoculated with biofertilizers at 30 DAP. The highest GI (54.5 cm) was obtained in treatments inoculated with *Trichoderma* at the rate of  $25\text{ kg P}_2\text{O}_5$ , whereas a GI of 52.5 cm was recorded for the treatment inoculated with *Bacillus subtilis* at the rate of  $50\text{ kg P}_2\text{O}_5$ . At 90 DAP, treatments inoculated with mycorrhizae and supplied with  $50\text{ kg P}_2\text{O}_5$  exhibited the highest GI (55 cm), followed by treatments inoculated with *Trichoderma* and *Bacillus subtilis*. However, the lowest values were recorded in treatments without inoculant and without phosphorus throughout the season (Figure 1). Studies conducted by Ruelas-Islas *et al.* (2018) observed that GI increased during flowering in bean cv. Azufrado Higuera and reached its maximum at the onset of pod filling, after which it declined as the crop approached maturity (100 DAP), particularly in treatments fertilized with  $50$  and  $100\text{ kg ha}^{-1}\text{ P}_2\text{O}_5$ .

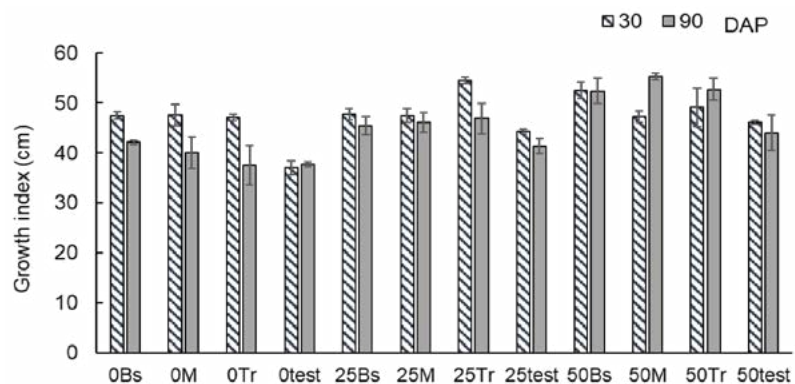
The evaluated growth components differed significantly among treatments involving phosphorus, biofertilizers, and their interaction ( $p < 0.05$ ). The greatest root length (24.6 cm), stem diameter (7.7 mm), root fresh and dry weight ( $29.3$  and  $21.2\text{ g plant}^{-1}$ , respectively), and stem dry weight (59.6 g) were recorded in plants fertilized with  $50\text{ kg ha}^{-1}\text{ P}_2\text{O}_5$  (Table 2). These findings are consistent with those reported by Shanka *et al.* (2016), who observed a significant increase in root length in response to high phosphorus levels, and by Alemu *et al.* (2018), who recorded the longest root (23.57 cm) in the cultivar Tatu at a rate of  $69\text{ kg ha}^{-1}\text{ P}_2\text{O}_5$ . Plants inoculated with mycorrhizae exhibited greater root length (29.9 cm), thicker stems (9.2 mm), higher root fresh and dry biomass (38.5 and

24.5 g plant<sup>-1</sup>, respectively), and greater stem dry weight (77.8 g plant<sup>-1</sup>) compared with non-inoculated plants. These results are in agreement with those of Gabre *et al.* (2020), who found that inoculation with *Rhizobium tropici* and co-inoculation with *R. tropici* + *T. asperellum* + *B. subtilis* produced the highest stem dry weight and longest root length in field-grown bean plants. Furthermore, Rodríguez-González *et al.* (2022) reported that bean plants inoculated with *Trichoderma* Ta37-23.74 showed increased shoot and root dry weight (4.22 and 0.62 g, respectively) compared with insect-damaged plants treated with the same strain. Likewise, Nayeema *et al.* (2022) observed a significant increase in root length (58, 54, and 42 mm) and stem length (78, 75, and 71 mm) following seed inoculation with different strains of *Trichoderma viride*. The interaction effect revealed that inoculation with mycorrhizae combined with 50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> was the most effective treatment for promoting growth and increasing root length. Similarly, Ruelas-Islas *et al.* (2018) reported the greatest stem diameter (5.0 mm), root fresh and dry weight (15 and 4.6 g, respectively), and stem dry weight (30 g) in plants fertilized with 50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, with no effect attributed to *Bacillus subtilis*.

**Table 1.** Growth index as a function of time.

Treatments	Days after planting		
	30	60	90
0	44.8 b	50.2 b	39.7 c
25	48.5 a	57.3 a	44.9 b
50	48.8 a	58.6 a	51.2 a
(p≤0.05)	0.001	<0.001	<0.001
<i>B. subtilis</i> (Bs)	50.2 a	60 a	49 a
<i>Trichoderma</i> (Tr)	50 a	61.2 a	48.7 a
Mycorrhizae (M)	49.3 a	62 a	50 a
Control (test)	44.3 b	55.4 a	44.5 a
(p≤0.05)	0.001	0.2	0.2
P×BF	0.001	0.1	0.001

†Means with different letters within a column are statistically different (Fisher P≤0.05). P×BF: interaction phosphorus-biofertilizer.



