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Agronomic Response of Common Bean "Azufrado Reyna" to Different Fertilization Sources
Respuesta Agronómica de Frijol Común "Azufrado Reyna" a Diferentes Fuentes de Fertilización

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SUMMARY

Common bean (*Phaseolus vulgaris* L.) is an important legume that constitutes part of the daily feeding in countries like Mexico. In Northern Sinaloa, bean yield remains low from its potential due to factors associated to agronomic management and the environment. Therefore, a field experiment was conducted in this area in order to investigate the response of common bean "Azufrado Reyna" to four different fertilization sources and rates on growth, dry matter production and yield. The experiment was conducted in a randomized complete block design with four replications. Based on the results, the fertilization sources enhanced the plant height in treatments with urea and Nitrofoska Triple 16® at the stage of pod filling (90 dap), while, plants under organic fertilization showed the lowest height throughout the season. Also, the widest stem diameter was attained at 60 dap in treatments with triple 16 application. The fertilizer sources did not influence growth index at stages of flowering to pod filling, the average values were 42 and 51 cm respectively. Nevertheless, the lowest growth index values were observed in the treatments with organic fertilization. Plants with bulk blend 30-10-12 accumulated the highest amount of biomass (6656 kg ha^{-1}), while the lowest accumulation (3391 kg ha^{-1}) was recorded on treatments with organic blend. NDVI values were not affected by fertilization source; in contrast to the SPAD lectures that were affected by the source and rate at 45, 90 and 105 dap. The highest yield was obtained on treatments with Triple 16 (3.5 Mg ha^{-1}), whereas, treatments with urea and organic fertilization had very similar yields (1.8 Mg ha^{-1}) and (1.6 Mg ha^{-1}) respectively. Also, treatments receiving fertilization with bulk blend 30-10-12 and Triple 16 showed that a highest biomass production was strongly related with final yield.

Index words: *dry matter production, yield, growth.*

RESUMEN

El frijol común (*Phaseolus vulgaris* L.) es una leguminosa que constituye parte de la alimentación diaria in países como México. En el norte de Sinaloa, el rendimiento de este cultivo se encuentra por debajo de su potencial debido a factores asociados al manejo agronómico y al ambiente. Se realizó un experimento con el propósito de investigar la respuesta del frijol común "Azufrado Reyna" a cuatro diferentes fuentes y dosis de fertilización en crecimiento, producción de materia seca y rendimiento. El experimento se condujo en un diseño de bloques completos al azar con cuatro repeticiones. Los resultados muestran que las fuentes de fertilización aumentaron

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la altura de planta en tratamientos con urea y Nitrofoska Triple 16® en la etapa de llenado de vaina (90 dds), mientras que las plantas con fertilización orgánica mostraron la menor altura. Además, el mayor diámetro de tallo se obtuvo a los 60 dds en tratamientos con triple 16. Las fuentes de fertilización no influenciaron el índice de crecimiento en etapas de floración hasta llenado de vaina, los valores promedio fueron de 42 a 51 cm respectivamente. No obstante, los menores valores de índice de crecimiento se observaron en los tratamientos con fertilización orgánica. Las plantas tratadas con 30-10-12 produjeron mayor cantidad de biomasa (6656 kg ha^{-1}), mientras que la menor acumulación (3391 kg ha^{-1}) fue en tratamientos con fertilización orgánica. Los valores de NDVI no fueron afectados por la fuente de fertilización, a diferencia de las lecturas SPAD a los 45, 90 y 105 dds. El mayor rendimiento se encontró en tratamientos con triple 16 (3.5 Mg ha^{-1}), los tratamientos con urea y fertilización orgánica tuvieron rendimientos similares (1.8 Mg ha^{-1} y 1.6 Mg ha^{-1}). Además, los tratamientos que recibieron fertilización con la mezcla 30-10-12 y Triple 16 mostraron que la mayor producción de biomasa estuvo relacionada con el rendimiento final.

Palabras clave: *producción de materia seca, rendimiento, crecimiento.*

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is a very important legume because it is highly consumed in many countries as a source of proteins, carbohydrates and minerals (Kumar, Kumar y Khan, 2020). The main advantage of this crop relies on its adaptation to a wide range of climatic conditions. Yield potential remains low in many places due to several factors that include water scarcity, low yielding varieties, inappropriate management practices (fertilization, irrigation), low soil fertility and the presence of pests and diseases (Uddin, Hassan, Rahman, and Uddin, 2018). According to Obssi, Abdullahi, and Tana (2022), the yield potential of this crop is influenced by soil fertility especially the level of phosphorous and nitrogen because both are used to express its genetic potential and to influence nodulation and N_2 fixation. Also, reports by Shanka, Dechassa, and Gebeyehu (2015) and Kasinath and Parama (2015) stated that genetic and physiological potential of crop plants vary on nutrient use efficiency.

Peres-Soratto, Aranda, de Freitas, and Nantes (2017) found that lower plant densities (5 and 7 plants m^{-1}) increased aboveground dry matter production and the number of pods per plant and did not reduce the grain yield. They also mentioned that without N fertilization, reduction of plant density decreased N concentration in common bean leaves. Other works mention that phosphorus has become the most limiting nutrient and its limited uptake by plants has limited grain production in common bean. In that sense, application of optimum fertilizer rates is essential for high yield and quality of grains. However, the response of the crop to the source and amount of nutrients varies with location, climate, soil type and stage of growth.

Obssi *et al.* (2022), evaluated different rates of P (0, 23, 46, 69 and 92 kg P_2O_5 ha^{-1}) and different plant densities; they found that rate of 46 kg P_2O_5 ha^{-1} and density of 166 667 plants ha^{-1} increased grain yield and all yield components in soils of Ethiopia. Abebe (2017) found that application of inoculants and phosphorus significantly improved yield and related traits of common bean. Different authors have reported the effect of NPKSB (nitrogen, phosphorus, potassium, sulfur and boron) fertilizers on common bean growth and yield (Wossen, 2017). In this aspect, Abebe and Mekonnen (2019) found high nodulation, plant height, aboveground dry biomass, number of pods per plant, hundred seed weight and grain yield attained from blended fertilizer rate of 41-46-30-7-0.1 NPKSB kilograms per hectare.

Chekanai, Chikowo, and Vanlauwe (2018) found that application of N or P equally increased common bean grain yield with no significant benefits of adding both nutrients. They argued that most growers should invest more in P fertilizers for common bean than in N due to the direct benefit of P in improving cropping system performance. Actually, fertilization of common bean in Sinaloa, relies mostly on N applications; while P is applied in most cases without an appropriate rate to meet crop demand. Therefore, the objectives of this study consisted of evaluating the performance of different fertilization sources and rates on growth and yield of common bean "Azufrado Reyna" under temperate climate conditions in winter.

