

Common bean (*Phaseolus vulgaris* L.) yield response to chemical and biological fertilization in different localities of Colombia

Respuesta productiva del cultivo del frijol (*Phaseolus vulgaris* L.) a la fertilización química y biológica en zonas productoras de Colombia

doi: 10.15446/rfnam.v71n3.72392

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ABSTRACT

Keywords:

Poultry manure
Mycorrhizae
Rhizobium
Phosphate rock

The research was carried out in 2015 in five bean producing locations in Colombia. The objective was to evaluate the effect of different treatments of chemical and biological fertilization on the yield of climbing and bush beans. According to the results obtained, in Antioquia, it is possible to replace the chemical fertilization by biological fertilization in the climbing bean Corpoica LAS-106 and the bush bean Citará. In Cundinamarca, similar situation was presented with “Cargamanto Rojo”. In Santander, it was found that the combination of mycorrhizae (AMF) and *Rhizobium* improves the performance of the bush bean ICA-Rovirense (2839.5 t ha⁻¹) and ICA-Radical-J1J1 (1955.7 t ha⁻¹), with respect to national average yield (1.2 t ha⁻¹). The use of biofertilizers (mycorrhizal fungi and *Rhizobium*) improved the yields in the bean crop, with the materials used (climbing and bush) and in the localities studied. There is an additive effect in the applications of the biofertilizers evaluated, since it is a higher yield in the bean crop when these were applied individually combined.

RESUMEN

Palabras clave:

Gallinaza
Micorrizas
Rhizobium
Roca fosfórica

La investigación se realizó en 2015 en cinco localidades productoras de frijol en Colombia. El objetivo fue evaluar el efecto de diferentes tratamientos de fertilización química y biológica sobre el rendimiento de frijoles volubles y arbustivos. De acuerdo con los resultados obtenidos, en Antioquia, es posible reemplazar la fertilización química por fertilización biológica en el frijol voluble Corpoica LAS-106 y el arbustivo Citará. En Cundinamarca, similar situación se presentó con el frijol “Cargamanto Rojo”. En Santander, se encontró que la combinación de micorrizas (AMF) y *Rhizobium* mejora el rendimiento de los frijoles arbustivos ICA-Rovirense (2839,5 t ha⁻¹) e ICA- Radical-J1J1 (1955,7 t ha⁻¹), con respecto al rendimiento promedio nacional (1,2 t ha⁻¹). El uso de biofertilizantes (hongos formadores de micorriza y *Rhizobium*) mejoró los rendimientos en el cultivo del frijol, con los materiales utilizados (volubles y arbustivos) y en las localidades estudiadas. Existe un efecto aditivo en las aplicaciones de los biofertilizantes evaluados, ya que se observó un mayor rendimiento en el cultivo de frijol cuando estos se aplicaron combinados que individualmente.

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Bean (*Phaseolus vulgaris* L.) is considered as one of the basic products of the peasant economy of small and medium-sized producers, located especially in the Andean region, with limitations in crop yields, high incidence of pests and diseases, and lack of good quality seeds (Pachón, 2010; Tofiño *et al.*, 2016; FAO, 2016).

According to Fenalce (2016), in 2015 94,341 hectares of bean were planted in Colombia, with a yield of 101,497 tons; 93% of the plantations were located in the Andean region, 5.6% in the Inter-Andean Valleys, and 1.4% in the Caribbean region. Approximately, 65% of the national bean yield comes from the climbing varieties of cold and moderate cold climates, and the remaining 35% corresponds to bush varieties in medium and warm climates. In the other hand, 50% of production is concentrated in the departments of Antioquia, Santander, Huila, Tolima and Nariño.

In the tropics, the majority of the soils are from extremely up to strongly acid (pH<5.5), rich in exchangeable Al, and low in nutrients (Barber, 1995; Zapata, 2004; Toledo, 2012; Osorio, 2018), which restricts agricultural productivity. To compensate these problems, it is necessary to apply high amounts of lime and fertilizers, which increase yield costs (Osorio, 2018).

The medium-climate soils (1000-2000 m of altitude) in Colombia are of low to medium fertility and have some limitations for the normal growth of crops, since in general, their pH tend to be strongly acid (4.2-5.5), high in Al, low to medium of assimilable K (<0.3 cmol_c kg⁻¹), low in exchangeable Mg (<1.0 cmol_c kg⁻¹), and low in organic matter (<5%). The usable P content presents predominance towards low values (<15 mg kg⁻¹) (Tamayo and Osorio, 2014).