**Figure 1.** Growth index as a function of phosphorus and biofertilizers.

**Table 2.** Effect of phosphorus and biofertilizers in growth components at 60 DAP.

Treatments	RL (cm)	SD (mm)	FRW (g plant <sup>-1</sup> )	DRW (g plant <sup>-1</sup> )	SDW (g plant <sup>-1</sup> )
0 kg ha <sup>-1</sup>	18 b	4.6 b	18.7 b	5.0 b	40.5 b
25 kg ha <sup>-1</sup>	19.5 b	6.9 a	24.8 ab	17.5 a	52 ab
50 kg ha <sup>-1</sup>	24.6 a	7.7 a	29.3 a	21.2 a	59.6 a
(p≤0.05)	<0.001	<0.001	0.003	0.001	<0.001
Bs	22.4 b	7.4 b	23.3 c	18.6 a	50 b
Tr	22.8 b	5.9 c	28.3 b	10.2 b	51.8 b
M	29.9 a	9.2 a	35.8 a	24.5 a	77.8 a
Control (test)	15.6 c	4.8 c	16.4 d	4.7 c	35.9 c
(p≤0.05)	<0.001	<0.001	<0.001	<0.001	<0.001
<b>Interaction</b>					
50 M	36.6 a	10.2 a	41.0 a	37.6 a	90.3 a
25 M	23.0 b	9.4 b	29.3 bc	31.3 b	78.6 b
50 Tr	23.0 b	7.2 d	31.6 b	15.3 d	56.3 c
0 M	22.6 b	5.2 ef	27.6 c	4.4 f	55.0 c
50 Bs	24.0 b	8.7 bc	26.3 cd	28.3 b	54.3 c
25 Bs	21.3 bc	8.1 c	23.0 de	24.3 c	47.6 d
25 Tr	19.1 cd	5.4 e	27.6 c	9.3 e	44.0 d
0 Bs	19.0 cd	4.5 fg	16.6 f	4.7 f	42.3 de
0 Tr	17.0 de	5.1 ef	20.0 ef	5.0 f	41.5 de
50 test	15.0 e	4.8 ef	18.3 f	3.7 f	37.6 e
25 test	14.6 e	4.9 ef	19.2 f	5.1 f	37.6 e
0 test	13.6 e	4.0 g	11.3 g	5.9 f	23.3 f
(p≤0.05)	<0.001	<0.001	<0.001	<0.001	<0.001

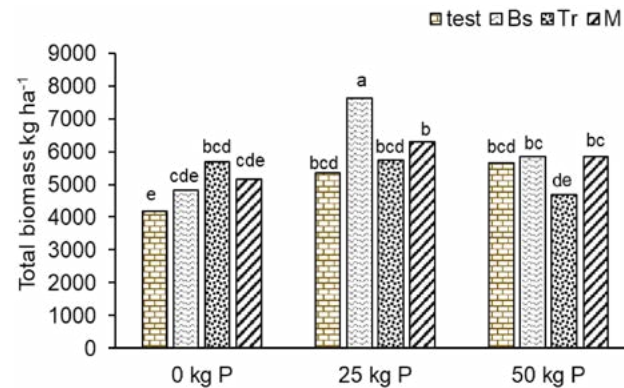
†Means with different letters within a column are statistically different (Fisher P≤0.05).

RL: root length, SD: stem diameter, FRW: fresh root weight, DRW: dry root weight, SDW: stem dry weight.

### Biomass Production

Maximum dry matter accumulation was recorded in plants treated with 25 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> (6,257 kg ha<sup>-1</sup>). However, this accumulation decreased slightly in plants fertilized with 50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> (5,520 kg ha<sup>-1</sup>) (Figure 2). These results are consistent with those reported by Alemu *et al.* (2018), who found that maximum dry matter production occurred in the cultivar fertilized with 69 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, attributing this effect to enhanced nutrient availability promoted by root development and biological nitrogen fixation. In addition, biofertilization was observed to differentially influence the pattern of biomass accumulation at each applied P rate. The interaction effect showed that the highest dry matter accumulation was recorded in plants treated with 25 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> and inoculated with *Bacillus subtilis* (7,639 kg ha<sup>-1</sup>) and mycorrhizae (6,304 kg ha<sup>-1</sup>). This accumulation declined in plants receiving the higher P rate, with no significant differences attributable to inoculation (Figure 2). In other crops, Quintarelli *et al.* (2025), Roussis *et al.* (2022), and Mohanty *et al.* (2021) reported that microbial biofertilizers stimulated root growth,

promoted higher nutrient uptake, and ultimately increased aboveground biomass and overall productivity.



**Figure 2.** Influence of phosphorus and biofertilizers in biomass production.

### Normalized Difference Vegetation Index (NDVI)

At present, this index is widely used to evaluate crop canopy characteristics (Reinermann *et al.*, 2020), leaf area index (Tan *et al.*, 2020), as well as nitrogen content (Elazab *et al.*, 2016). In this study, NDVI and SPAD values were recorded to monitor potential nutrient deficiencies and crop vigor throughout the growing season. NDVI values increased with increasing phosphorus application, reaching 0.86 at the pod-filling stage (75 DAP), and subsequently declined to 0.4 as the crop progressed toward maturity (Table 3). These results are consistent with those reported by Farías *et al.* (2023), who found that NDVI values in soybean fertilized with PK at two different times (at planting and post-planting) increased from the vegetative stage (V2), reached their maximum during the reproductive stage (R4), when leaf area index was highest, and then declined as the plants entered senescence due to chlorophyll degradation. No statistically significant differences were observed among treatments inoculated with biofertilizers. Nevertheless, the values recorded were consistent with those described above at the same phenological stages. The inoculation  $\times$  fertilization relationship revealed high NDVI values (0.86), particularly in treatments receiving 50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> combined with mycorrhizae. However, inoculation with *Bacillus* and mycorrhizae showed no effect in treatments without phosphorus application (Table 3).

In agreement with these findings, Mthiyane *et al.* (2024) reported the highest NDVI values (approximately 0.75) under inorganic fertilization, biofertilization, and combined organic fertilization + biofertilization, indicating adequate chlorophyll content and vigorous growth in rice. Likewise, Quintarelli *et al.* (2025) demonstrated that NDVI readings in tomato increased from 12 DAT to 36 DAT, reaching values of approximately 0.8, and subsequently declined following inoculation with two microbial biofertilizers (Mycosat F<sup>®</sup>: mycorrhizae + *Streptomyces*, and Mycoup<sup>®</sup>: mycorrhizae + rhizosphere bacteria).