MATERIALS AND METHODS

Description of the Study Area

A field experiment was conducted during the winter season 2022-2023 at Facultad de Agricultura del Valle del Fuerte. The weather is hot during summer (maximum temperatures up to 40 °C) and moderate cold during winter (12-30 °C). The annual precipitation ranges between 700-750 mm and its distribution are highly variable. Soil tillage techniques were those employed by growers of the region. A composite surface 30 cm soil samples were collected before fertilization. The physical and chemical properties are described in Table 1.

Planting and Fertilization

Planting was realized on a moistened soil (November 3rd, 2023) with a density of 11 seeds m^{-1} with variety "Azufrado Reyna". Irrigation scheduling was managed by the water balance method (Sifuentes, Macías, Quintana, and González, 2012) which estimates the depletion levels in the root zone. Irrigation targets were set as a 50% depletion of plant available water. Besides, Insecticide applications (Sivanto®) were performed to control whitefly (*Bemisia tabaci* Gennadius) and aphids at a rate of 2.5 L ha^{-1}. Weeds were manually controlled throughout the season.

Treatments and Experimental Design

Treatments consisted on four fertilization sources: T1: Bulk blend (30-10-12®, Quimagro S. A. de C.V.) 400 kg ha^{-1}, T2: Nitrofoska Triple 16® Eurochem group, 500 kg ha^{-1}, T3: organic blend (local formulation) 20 L ha^{-1}, T4: control, (urea® Tepeyac S.A de C.V.) 200 kg ha^{-1}. The experiment was arranged in a randomized complete block design with four replications. The experimental unit had a dimension of 32 square meters.

Table 1. Soil fertility analysis.

pH	7.2
Texture	Clay loam
E.C. 25 °C (dS m^{-1})	1.38
Organic matter (%)	0.48
Bulk density	1.15 g cm^{-3}
MACRONUTRIENTS	mg kg^{-1}
Nitrógen (NO_3^-)	365
Soluble Phosphorus (PO_4^-)	12
Soluble K	28
Exchangeable K	387
Exchangeable Ca	1900
Exchangeable Mg	540
Sodium	184
MICRONUTRIENTS	
Iron	8.60
Manganese	12.32
Copper	1.60
Zinc	1.23

Measurements

Plant measurements were made from five plants of each treatment at every other week representing the following stages of growth: third trifoliate, flowering, pod filling and physiological maturity. Such parameters were plant height (measuring the length of the longest branch from the base to the apex), width of canopy and stem diameter.

NDVI values (normalized difference vegetation index) were measured by Greenseeker handheld crop sensor (Trimble® Navigation Ltd., Sunnyvale, CA) and can be used as an indicator of chlorophyll, biomass and nutrient in leaf tissue. This device was placed at approximately 50 cm above plant canopy on a row segment and generate values between -1 and +1, where vegetated areas exhibit positive values, while non-vegetated areas exhibit lower or negative values (Johansen and Tømmervik, 2014).

The SPAD readings were taken as an average of three different leaf readings located in the middle of the plant, and in the middle of the leaf excluding the midrib.

Growth index was realized following the methodology proposed by Atland *et al.* (2003) GI = [(height + width (east to west) + width (north to south)/3)].

Fresh matter sampling consisted on harvesting 0.16 m^2 of complete plants per plot. Plant material was weighed and then dried in a forced air oven (70 °C) and newly weighed. At the end of experiment, yield and its components were determined from two central rows. Numbers of pods per plant were counted, pods were threshed by hand and seeds were counted on twenty pods. Grain yield was corrected for 14% moisture content after determining humidity level with a grain moisture tester (Wile 55®).

Statistical Analysis

All data was subject to an appropriate analysis of variance. Treatment mean differences were separated using Tukeys' least significance difference (LSD) test at ($P \leq 0.05$), (Minitab, 2017). Pearson correlation analysis were also realized and tested on significance level.

RESULTS AND DISCUSSION

According to results, statistical differences ($P < 0.05$) were found in plant height on treatments receiving bulk blend (30-10-12) and organic fertilization at 30 dap (days after planting). However, treatments with triple 16, 30-10-12 and urea showed a similar trend in height except for treatments that received organic fertilization at 45 and 60 dap. The highest plant height was observed in treatments with urea and triple 16 at the stage of pod filling (90 dap). After that period, the height of plant decreased in all treatments. It was also observed that plants under organic fertilization showed the lowest height throughout the season (Figure 1a).

On the other hand, no statistical differences ($P > 0.05$) were found in stem diameter early in the season (30 dap) for all treatments applied. However, differences were found in later stages specifically in treatments that received organic fertilization and triple 16; while treatments with urea and 30-10-12 showed no variations in stem diameter all over the season. It was observed that the widest stem diameter was attained at 60 dap in treatments with triple 16 application (Figure 1b). According to previous works by Meseret and Amin (2014) increasing phosphorus rates (40 kg ha^{-1}) had a non-significant response of plant height, arguing the nutrient interactions affecting the availability of other nutrients for plant uptake.

Accordingly, Shumi, Alemayehu, Afeta, and Debelo (2018) stated that increasing rates of P levels in blended NPS fertilizer up to 150 kg ha^{-1} enhanced in plant height (56.79 cm), while the lowest plant height (38.01 cm) was recorded on the control. On the other hand, Tamayo-Aguilar, Juárez, Capdevila, Lescaille, and Terry (2020) reported that plant height and stem diameter increased on treatments with application of biofertilizers (*Rhizophagus irregularis* + Spiruvins) at 30 and 45 dap; arguing that the positive effect could be related to the bioactive compounds that promoted nutrient uptake and translocation as previously reported by Calero-Hurtado, Pérez, Quintero, Olivera, and Peña (2019) and Martínez-Sánchez *et al.* (2017). Other works by Colás-Sánchez, Díaz, Rodríguez, Gatorno, and Rodríguez (2018) reported that plant height increased by 50% over the control plants at 21 dap; While, Aguirre-Medina, Yeekón, and Espinosa (2019), found significant values of stem diameter of Primavera tree (*Tabebuia donnell-smithii*) when applying organic fertilizers + mycorrhizae under greenhouse conditions.