**Table 3.** NDVI values as a function of time.

Treatments	Days after planting					
	15	30	45	60	75	90
0	0.71	0.81 b	0.81 b	0.81 b	0.58 b	0.33 c
25	0.73	0.84 a	0.85 a	0.84 a	0.65 a	0.42 b
50	0.73	0.84 a	0.86 a	0.84 a	0.70 a	0.48 a
( $p \leq 0.05$ )	NS	<0.001	<0.001	0.08	<0.001	<0.001
Bs	0.74	0.83	0.85	0.84 ab	0.63	0.39
Tr	0.73	0.84	0.85	0.84 ab	0.65	0.41
M	0.71	0.84	0.85	0.85 a	0.68	0.44
Control (test)	0.71	0.83	0.85	0.81 b	0.63	0.38
( $p \geq 0.05$ )	NS	NS	NS	0.1	NS	NS
<b>Interaction</b>						
50 M	0.70	0.84 ab	0.87 a	0.86 a	0.75 a	0.51 a
25 M	0.72	0.85 a	0.86 abc	0.85 ab	0.72 ab	0.51 a
50 Bs	0.74	0.85 a	0.86 ab	0.85 ab	0.69 abcd	0.47 a
50 test	0.71	0.85 a	0.87 ab	0.85 abc	0.70 abc	0.47 ab
50 Tr	0.71	0.84 ab	0.85 bcd	0.83 cde	0.67 abcd	0.46 ab
25 Tr	0.76	0.85 a	0.87 ab	0.85 abc	0.66 bcd	0.44 abc
25 Bs	0.73	0.83 abc	0.86 abc	0.85 ab	0.64 bcde	0.38 bcd
25 test	0.69	0.84 ab	0.84 cd	0.83 bcde	0.60 de	0.35 cd
0 Tr	0.72	0.83 ab	0.84 cd	0.84 abcd	0.61 cde	0.35 cd
0 test	0.74	0.81 cd	0.84 cd	0.81 e	0.61 de	0.33 d
0 Bs	0.76	0.80 d	0.83 d	0.82 de	0.57 e	0.33 d
0 M	0.73	0.82 bcd	0.84 cd	0.84 abcd	0.57 e	0.31 d
( $p \leq 0.05$ )	NS	0.03	0.009	0.01	0.003	<0.001

<sup>†</sup>Means followed by distinct letters are statistically different (Fisher  $p \leq 0.05$ ).

### Greenness Index (SPAD)

Statistically significant differences in SPAD values were observed at 60 and 90 DAP, with higher values recorded in treatments receiving elevated phosphorus rates. These values also increased as a function of inoculation ( $p \leq 0.05$ ), and the phosphorus  $\times$  biofertilizer interaction exerted a distinct influence, such that the highest values were not consistently associated with the same biofertilizer across treatments (Table 4). Several studies have indicated that SPAD values are directly associated with chlorophyll content, with readings ranging from 0 to 99 in proportion to chlorophyll concentration (Basyouni and Dunn, 2015). Mthiyane *et al.* (2024) recorded the highest chlorophyll content (33 to 47 SPAD units) in treatments combining organic fertilization and biofertilizers, surpassing the other fertilization treatments. Similarly, Redondo-Gómez *et al.* (2023) reported that biofertilizers influenced chlorophyll content as well as Fe and Zn uptake. Other studies have shown that biofertilizers promote chlorophyll synthesis by improving the bioavailability of N and Mg, thereby enhancing photosynthetic capacity (Sarkodee-Addo *et al.*, 2021; Shan *et al.*, 2023).

**Table 4.** Greenness index (SPAD) values as a function of time.

Treatments	Days after planting		
	30	60	90
0	35.2	28.1 b	21.8 b
25	35.3	29.3 ab	22.8 ab
50	36.4	29.8 a	23.5 a
( $p \geq 0.05$ )	NS	0.08	0.07
Bs	37.6 a	29.6 ab	23.6 a
Tr	35.2 b	30.1 a	29.6 a
M	34.7 b	28.6 ab	22.5 ab
Control (test)	35.0 b	27.9 b	21.4 b
( $p \leq 0.05$ )	0.04	0.06	0.04
<b>Interaction</b>			
0 Bs	37.9 a	28.7 abc	22.5 abcd
0 Tr	36.1 ab	30.0 ab	23.6 abc
0 M	33.7 bc	27.1 bc	21.1 cd
0 test	33.2 bc	26.7 c	20.0 d
25 Bs	37.4 a	30.1 ab	23.5 abc
25 Tr	35.8 ab	30.7 a	24.0 ab
25 M	31.9 c	28.2 abc	21.9 bcd
25 test	36.1 ab	27.9 abc	21.7 bcd
50 Bs	37.5 a	30.0 ab	23.5 abc
50 Tr	33.9 bc	29.6 abc	23.3 abc
50 M	38.5 a	30.6 a	24.6 a
50 test	35.8 ab	28.9 abc	22.5 abcd
( $p \geq 0.05$ )	0.02	0.1	0.04

<sup>†</sup>Means followed by distinct letters are statistically different (Fisher  $p \leq 0.05$ ).

### Yield and Its Components

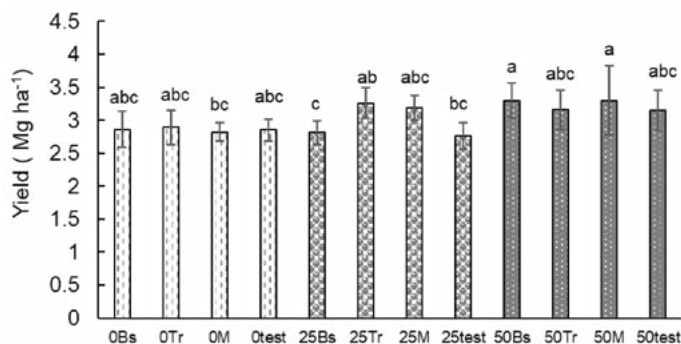
Yield components differed significantly in response to the applied phosphorus rates. The highest weight of 20 pods (272.5 g) was recorded in plants fertilized with 50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>. Grain weight was very similar in plants treated with 25 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> (183.5 g) and 50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> (192 g), whereas the lowest value was observed in the control plants. No statistically significant differences were detected in 100-grain weight (Table 5). In this regard, Alemu *et al.* (2018) reported a 100-grain weight of approximately 37.7 g plant<sup>-1</sup> and a total yield of 2,821 kg ha<sup>-1</sup> with the application of 69 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>. Uddin *et al.* (2018) found that the BARI Jharseem-3 variety, combined with 1.5 kg ha<sup>-1</sup> borax, produced the highest 1,000-seed weight (412.74 g), seed yield (1.54 Mg ha<sup>-1</sup>), and biological yield (4.59 Mg ha<sup>-1</sup>). Likewise, Mekonnen and Saliha (2018) reported that fertilization with 100 kg ha<sup>-1</sup> NPSZnB maximized grain yield, 100-grain weight, and harvest index in the common bean variety Hawassa Dume in southern Ethiopia. Furthermore, biofertilization showed that plants treated with mycorrhizae increased pod weight (272 g), grain weight (190 g), and 100-grain weight (44 g) (Table 5). The interaction effect revealed that plants treated with

50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> + Bs + mycorrhizae exhibited the greatest pod weight (302.6 g and 287 g). Grain weight was higher in plants treated with 25 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> + M (222 g) and 50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> + Bs, whereas 100-grain weight was highest (47 g) in plants treated with 25 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> + Tr (Table 5). It was also observed that unfertilized and non-inoculated plants attained a yield of 2.8 Mg ha<sup>-1</sup>. In contrast, plants fertilized with 25 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> and inoculated with Bs and mycorrhizae achieved the highest yield (3.1 Mg ha<sup>-1</sup>) compared with the remaining treatments. Plants treated with 50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> + Bs + mycorrhizae attained a slightly higher yield (3.3 Mg ha<sup>-1</sup>) (Figure 3). Gabre *et al.* (2020) reported that co-inoculation with *R. tropici* + *T. asperellum* increased the number of pods, the number of grains per pod, and the highest common bean yield (3,185.50 kg ha<sup>-1</sup>), whereas treatments inoculated with *B. subtilis* attained a yield of 3,152.64 kg ha<sup>-1</sup>. These findings are also consistent with those of Carrillo *et al.* (2020) and Wang *et al.* (2022), who reported that plant growth-promoting microorganisms (PGPM) enhanced plant vigor, stimulated flowering, and increased tomato yield. Similarly, Chávez-Rea and Vázquez-Guzmán (2021) reported that the application of 500 mL of *Bacillus subtilis* (NITO<sup>®</sup>) favored the yield of bean cv. Centenario (3.7 kg ha<sup>-1</sup>) and also increased the concentration of available phosphorus (352 ppm).

**Table 5.** Yield components of common bean.

Treatments	Dry weight of pods (g)	Grain dry weight (g)	Weight of 100 grains (g)
0	230 b	158 b	37.5 a
25	253 ab	183.5 a	39.4 a
50	272.5 a	192 a	40.2 a
(p≤0.05)	0.003	<0.0001	0.002
Bs	264 ab	180 ab	38 b
Tr	240 ab	165 b	44 a
M	272 a	196 a	44 a
control (test)	231 b	170 b	32 c
(p≤0.05)	0.01	<0.0001	<0.0001
<b>Interaction</b>			
0 Bs	244 bcdef	158 ef	36 gh
0 Tr	231 def	169 de	40.5 def
0 M	245 bcdef	162 de	41 cde
0 test	209 f	145 f	31 i
25 Bs	253 bcdef	174 d	38 fg
25 Tr	265 abcde	167 de	47 a
25 M	284 abc	222 a	43 bcd
25 test	265 abcde	172 de	33 hi
50 Bs	302.6 a	209 ab	37 g
50 Tr	224 ef	159 ef	44 b
50 M	287 ab	205 bc	43.8 bc
50 test	275.5 abcd	193 c	33 hi
(p≈0.05)	0.04	<0.0001	0.009

<sup>†</sup>Means followed by distinct letters are statistically different (Fisher p≤0.05).



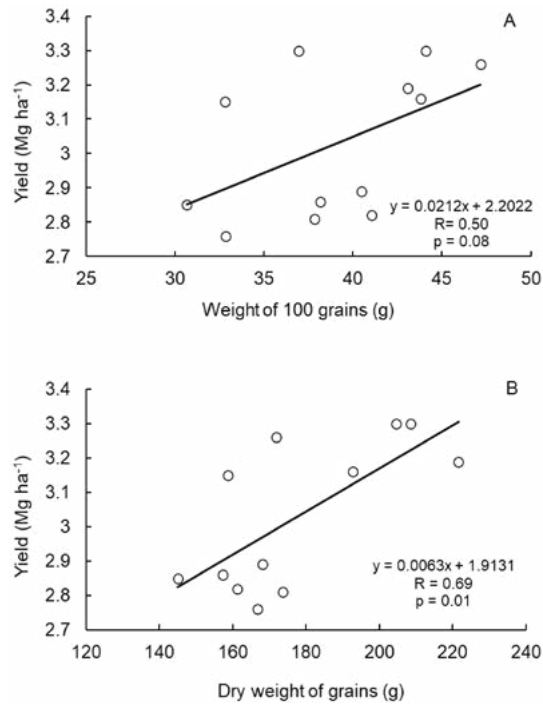
**Figure 3.** Influence of phosphorus and biofertilization on total yield.