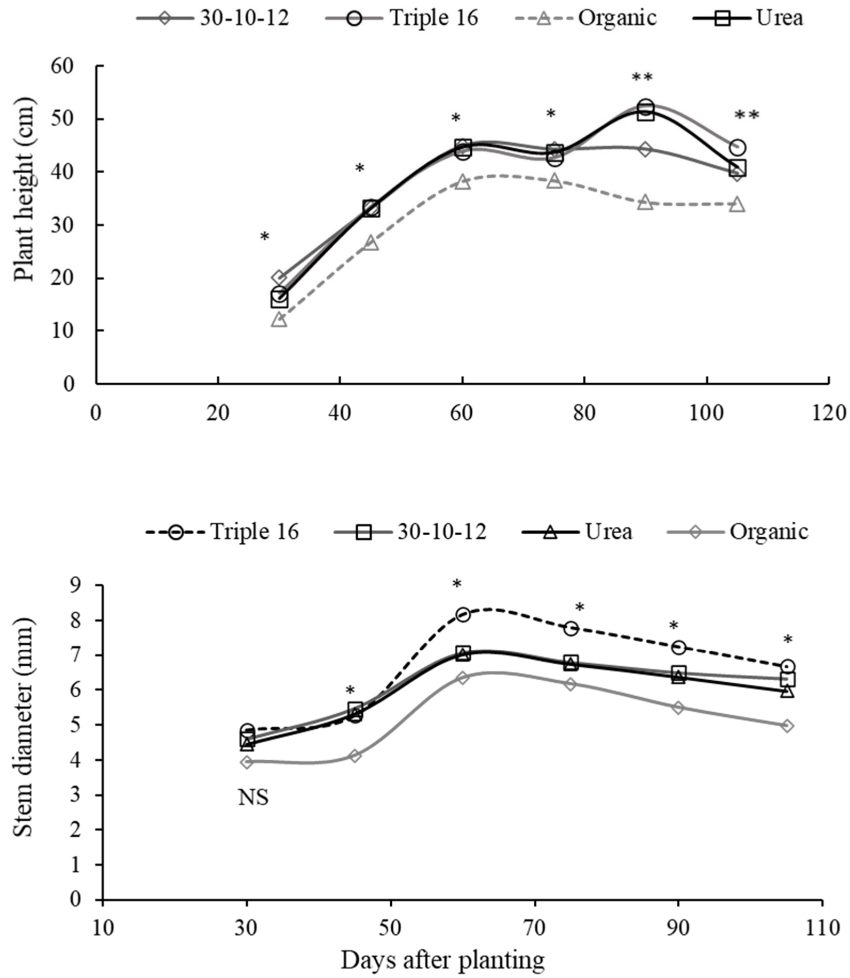

Figure 1. Plant height (a) and stem diameter (b) of common bean as a function of time.

Espinoza-Galaviz *et al*. (2023) reported that plant height increased 16.8% with application of humic and fulvic acids; while, El-Sawy, Marzouk, El-Tohamy, and Abou (2020) reported that plant height enhanced with different rates of fulvic acids on three varieties. Also, Mekonnen and Saliha (2018) found plant height increased on treatments with 100 kg ha^{-1} and 150 kg ha^{-1} of NPSZnB (17.8% N, 35.7% P_2O_5, 7% S, 2.2% Zn, 0.1% B) applications. Other works by Nebret and Nigussie (2017) reported that increasing nitrogen from 0 to 23 and 46 kg N ha^{-1}, plant height enhanced by about 5.4 and 9%, respectively. Nevertheless, when applying beyond 100 kg ha^{-1} drastically decreased plant height. The same pattern was also observed by Kumar, Kumar, and Kumar (2023) who exhibited that foliar application of Zinc (0.5%) and Boron (0.1%) increased the number of branches, plant height and yield attributes of chickpea.

In regards the growth index pattern, the treatments influenced this parameter as a function of time ($P < 0.05$). It was observed an initial period of slow growth at third trifoliate increasing rates at 30 dap, reaching a plateau at the beginning of pod filling stage (60 dap) and then declining as the crop progressed to maturity (100 dap), (Table 2). It was observed that treatments did not influence growth index at stages of flowering (45 dap) to pod filling (75 dap), the average values were 42 and 51 cm respectively. Nevertheless, the lowest growth index values were observed in the treatments with organic fertilization throughout the season.

Overall, very few reports have related growth index values for other crops such as Pansy or Violet (*Viola adorata*) and habanero pepper (*Capsicum chinense* Jacq.) In that aspect, Torres-Bojórquez, Morales, Grijalva, Cervantes, and Núñez (2017) reported that growth index values increased as a function of time on habanero pepper plants, reaching the highest value on treatments with silver plastic cover. Ruelas-Islas, Reyes, Núñez, Flores, and Villarreal (2018) reported an average growth index value of 52 cm at 90 dap on common bean Azufrado Higuera.

Table 2. Growth index of common bean as a function of time.

Fertilizer source	Growth index (cm) Days after planting					
	30	45	60	75	90	105
Bulk blend 30-10-12	39.48 a	45.78 a	53.94 a	52.72 a	52.72 ab	49.83 a
Triple 16	38.50 a	44.80 a	52.04 a	51.48 a	55.01 a	51.0 a
Organic blend	28.23 b	34.0 a	46.63 a	45.17 a	44.39 b	40.0 b
Urea	37.18 ab	45.63 a	52.31 a	52.64 a	54.87 a	51.33 a
Mean	35.8	42.5	51.2	50.5	52	48
($P \geq 0.05$)	0.015	0.05	0.08	0.08	0.01	0.01

† Means followed by distinct letters are statistically different (Tukey $P \leq 0.05$).

Dry Matter Production (DM)

In this study, there was a significant response of treatments ($P < 0.05$) from stages of flowering to maturity (Figure 2). Treatments with application triple 16 and bulk blend 30-10-12 showed no differences in dry matter accumulation early in the season as compared to the rest of treatments (organic blend and urea). It was observed that treatments with bulk blend 30-10-12 fertilization accumulated the highest amount of dry matter (6656 kg ha^{-1}), while the lowest accumulation (3391 kg ha^{-1}) was recorded on treatments with organic blend all over the season. In this sense, Ruelas-Islas *et al*. (2018) found that a P rate (50 kg ha-^{1}) substantially increased biomass production as compared to a higher P rate (100 kg ha^{-1}).