### Relationship Between Yield and Its Components

Correlation analysis revealed a positive relationship between yield and 100-grain weight ( $r=0.50$ ). The heaviest grain sample (45 g) was associated with the highest yield ( $>3.0$  Mg ha<sup>-1</sup>) in plants fertilized with 50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> (Figure 4A). Likewise, a positive and significant correlation was observed between yield and total grain dry weight ( $r=0.69$ ). The highest yield values were associated with greater grain dry weight (Figure 4B). Arriagada *et al.* (2023) reported a positive correlation between 100-grain weight and yield in native lines from Central and South America. Similarly, Tola *et al.* (2023) indicated that total seed weight positively contributed to yield variability. Demessie *et al.* (2024) also found a positive and significant correlation between yield and the number of pods per plant, seeds per pod, and total biomass in 12 bean varieties grown at two locations in Ethiopia. Other studies have likewise reported a significant and positive correlation, particularly for components such as number of pods per plant and grain yield (Contreras-Rojas *et al.*, 2024; Kalauni and Dhakal, 2020; Jasim and Esho, 2020). In contrast, Tapia *et al.* (2022) found that the percentage reduction in pods was negatively related to the percentage reduction in yield. Similarly, Díaz *et al.* (2022) reported a negative correlation between yield and its components in common bean. Finally, Gabre *et al.* (2020) stated that yield was directly related to biomass, root dry weight, 1,000-grain weight, and grains per plant, arguing that the use of plant growth-promoting rhizobacteria (PGPR) + *Rhizobium* stimulated root development, biological nitrogen fixation, and nutrient uptake, which ultimately had a positive impact on total yield.

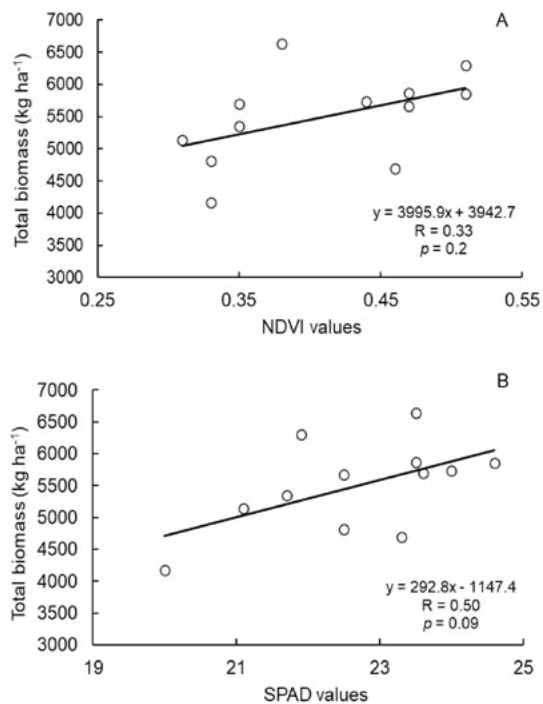
### Relationship Between Biomass and NDVI-SPAD Values

As shown by the data, NDVI values (approximately 0.50) were positively correlated with the highest biomass production at maturity (5,500 kg ha<sup>-1</sup>) in plants inoculated and fertilized with 50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> (Figure 5A). In this regard, Farías *et al.* (2023) found a positive correlation between soybean biomass (5,000 kg ha<sup>-1</sup>) and NDVI values (0.90). Werner *et al.* (2018) reported an NDVI saturation effect during the reproductive stages of soybean, characterized by stable NDVI values despite increased shoot biomass. In addition, Andrade *et al.* (2022) found a positive relationship between NDVI values and biomass, leaf area index, and soil cover fraction. Likewise, Sarmiento *et al.* (2020) used NDVI values to predict phenological stages and biomass production in soybean.



**Figure 4.** Correlation of yield and its components.

A positive, although not significant, correlation was also observed between SPAD values (24-25) and the highest biomass accumulation (5,500 kg ha<sup>-1</sup>) (Figure 5B). Szulc *et al.* (2021) found that humidity and heat influenced SPAD leaf greenness, whereas direct planting reduced chlorophyll content in silage maize.



**Figure 5.** Correlation of biomass with NDVI (A) and SPAD values (B).

## CONCLUSION

The application of phosphorus at rates of 50 kg ha<sup>-1</sup> or lower, in combination with biofertilizers, is recommended to improve the agronomic performance, overall growth, and yield of common bean cultivated in undisturbed soils under temperate climatic conditions. Further research should evaluate different plant growth-promoting microorganisms across diverse soil types under reduced fertilization regimes in order to determine whether yield can be sustained.