Mweetwa, Chilombo, and Gondwe (2016) stated that inoculation of bean crop with *Rhizobium* alone or combined with *Trichoderma* enhanced biomass production all over the season. However, the same authors suggested that not in all cases the inoculation with microorganisms have a positive influence on growth and yield. Westermann, Teran, Muñoz, and Singh (2011) reported a mean biomass production of 3450 kg ha^{-1} on 16 bean genotypes and seven organic and conventional planting systems. Mekonnen and Saliha (2018) reported that increasing rates of NPSZnB from 50 and 100 kg N ha^{-1} also increased total biomass by 5.84% and 18.61% respectively; but they also reported that increasing rates above 100 kg ha^{-1} decreased the biomass production.

Also, works by Tarekegn and Serawit, (2017) reported that dry matter production of common bean increased with different levels of nitrogen and phosphorus fertilizers. Furthermore, Abebe and Mekonnen (2019) reported that the maximum biomass accumulation (17 195 kg ha^{-1}) on common bean increased with blended fertilizer rate of (61.5-69-60-10.5-0.15 kg ha^{-1}) of NPKSB; while the minimum biomass accumulation (10 560 kg ha^{-1}) was recorded on the control treatment. Finally, Escalante-Estrada and Rodríguez (2017) reported that the source of nitrogen fertilizer affected biomass production, arguing that ammonium sulphate had resulted in higher biomass production, grain yield and its components in bush bean Michoacan 12-A-3.

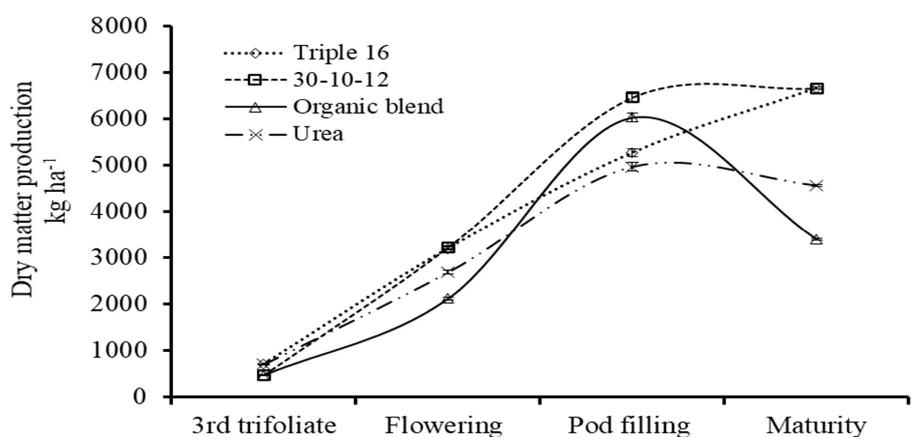

Figure 2. Dry matter production of common bean.

NDVI and SPAD Values and the Relationship with Biomass

The fertilization source showed no significant influence of NDVI values as a function of time (Table 3). Nevertheless, the highest DM accumulation was observed when the NDVI values fluctuated between 0.70 and 0.75 (Figure 3a). A bunch of studies have shown a correlation between NDVI and leaf N content in crops like maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), and pecan (*Carya illinoinensis* (Wang.) K. Koch), but very few studies relate the NDVI and SPAD values with other parameters such as biomass. Basyouni, Dunn, and Goad (2017) exhibited that GreenSeeker™ readings were less correlated with leaf N content at early stages of carnation growth (*Dianthus caryophyllus*); while the quality increased as fertilizer rates increased.

In this study, the SPAD lectures were affected by the fertilizer source and rate at 45 dap (flowering), 90 dap (pod filling) and 105 dap (maturity) and those values declined (28 and 19) as the crop progressed to maturity (Table 4). It was also observed a positive relationship of SPAD values (22) and final DM accumulation (6000 kg ha^{-1}) at maturity (Figure 3b); the low values were expected due to the stage of crop. Many studies mention that SPAD values estimate the amount of chlorophyll present in leaves giving values from 0 to 99, which is said to be proportional to that concentration (Basyouni, Dunn, and Goad, 2015), and they can be used to track possible nitrogen deficiencies of field crops during the season.

In that aspect, Escalona, Santana, Acevedo, Rodríguez, and Merú (2009) reported that the source of N fertilizer affected the SPAD lectures and nitrate content on leaves of lettuce. Other studies have reported SPAD values on carnation (*Dianthus caryophyllus*) chlorophyll degradation to maximize postharvest vase life as well as the response to different fertilizer rates (Kazemi, Gholami, Asadi, Aghdasi, and Almasi, 2012). On the other hand, Khoddamzadeh and Dunn (2016) reported that SPAD values increased progressively as increasing fertilizer rates a in *Chrysanthemum* plants. While, Basyouni *et al.* (2017) reported that GreenSeeker™ values are less correlated with leaf N content as compared with the SPAD and at LEAF readings.

Yield and Components

The overall yield was primarily influenced by fertilization sources. The highest yield was obtained on treatments with Nitrofoska Triple 16 (3.5 Mg ha^{-1}) which is considered high as compared to most yields in the area. Treatments with urea and organic fertilization had very similar yields (1.8 Mg ha^{-1}) and (1.6 Mg ha^{-1}) and were lower as compared to the other treatments (Figure 4). These results differed from those found by El-Sawy *et al.* (2020) who reported that seed yield of common bean increased when applying humic and fulvic acids.

Works by Nebret and Nigussie, (2017) reported that maximum grain yield of common bean was obtained with 23 kg ha^{-1} N, but beyond that level the yield was reduced. They argued that the negative effect of higher N rate on grain yield might be attributed to reduced nitrogen fixation or the tendency to enhance vegetative growth resulting in self-shading. Núñez-Vázquez *et al.* (2020) found that application of Spirulin + vinasse combined with Quitomax® increased the grain and pod production in bean plants.

With respect to yield components, it was observed that the number of normal pods (sample of 10 plants) and number of normal seeds in all pods significantly decreased on treatments with organic blend (142 pods and 77 seeds) as compared to the rest of the sources (Table 5). These results coincide with those reported by Meseret and Amin (2014) who found a higher number of pods per plant (48.16) when applying 20 kg ha^{-1} over the rest of fertilizer levels. Their results were similar to those previously reported in which the authors stated that different fertilizer rates promoted higher number of pods per plant. In the same manner, Ashwin, Bagyaraj, and Raju (2023),

Table 3. NDVI values as affected by fertilizer source.