## REFERENCES

- Abebe, A., & Mekonnen, Z. (2019). Common Bean (*Phaseolus vulgaris* L.) Varieties Response to Rates of Blended NPKSB Fertilizer at Arba Minch, Southern Ethiopia. *Advances in Crop Science and Technology*, 7(3), 1-8.
- Obssi, A., Abdulahi, J., & Tana, T. (2022). Effect of phosphorus fertilizer rates and plant density on yield And yield related traits of common bean (*Phaseolus vulgaris* L.) In Dangur district, North- Western Ethiopia. *World Rural Observations*, 14(1), 58-84. <https://doi.org/10.7537/marswro140122.07>
- Shanka, D., Dechassa, N., & Gebeyehu, S. (2016). Response of common bean cultivars to phosphorus application in Boloso Sore and Sodo Zuria Districts, Southern Ethiopia. *East African Journal of Sciences*, 9(1), 49-60. <https://doi.org/10.4314/eajsci.v9i1>
- Hossain, F., Malik, A.U., Haji, M.A., & Malghani, A.L. (2011). Growth and yield response of two cultivars of mung bean (*Vigna radiata* L.) to different potassium levels. *The Journal of Animal and Plant Sciences*, 21(3), 622-625. <https://www.researchgate.net/publication/2677905691>
- Ruelas, J.D.R.I., Á.R. Olivas, F. Núñez-Ramírez, J.F. Velázquez & F.V. Guerrero. (2018). Effect of phosphorus rates and *Bacillus subtilis* on growth, dry matter production and yield of common bean in Sinaloa, Mexico. *International Journal of Agriculture and Biology*, 20, 1818-1824. <https://doi.org/10.17957/IJAB/15.0698>
- Sharma, V., Kaur, J., & Sharma, S., (2020). Plant growth promoting rhizobacteria: potential for sustainable agriculture. *Biotechnology Vegetal*, 20(3): 159-165.
- Pirttilä, A.M., Mohammad Parast Tabas, H., Baruah, N., & Koskimäki, J.J. (2021). Biofertilizers and Biocontrol Agents for Agriculture: How to Identify and Develop New Potent Microbial Strains and Traits. *Microorganisms*, 9, 817. <https://doi.org/10.3390/microorganisms9040817>
- Gonzales-Marquetti, I., Yinfante-Martínez, D., Gorrita, S., Morales-Mena, B., Napoles, M.C., Delgado-Oramas, B.P., & Martínez-Coca, B. (2021). Effects of *Trichoderma asperellum* Samuels, Lieckfeldt & Nirenberg and Azofert® on growth and development of *Phaseolus vulgaris* L. *Revista de Protección Vegetal*, 36(3), 1-9. <https://www.censa.edicionescervantes.com/index.php/RPV/article/view/1171/1941>
- Mora, J., Regalado, G., De la Cruz, A., Fung-Corro, J.R. (2024). Evaluation of the use of *Trichoderma* sp. and mountain microorganisms as biostimulants for the growth of *Phaseolus* sp. *Revista Ciencia e Ingeniería*, 17(2), e12809589. <https://doi.org/10.5281/zenodo.12809589>
- Mohamed, I., Eid, K.E., Abbas, M.H.H., Salem, A.A., Ahmed, N., Ali, M., Shah, G.M., & Chen, F. (2019). Use of plant growth promoting Rhizobacteria (PGPR) and mycorrhizae to improve the growth and nutrient utilization of common bean in a soil infected with white rot fungi. *Ecotoxicology and Environmental Safety*, 171, 539-548. <https://doi.org/10.1016/j.ecoenv.2018.12.100>
- Hoyos-Carvajal, L., Cardona, A., Osorio, W., & Ordúz, S. (2015). The effect of various isolates of *Trichoderma* spp. on nutrient uptake in beans (*Phaseolus vulgaris*) in two soil types. *Revista Colombiana de Ciencias Hortícolas*, 9(2), 268-278. <http://dx.doi.org/10.17584/rcch.2015v9i2.4183>
- Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias-INIFAP, (2017). [https://vun.inifap.gob.mx/VUN\\_MEDIA/BibliotecaWeb/\\_media/\\_agendas/4142\\_4839\\_Agenda\\_T%C3%A9cnica\\_Sinaloa\\_2017.pdf](https://vun.inifap.gob.mx/VUN_MEDIA/BibliotecaWeb/_media/_agendas/4142_4839_Agenda_T%C3%A9cnica_Sinaloa_2017.pdf)
- Atland, J.E., Gilliam, C.H., Keever, G.J., Edwards, J.H., Sibley, J.L., & Fare, D.C. (2003). Rapid determination of nitrogen status in pansy. *Hortscience* 38: 537-541.
- Torres-Bojórquez, A.I., Morales-Maza, A., Grijalva-Contreras, R.L., Cervantes-Díaz, L., & Núñez-Ramírez, F. (2017). Hierro foliar y acolchado plástico en *Capsicum chinense* Jacq. infectado con tospovirus. *Revista Mexicana de Ciencias Agrícolas*, 8(2), 369-380. <https://www.scielo.org.mx/pdf/remexca/v8n2/2007-0934-remexca-8-02-369.pdf>