Fertilizer source	Days after planting					
	30	45	60	75	90	105
Bulk blend 30-10-12	0.70 a	0.77 a	0.78 a	0.69 a	0.54 a	0.51 a
Triple 16	0.70 a	0.75 a	0.75 a	0.70 a	0.53 a	0.49 a
Organic blend	0.64 a	0.75 a	0.71 a	0.64 a	0.50 a	0.42 a
Urea	0.70 a	0.73 a	0.74 a	0.72 a	0.56 a	0.51 a
Mean	0.68	0.75	0.74	0.68	0.53	0.48
($P \geq 0.05$)	0.5	0.4	0.1	0.2	0.5	0.2

† Means followed by distinct letters are statistically different (Tukey $P \leq 0.05$).

Table 4. SPAD values as affected by fertilizer source.

Fertilizer source	Days after planting					
	30	45	60	75	90	105
NPK blend 30-10-12	38.57 a	37.35 ab	38.35 a	32.78 a	31.81 a	20.75 b
Triple 16	38.72 a	36.78 b	37.55 a	30.72 a	28.55 ab	22.84 a
Organic blend	37.97 a	42.42 ab	37.10 a	28.86 a	24.64 b	19.00 c
Urea	38.35 a	43.35 a	36.95 a	32.62 a	29.19 ab	16.75 d
Mean	38.4	40	37.5	15.4	28.5	19.8
($P \geq 0.05$)	0.9	0.02	0.8	0.2	0.006	0.001

† Means followed by distinct letters are statistically different (Tukey $P \leq 0.05$).

Kocira *et al*. (2020) and Romero-Félix *et al*. (2023) found increases in the number of pods and seeds when applying biostimulants. Uddin, Mira, Sarker, and Akondo (2020) showed that boron improved the grain and straw yield, nutrient content, nutrient uptake and quality in legume crops. In their studies, they mention that boron rates (0.5, 1.0 and 1.5 kg B ha^{-1} Borax®) affected the yield and its components of three bean varieties. They found that Variety BARI Jharseem-3 (black seed) along with 1.5 kg ha^{-1} boron had the highest number of pods/plant (5.02), number of seeds/pod (4.04), 1000-seed weight (412.74 g), seed yield (1.54 Mg ha^{-1}), biological yield (4.59 Mg ha^{-1}). While, Mekonnen and Saliha (2018) found that application of 100 kg ha^{-1} NPSZnB maximized grain yield, number of pods per plant, hundred seed weight and harvest index of common bean variety "Hawassa Dume® red seed" in South Ethiopia. Other works by Alemu, Nebiyu, and Getachew (2018) reported that the number of pods per

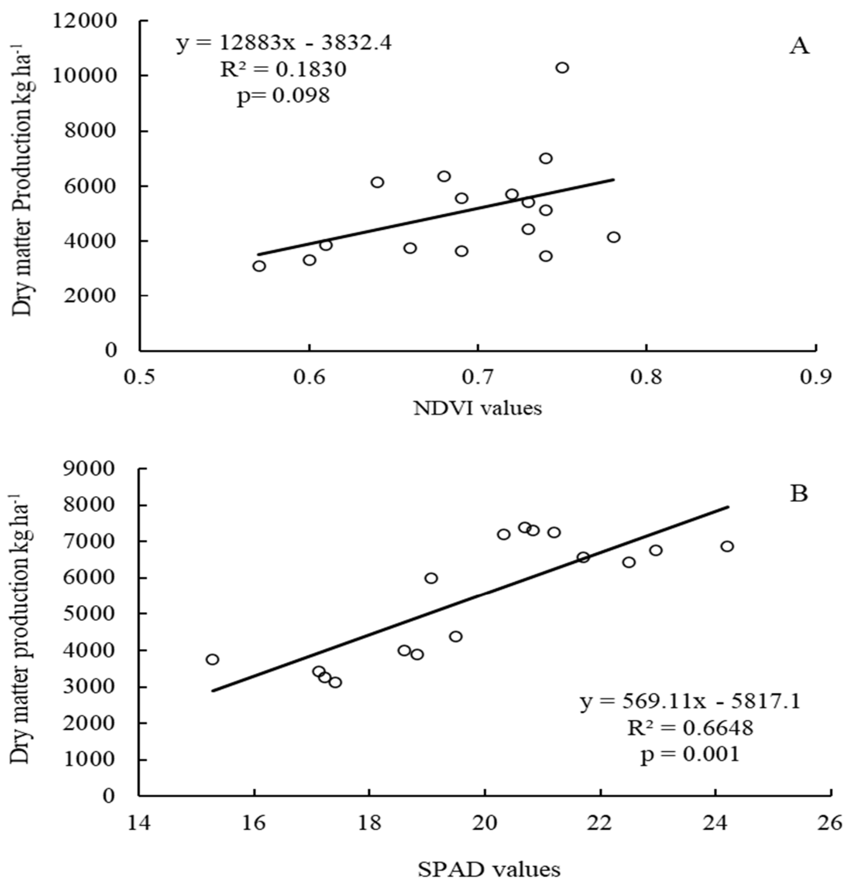

Figure 3. Relationship between dry matter production and NDVI values (A), dry matter production and SPAD values at maturity (B).

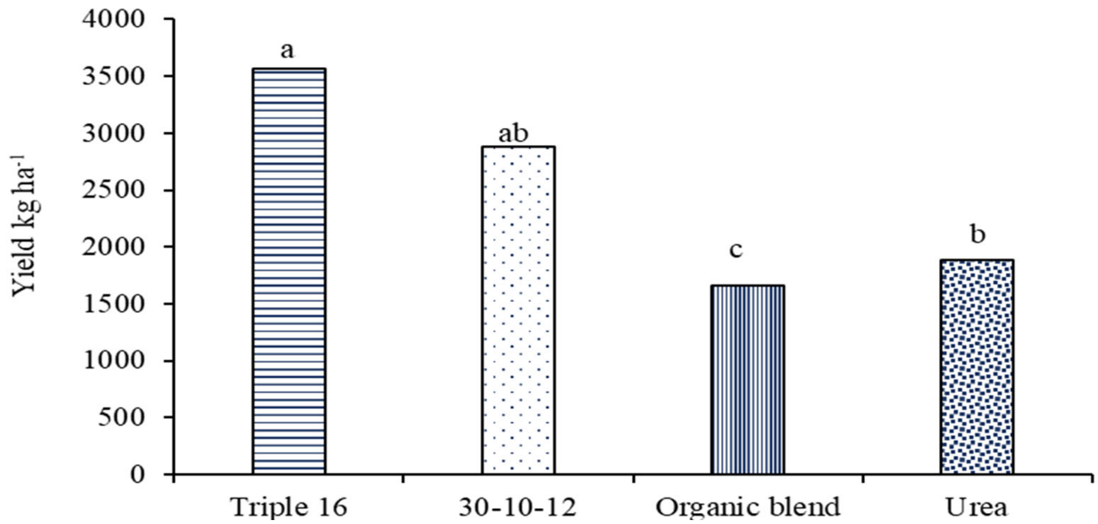

Figure 4. Yield of common bean "Azufrado Reyna".

plant enhanced as increasing the rate of P up to 69 kg P_2O_5 ha^{-1}. They relate that the increase could be due the metabolic role of P in influencing the reproductive growth as stated by Rafat and Sharifi, (2015). Different authors have reported that variations in the number of pods per plant on common bean are due to P applications (Dereje, Nigussie, Setegn, and Eyasu, 2016). Finally, Quintero-Rodríguez, Calero, Pérez, and Enríquez (2018) mentioned that the number of pods is an important indicator of yield potential.

Figure 5 shows the regression models between the yield and related components as well as yield and biomass production. The correlation analysis showed that regardless the fertilization source, the overall yield was related with the number of pods (Figure 5a). Besides, the number of seeds (sample of 10 plants) that maximized yield were approximately between 83 to 93 (Figure 5b); while hundred seed weight was also positively correlated with final yield and ranged between 50 and 65 g (Figure 5c). Furthermore, biomass production was correlated with final yield (r = 0.82) (Figure 6).

In that sense, Szparaga *et al.* (2018) exhibited a positive and significant correlation between yield with the number of pods and number of seeds when applying biostimulants on soybean (*Glycine max* L.). In addition, Alemu *et al.* (2018) found that yield was positively correlated with number of pods per plant (r = 0.93), number of seeds per pod (r = 0.8), hundred seed weight and dry biomass (r = 0.82); which also coincided with other works reporting that seed yield was highly correlated with number of pods per plant, seeds per pod, dry biomass yield and hundred seed weight.

Table 5. Yield components of common bean "Azufrado Reyna".

Fertilizer source	Number of pods	Number of seeds	Weight of 100 grains
Bulk blend 30-10-12	257 a	89 a	40 a
Triple 16	245 a	88 a	40 a
Organic blend	142 b	77 b	35 a
Urea	259.5 a	80 ab	38 a
Mean	226	83	38
($P \leq 0.05$)	0.001	0.01	0.4

[†] Means followed by distinct letters are statistically different (Tukey $P \leq 0.05$).

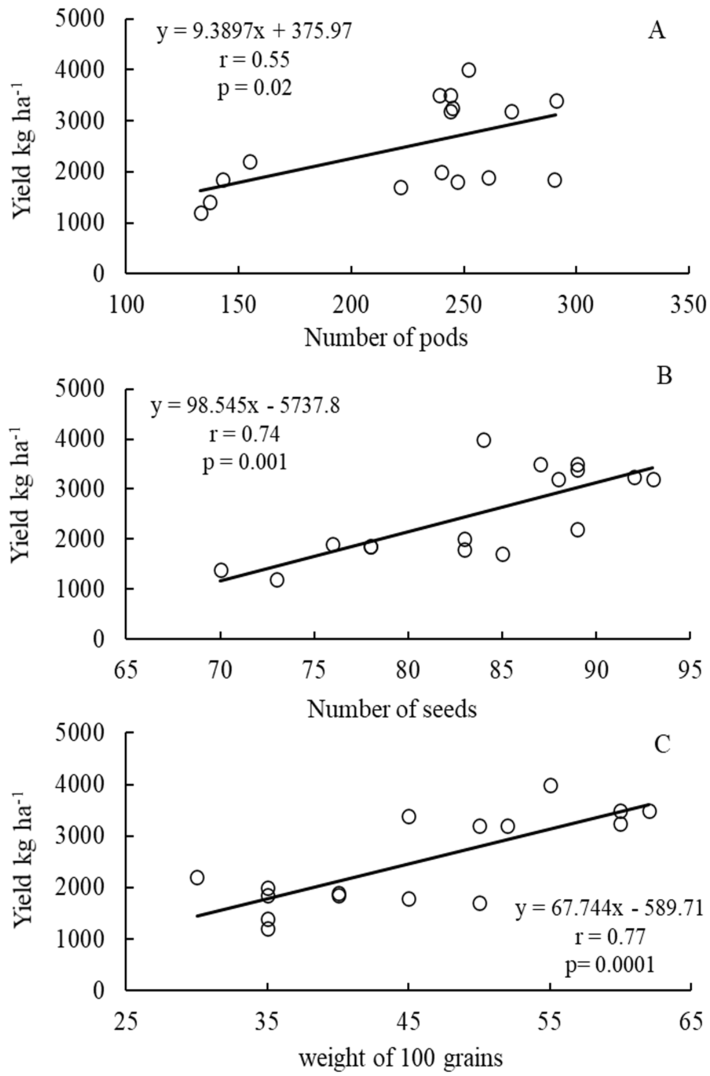

Figure 5. Relationship between yield and number of pods (A), yield and number of seeds (B), yield and 100 seed weight (C).

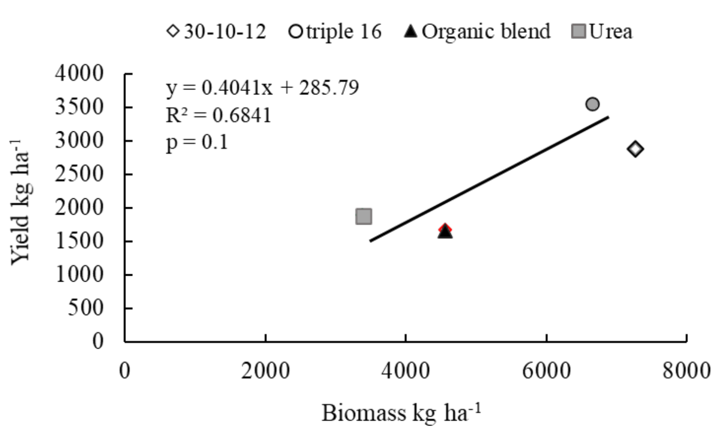

Figure 6. Relationship between yield and biomass of common bean.

CONCLUSIONS

Fertilization sources and rates affected differently the agronomic response of common bean in terms of growth; such as plant height and stem diameter.

Fertilization provided by Nitrofoska Triple 16® attained a higher yield and its related components as due to the balanced source of nutrients available during the whole season.

Treatments receiving bulk blend 30-10-12® and Nitrofoska Triple 16 showed that a highest biomass production was strongly related with final yield. It is advisable to apply fertilization sources that guarantee nutrients to last longer in soils and be readily available for plant uptake

ETHICS STATEMENT

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF SUPPORTING DATA

The data set in this experiment is available by the corresponding author if it is requested.