- Johansen, B., & Tømmervik, H. (2014). The relationship between phytomass, NDVI and vegetation communities on Svalbard. *International Journal of Applied Earth Observation and Geoinformation*, 27(A), 20-30. <https://doi.org/10.1016/j.jag.2013.07.001>
- Shapiro, S.S., & Wilk, M.B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, 52(3/4), 591-611. <https://doi.org/10.2307/2333709>
- Minitab, 2018. Statistical software. PA: Minitab, Inc.
- Alemu, A., Nebiyu, A., & Getachew, M. (2018). Growth and yield of common bean (*Phaseolus vulgaris* L.) cultivars as influenced by rates of phosphorus at Jimma, Southwest Ethiopia. *Journal of Agricultural Biotechnology and Sustainable Development*, 10(6), 104-115. <http://dx.doi.org/10.5897/JABSD2018.0312>
- Gabre, V.V., Wilson, S.V., Moraes, B.A., Furmam, F.G., Galvão, C.W., Gonçalves, D.R.P., & Etto, R. M. (2020). Multiple Effect of Different Plant Growth Promoting Microorganisms on Beans (*Phaseolus vulgaris* L.) Crop. *Brazilian Archives of Biology and Technology*, 63, no.spe: e20190493. <http://dx.doi.org/10.1590/1678-4324-solo-2020190493>
- Rodríguez-González, Á., Carro-Huerga, G., Guerra, M., Mayo-Prieto, S., Porteous-Álvarez, A.J.; Lorenzana, A., Campelo, M.P., Fernández-Marcos, A., Casquero, P.A., & Gutiérrez, S. (2022). Spores of *Trichoderma* Strains over *P. vulgaris* Beans: Direct Effect on Insect Attacks and Indirect Effect on Agronomic Parameters. *Insects*, 13, 1086. <https://doi.org/10.3390/insects13121086>
- Nayeema, Jan., Wasim Sajad, Malik., Abdul Hamid, Wani., Mansoor Ahmad, Malik., Shaiesta, Hassan., & Mohd Yaqub, Bhat. (2022). *In vitro* antagonistic activity of *Trichoderma viride* isolates against *Sclerotinia sclerotiorum* and their role in growth promotion of common bean. *Journal of Biopesticides*, 15(1), 20-25. <https://jbiopestic.com/journals/20-25.pdf>
- Quintarelli, V., Borgatti, D., Baretta, M., Stazi, S.R., Allevato, E., Pancaldi, S., Baldisserotto, C., Mancinelli, R., Tedeschi, P., Radicetti, E., & Ben-Hassine, M. (2025). Microbial biofertilizers and algae-based biostimulant affect fruit yield characteristics of organic processing tomato. *Journal of the Science of Food and Agriculture*, 105, 530-539. <https://doi.org/10.1002/jsfa.13851>
- Roussis, I., Beslemes, D., Kosma, C., Triantafyllidis, V., Zotos, A., & Tigka, E. (2022). The influence of arbuscular mycorrhizal fungus *Rhizophagus irregularis* on the growth and quality of processing tomato (*Lycopersicon esculentum* Mill.) seedlings. *Sustainability*, 14(15), 9001. <https://doi.org/10.3390/su14159001>
- Mohanty, P., Singh, P.K, Chakraborty, D., Mishra, S., & Pattnaik, R. (2021). Insight Into the Role of PGPR in Sustainable Agriculture and Environment. *Front Sustain Food Syst*, 5, 667150. <https://doi.org/10.3389/fsufs.2021.667150>
- Reinermann, S., Asam, S., & Kuenzer, C. (2020). Remote sensing of grassland production and management-A review. *Advances of remote sensing in pasture management*, 12(2), 1949. <https://dx.doi.org/10.3390/rs12121949>
- Tan, C.W., Zhang, P., Zhou, X.X., Wang, Z.X., Xu, Z.Q., & Mao, W. (2020). Quantitative monitoring of leaf area index in wheat of different plant types by integrating NDVI and Beer-Lambert law. *Scientific Reports*, 10, 929. <https://doi.org/10.1038/s41598-020-57750-z>
- Elazab, A., Ordóñez, R.A., Savin, R., Slafer, G.A., & Araus, J.L. (2016). Detecting interactive effects of N fertilization and heat stress on maize productivity by remote sensing techniques. *European Journal of Agronomy*, 73, 11-24. <https://doi.org/10.1016/j.eja.2015.11.01>
- Fariás, G.D., Bremm, C., Bredemeier, C., de Lima Menezes, J., Alves, L.A., Tiecher, T., Martins, A.P, Fioravanco, G.P., da Silva, G.P., & de Faccio Carvalho, P.C. (2023). Normalized Difference Vegetation Index (NDVI) for soybean biomass and nutrient uptake estimation in response to production systems and fertilization strategies. *Frontiers in Sustainable Food Systems*, 6, 959681. <https://doi.org/10.3389/fsufs.2022.959681>
- Mthiyane, P., Aycan, M., & Mitsui, T. (2024). Integrating Biofertilizers with Organic Fertilizers Enhances Photosynthetic Efficiency and Upregulates Chlorophyll-Related Gene Expression in Rice. *Sustainability*, 16, 9297. <https://doi.org/10.3390/su16219297>
- Basyouni, R., Dunn, B., & Goad, C. (2015). Use of nondestructive sensors to assess nitrogen status in potted poinsettia (*Euphorbia pulcherrima* L. (Willd. ex Klotzsch)) production. *Scientia Horticulturae*, 192, 47-53. <https://doi.org/10.1016/j.scienta.2015.05.011>
- Redondo-Gómez, S., Mesa-Marín, J., Pérez-Romero, J.A., Mariscal, V., Molina-Heredia, F.P., Álvarez, C., Pajuelo, E., Rodríguez-Llorente, I.D., & Mateos-Naranjo, E. (2023). Plant Growth Promoting Rhizobacteria Improve Rice Response to Climate Change Conditions. *Plants*, 12, 2532. <https://doi.org/10.3390/plants12132532>