COMPETING INTERESTS

The authors declare no competing interests.

AUTHORS' CONTRIBUTIONS

Original draft preparation: J.R.R.I. Formal analysis, J.R.R.I. Review and editing: H.C.M., and C.S.R.F. Methodoly: E.S.I. Visualization and supervision: C.M.P.

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REFERENCES

Abebe, Z. (2017). On-farm Yield variability and Responses of Common bean (*Phaseolus vulgaris* L.) Varieties to *Rhizobium* Inoculation with Inorganic Fertilizer Rates. *Journal of Animal & Plant Sciences*, *32*(2), 5120-5133.

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), 2-8.

Aguirre-Medina, J. F., Yeekón-Méndez, L., & Espinosa-Zaragoza, S. (2019). Influencia de hongos endomicorrízicos en el crecimiento de (*Tabebuia donnell-smithii* Rose). *Ecosistemas y Recursos Agropecuarios*, *6,* 11-21. https://doi.org/10.19136/era.a6n16.1538

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. https://doi.org/10.5897/JABSD2018.0312

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. https://doi.org/10.21273/HORTSCI.38.4.537

Ashwin, R., Bagyaraj, D. J., & Raju, B. M. (2023). Ameliorating the drought stress tolerance of a susceptible soybean cultivar, MAUS 2 through dual inoculation with selected rhizobia and AM fungus. *Fungal Biology and Biotechnology*, *10*(1), 10. https://doi.org/10.1186/s40694-023-00157-y

Basyouni, R., Dunn, B. L., & 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

Basyouni, R., Dunn, B. L., & Goad, C. (2017). The use of nondestructive sensors to assess nitrogen status in potted dianthus (*Dianthus chinensis* L.) production. *Canadian Journal of Plant Science, 97,* 44-52. https://doi.org/10.1139/cjps-2016-0059

Calero-Hurtado, A., Pérez-Díaz, Y., Quintero-Rodríguez, E., Olivera-Viciedo, D., & Peña-Calzada, K. (2019). Efecto de la aplicación asociada entre *Rhizobium leguminosarum* y microorganismos eficientes sobre la producción del fríjol común. *Ciencia y Tecnología Agropecuaria, 20*(2), 295-322. https://doi.org/10.21930/rcta.vol20_num2_art:1460

Colás-Sánchez, A., Díaz-Pérez, B., Rodríguez-Urrutia, A., Gatorno-Muñóz, S., & Rodríguez-López, O. (2018). Efecto de la Biofertilización en la morfo fisiología y rendimiento del frijol común (*Phaseolus vulgaris* L.). *Revista Centro Agrícola, 45,* 34-42.