- Sarkodee-Addo, E., Tokiwa, C., Bonney, P., Aboagye, D.A., Yeboah, A., Abebrese, S.O., Bam, R., Nartey, E.K., Okazaki, S., & Yasuda, M. (2021). Biofertilizer Activity of *Azospirillum* sp. B510 on the Rice Productivity in Ghana. *Microorganisms*, 9, 2000. <https://doi.org/10.3390/microorganisms9092000>
- Shan, S., Wei, Z., Cheng, W., Du, D., Zheng, D., & Ma, G. (2023). Biofertilizer Based on Halotolerant Microorganisms Promotes the Growth of Rice Plants and Alleviates the Effects of Saline Stress. *Frontiers in Microbiology*, 14, 1165631. <https://doi.org/10.3389/fmicb.2023.1165631>
- Uddin, F.M.J., Hassan, N., Rahman, M.R., & Uddin, M.R. (2018). Effect of bio fertilizer and weeding regimes on yield performance of bush bean (*Phaseolus vulgaris* L.). *Archives of Agriculture and Environmental Science*, 3(3), 226-231. <https://dx.doi.org/10.26832/24566632.2018.030303>
- Mekonnen, L., & Saliha, J. (2018). The Response of Common Bean (*Phaseolus vulgaris* L.) to Various Levels of Blended Fertilizer. *International Journal of Research in Agriculture and Forestry*, 5(7), 15-20.
- Carillo, P., Kyriatzi, A., Kyriacou, M.C., Dell'Aversana, E., Fusco, G.M., Corrado, G., & Roupheal, Y. (2020). Biostimulatory Action of Arbuscular Mycorrhizal fungi enhances productivity, functional and sensory quality in 'Piennolo del Vesuvio' Cherry tomato landraces. *Agronomy*, 10(6), 911. <https://doi.org/10.3390/agronomy10060911>
- Wang, L., Chen, X., Wang, S., Du, Y., Zhang, D., & Tang, Z. (2022). Effects of arbuscular mycorrhizal symbiosis on the growth and reproduction of cherry tomato can be persistent to the next generation. *European Journal of Soil Biology*, 112, 103429. <https://doi.org/10.1016/j.ejsobi.2022.103429>
- Chávez-Rea, M.A., & Vásquez-Guzmán, J.E. (2021). Efecto de la aplicación de tres dosis de *Bacillus subtilis* en tres variedades de fréjol arbustivo. Creative Commons Atribución-NoComercial 4.0 Internacional, 1-11. <https://doi.org/10.29166/siembra.v8i2.2657>
- Arriagada, O., Arévalo, B., Cabeza, R.A., Carrasco, B., & Schwember, A.R. (2023). Meta-QTL Analysis for Yield Components in Common Bean (*Phaseolus vulgaris* L.). *Plants*, 12, 117. <https://doi.org/10.3390/plants12010117>
- Tola, M., Tesso, B., & Amsalu, B. (2023) Genetic Variability and Association of Yield and Yield-Related Traits under Moisture Stress in Common Bean Genotypes (*Phaseolus vulgaris* L.) at Melkassa and Miesso, Ethiopia. *Advances in Agriculture*, <https://doi.org/10.1155/2023/8697497>
- Demessie, F., Gebresilassie, W., Garedew, W., & Shifaraw, G. (2024). Evaluation of Common Bean (*Phaseolus vulgaris* L) Cultivars for Yield and Yield-Related Traits at Sekoru District, South Western Ethiopia. *American Journal of Applied Scientific Research*, 10(1), 1-16. <https://doi.org/10.11648/j.ajasr.20241001.11>
- Contreras-Rojas, M., Guzmán, D., Mercado, S., & Salazar-Villareal, F. (2024). Path analysis of yield and yield components in snap bean (*Phaseolus vulgaris* L.) genotypes. *Euphytica*, 220(36). <https://doi.org/10.1007/s10681-024-03298-2>
- Kalauni, S., & Dhakal, D. (2020). Correlation and Path Coefficient Analysis of Seed Yield and Yield Components of French Bean (*Phaseolus vulgaris* L.) Genotypes in Sub-tropical Region. *Turkish Journal of Agriculture. Food Science and Technology*, 8(9), 1928-1934. <https://doi.org/10.24925/TURJAF.V8I9.1928-1934.3528>
- Jasim, E.A., & Esho, K.B. (2020) Correlation and Path Coefficient Analysis in Some Varieties of Phaseolus (*Phaseolus vulgaris* L.). *International Journal of Science and Research*, 9(8), 948-952. <https://doi.org/10.21275/SR20812140529>
- Tapia, G., Méndez, J., Inostroza, L., & Lozano, C. (2022). Water Shortage Affects Vegetative and Reproductive Stages of Common Bean (*Phaseolus vulgaris*) Chilean Landraces, Differentially Impacting Grain Yield Components. *Plants*, 11, 749. <https://doi.org/10.3390/plants11060749>
- Diaz, S., Polania, J., Ariza-Suarez, D., Cajiao, C., Grajales, M., Raatz, B., & Beebe, S.E. (2022). Genetic Correlation Between Fe and Zn Biofortification and Yield Components in a Common Bean (*Phaseolus vulgaris* L.). *Frontiers in Plant Science*, 12, 739033. <http://dx.doi.org/10.3389/fpls.2021.739033>
- Werner, F., Aguiar e Silva, M.A., Ferreira, A.S., Neumaier, N., & Balbinot, A.A. (2018). Dinâmica da cobertura do solo por plantas e NDVI de cultivares de soja em diferentes arranjos espaciais de plantas. *Colloquium Agrariae*, 14, 183-190. <https://doi.org/10.5747/ca.2018.v14.n2.a220>
- Andrade, T.G., Andrade-Junior, A.S., Souza, M.O., Lopes, J.W.B., & Vieira, P.F.M.J. (2022). Soybean yield prediction using remote sensing in southwestern Piauí state, Brazil. *Revista Caatinga*, 35, 105-116. <https://doi.org/10.1590/1983-21252022v35n111rc>
- Sarmiento, C.M., Coltri, P.P., Alves, M.C., & Carvalho, L.G. (2020). A spectral agrometeorological model for estimating soybean grain productivity in Mato Grosso, Brazil. *Engenharia Agrícola*, 40, 405-412. <https://doi.org/10.1590/1809-4430-eng.agric.v40n3p405-412/2020>

Szulc, P., Bocianowski, J., Nowosad, K., Zielewicz, W., & Kobus-Cisowska, J. (2021). SPAD Leaf greenness index: green mass yield indicator of Maize (*Zea mays* L.), Genetic and Agriculture Practice Relationship. *Plants*, 10, 830. <https://doi.org/10.3390/plants10050830>