Chekanai, V., Chikowo, R., & Vanlauwe, B. (2018). Response of common bean (*Phaseolus vulgaris* L.) to nitrogen, phosphorus and rhizobia inoculation across variable soils in Zimbabwe. *Agriculture, Ecosystems & Environment, 266,* 167-173. https://doi.org/10.1016/j.agee.2018.08.010
Dereje, S. H., Nigussie, D., Setegn, G., & Eyasu, E. (2016). P Use efficiency of common bean (*Phaseolus Vulgaris* L.) and response of the crop to the application of p, lime, and compost in Boloso Sore and Sodo Zuria Districts, Southern Ethiopia. *East South African Journal of Science, 9*(1), 57.
Escalante-Estrada, J. A. S., & Rodríguez-González, M. T. (2017). Biomass and yield of common bean (*Phaseolus vulgaris* L.) as a function of the nitrogen source. *Publications from USDA-ARS / UNL Faculty, 1668*, 1-3.
Espinoza-Galaviz, J. Y., Romero-Félix, C. S., Sánchez-Soto, B., Sauceda-Acosta, R. H., Almada-Ruíz, V. G., & Lugo-García, G. A. (2023). Biostimulants on yield and its components in common bean (*Phaseolus vulgaris* L.), *Revista Agroproducividad,16*(5), 21-127. https://doi.org/10.32854/agrop.v15i4.2462
Escalona, A., Santana, M., Acevedo, I., Rodríguez, V., & Merú-Marcó, L. (2009). Efecto de las fuentes nitrogenadas sobre el contenido de nitratos y lecturas "spad" en el cultivo de lechuga. *Agronomía Tropical, 59(1),* 99-105.
El-Sawy, S. M., Marzouk, N. M., El-Tohamy, W. A., & Abou-Hussein, S. D. (2020). Foliar application of fulvic acid for increasing the productivity and fruit quality of snap bean (*Phaseolus vulgaris* L.) in sandy soil. *Plant Archives, 20*(2), 9175-9182.
Johansen, B., & Tømmervik, H. (2014). The relationship between phytomass, NDVI and vegetation communities on Svalbard. *International Journal of Applied Earth Observation and Geoinformation, 27,* 20-30. https://doi.org/10.1016/j.jag.2013.07.001
Kasinath, B. L., & Parama, V. R. R. (2015). Differential response of french bean varieties to NPK fertilization with or without farm yard manure in an Alfisol. *Scholars Academic Journal of Biosciences, 3,* 335-337.
Kazemi, M., Gholami, M., Asadi, M., Aghdasi, S., & Almasi, M. (2012). Response of carnation (*Dianthus caryophyllus* L.) to salicylic acid and glutamine. *Asian Journal of Biochemistry, 7,* 158-164. https://doi.org/10.3923/ajb.2012.158.164
Kocira, A., Lamorska, J., Kornas, R., Nowosad, N., Tomaszewska, M., Leszczyńska, D., … & Tabor, S. (2020). Changes in biochemistry and yield in response to biostimulants applied in bean (*Phaseolus vulgaris* L.). *Agronomy, 10*(2), 189. https://doi.org/10.3390/agronomy10020189
Khoddamzadeh, A. A., & Dunn, B. L. (2016). Application of optical sensors for nitrogen management in chrysanthemum. *Hortscience, 51*(7)*,* 915-920. https://doi.org/10.21273/HORTSCI.51.7.915
Kumar, V., Kumar, P., & Khan, A. (2020). Optimization of PGPR and silicon fertilization using response surface methodology for enhanced growth, yield and biochemical parameters of French bean (*Phaseolus vulgaris* L.) under saline stress. *Biocatalysis and Agricultural Biotechnology*, *23,* 101463. https://doi.org/10.1016/j.bcab.2019.101463
Kumar, R., Kumar-Saren, B., & Kumar-Patel, S. (2023). Effect of foliar application of zinc and boron on growth attributes and yield of chickpea (*Cicer arietinum* L.) varieties. *International Journal of Plant & Soil Science, 35*(21), 958-965. https://doi.org/10.9734/IJPSS/2023/v35i214066
Martínez-Sánchez, A., Ortega-Arias-Carbajal, G. M., González-Pardo, G., Armenteros-Galarraga, S., Peña-Martínez, M. A., Legrá-Mora, S., ... & Delgado-Arieta, G. (2017). Estudio de estabilidad del inóculo LB-1 del bioproducto Lebame. *ICIDCA. Sobre los Derivados de la Caña de Azúcar, 51*(2), 17-20.
Meseret, T., & Amin, M. (2014). Effect of different phosphorus fertilizer rates on growth, dry matter yield and yield components of common bean (*Phaseolus vulgaris* L.). *World Journal of Agricultural Research, 2*, 88-92. https://doi.org/10.12691/wjar-2-3-1
Mekonnen, L., & Saliha, J. (2018). The Response of Common Bean (*Phaseoluse Vulgaris* L.) to Various Levels of Blended Fertilizer. *International Journal of Research in Agriculture and Forestry, 5*(7)*,* 15-20.
Minitab (2017). *Minitab Statistical Software User´s Guide. Version 18.1.* State College, PA, USA: Minitab Inc.
Mweetwa, A. M., Chilombo, G., & Gondwe, B. M. (2016). Nodulation, nutrient uptake and yield of common bean inoculated with *Rhizobia* and *Trichoderma* in an Acid Soil. *Journal of Agricultural Science*, *8*(12), 61-70. https://doi.org/10.5539/jas.v8n12p61
Nebret, T., & Nigussie, D. (2017). Effect of nitrogen and sulphur application on yield components and yield of common bean (*Phaseolus Vulgaris* L.) in Eastern Ethiopia. *Academic Research Journal of Agricultural Science and Research, 5*(2), 77-89.
Núñez-Vázquez, M. C., Delgado-Acosta, C., López-Padrón, I., Martínez-González, L., Reyes-Guerrero, Y., Pérez-Domínguez, G., & Brito-Sánchez, D. (2020). New biostimulant and its influence on the production of common beans. *Cultivos Tropicales, 41*(4), e08.
Obssi, A., Abdullahi, 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), 58-85.
Peres-Soratto, R., Aranda-Catuchi, T., de Freitas-Cordova-de Souza, E., & Nantes-Garcia, J. L. (2017). Plant density and nitrogen fertilization on common bean nutrition and yield. *Revista Caatinga, Mossoró, 30*(3), 670-678. https://doi.org/10.1590/1983-21252017v30n315rc
Quintero-Rodríguez, E., Calero-Hurtado, A., Pérez-Díaz, Y., & Enríquez-Gómez, L. (2018). Efecto de diferentes bioestimulantes en el rendimiento del frijol común. *Centro Agrícola, 45*(3), 73-80.
Rafat, M., & Sharifi, P. (2015). The effect of P on yield and yield components of greenbean. *Journal of Soil and Nature, 8*(1), 9-13.
Romero-Félix, C. S., Pellegaud-del Paso, D. F., Salas-Arellanes, J. A., Sauceda-Acosta, R. H., Buelna-Tarín, S., & López-Valenzuela, B. E. (2023) Bioestimulantes en el crecimiento y rendimiento de *Phaseolus vulgaris* L. en el Norte de Sinaloa. *Ecosistemas y Recursos Agropecuarios*, *10*(2), e3650. https://doi.org/10.19136/era.a10n2.3650
Ruelas-Islas, J. R., Reyes-Olivas, A., Núñez-Ramírez, F., Flores-Velázquez., & Villarreal-Guerrero, F. (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 & Biology*, *20*, 1818-1824.
Shanka, D., Dechassa, N., & Gebeyehu, S. (2015). 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.
Sifuentes, I. E., Macías, J., Quintana, J., & González, C. V. (2012). *IrriModel 1.0: Programación integral y gestión del riego a través de internet*. México: INIFAP-CIRNO-CEVAF.
Shumi, D., Alemayehu, D., Afeta, T., & Debelo, B. (2018). Effect of Phosphorus Rates in Blended Fertilizer (NPS) and Row Spacing on Production of Bushy Type Common Bean (*Phaseolus Vulgaris* L.) at Mid-land of Guji, Southern Ethiopia. *Journal of Plant Biology & Soil Health, 5*(1), 7.
Szparaga, A., Kocira, S., Kocira, A., Czerwińska, E., Świeca, M., Lorencowicz, E., ... & Oniszczuk, T. (2018). Modification of growth, yield, and the nutraceutical and antioxidative potential of soybean through the use of synthetic biostimulants. *Frontiers in Plant Science, 9*, 1401. https://doi.org/10.3389/fpls.2018.01401
Tamayo-Aguilar, Y., Juárez-López, P., Capdevila-Bueno, W., Lescaille-Acosta, J., & Terry-Alfonso, E. (2020). Bioproductos en el crecimiento y rendimiento de *Phaseolus vulgaris* L. var. Delicia 364. *Terra Latinoamericana*, *38*(1)*,* 667-678. https://doi.org/10.28940/terra.v38i3.672
Tarekegn, Y., & Serawit, S. (2017). Growth, symbiotic and yield response of N-fertilized and Rhizobium inoculated common bean (*Phaseolus vulgaris* L.). *African Journal of Plant Science, 11*(6),197-202. https://doi.org/10.5897/AJPS2017.1528

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://doi.org/10.29312/remexca.v8i2.57

Uddin, F. M. J., Mira, H. H., Sarker, U. K., & Akondo, M. R. I. (2020). Effect of variety and boron fertilizer on the growth and yield performance of French bean (*Phaseolus vulgaris* L.). *Archives of Agriculture and Environmental Science, 5*(3), 241-246. https://doi.org/10.26832/24566632.2020.050302

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://doi.org/10.26832/24566632.2018.030303

Westermann, D. T., Teran, H., Muñoz-Perea, C. G., & Singh, S. P. (2011). Plant and seed nutrient uptake in common bean in seven organic and conventional production systems. *Canadian Journal of Plant Science, 91*, 1089-1099. https://doi.org/10.4141/cjps10114

Wossen, T. (2017). Determination of optimum rate of blended fertilizer for pod yield of snap bean (*Pharsalus vulgaris* L.) at Teda, North Gondar, Ethiopia. *International Journal of Sciences*, *Basic and Applied Research, 32*(1), 66-79.