Moderate cold climate soils have high anionic exchange capacity, high phosphate binding, high organic matter content (<15%), but a very low mineralization of the organic matter (<1%). These soils have strongly acidic pH (4.0-5.5) and low levels of exchangeable bases, and in many cases, imbalances among the bases (Tamayo and Osorio, 2014).

It is considered that the use of biofertilizers could improve the quality of the soils and, therefore, the yield of the crops. Corpoica has been working with arbuscular mycorrhizal

fungi (AMF), and bacteria of the genus *Rhizobium*, considered at the moment and worldwide, as biofertilizers for most of the crops. The combined use of both types of microorganisms, improves the yield conditions in more efficiently way than with the individual use of them, and are fundamental in the programs of integrated soil and crop management (Tamayo, 2016). According to what it was mentioned above, a study was established to determine the effect of the application of biofertilizers (mycorrhizal fungi and *Rhizobium*) on the yield of climbing and bush beans, in different producing localities of this specie in Colombia.

The use of microorganisms in the form of biofertilizers can have a positive effect on the yield in the bean crop in Colombia.

MATERIALS AND METHODS

The study was carried in 2015 (first semester), in different localities in the departments of Antioquia, Cundinamarca and Santander. In Antioquia, two experimental plots were established in two localities: CI La Selva (altitude of 2120 m, annual average temperature of 17 °C, average annual rainfall of 1850 mm, at 06°08'06"N, 75°25'03W), with climbing beans ICA-Viboral and Corpoica LAS-106 (both at a planting distance of 0.23 m among plants and 1.2 m among rows). The other locality was CI El Nus (altitude of 848 m, annual average temperature of 24 °C, average annual rainfall of 2500 mm, at 06°26'17.2"N, 74°49'32.1"W), with the bush bean varieties Quimbaya and Citará (both at a planting distance of 0.15 m among plants and 0.5 m among rows), in which it was evaluated the effect of several treatments with biological fertilizers. The treatments used were: Organic matter (poultry manure) (2 t ha⁻¹); *Rhizoglossum* sp. (15 g per plant), with a concentration of 250 spores g⁻¹, with 50 infective mycorrhiza propagules g⁻¹; commercial strains of *Rhizobium* (100 bacteria g⁻¹) (0.01 L per kg of seed) and/or with phosphate rock (PR) (600 kg ha⁻¹), in simple and combined form. All treatments received 20 g of KCl per linear meter, except for the chemical farmer treatment (control) (350 kg ha⁻¹ of 10-30-10). Each experimental unit consisted of six rows, 10 m long and 0.6 m wide each. A randomized complete block experimental design with four replications, was used.

In Cundinamarca, a plot was established in the municipality of Pasca (at an altitude of 2180 m, annual average

temperature of 17 °C, an average annual rainfall of 1100 mm, at 4°18'27"N 74°18'03"W), with climbing bean "Cargamanto Rojo" (at a planting distance of 0.23 m among plants and 1.2 m among rows). The treatments used were: Organic matter (poultry manure) (2 t ha⁻¹); with *Rhizoglyphus* sp. (15 g per plant), with a concentration of 250 spores g⁻¹, with 50 infective mycorrhiza propagules g⁻¹; commercial strains of *Rhizobium* (100 bacteria g⁻¹) (0.01 L per kg of seed) and/or with phosphate rock (PR) (600 kg ha⁻¹), in simple and combined form. All treatments received 20 g of KCl per linear meter, except for the chemical farmer treatment (control) (350 kg ha⁻¹ of 10-30-10). Each experimental unit consisted of six rows, 10 m long and 0.6 m wide each. A randomized complete block experimental design with four replications, was used.

In Santander, two experimental plots were established in two localities: CI El Arsenal (altitude of 1450 m, annual average temperature of 22 °C, average annual rainfall of 1292 mm, at 6°40'05"N 72°42'00"W), with the bush bean variety ICA-Rovirense. The other locality was Curití (at an altitude of 1409 m, annual average temperature of 20 °C, an average annual rainfall of 1500 mm, at 6°36'16"N 73°04'05"W), with the bush bean variety ICA- Radical-J1J1. In both localities were used a planting distance of 0.15 m among plants and 0.5 m among rows, in which the effect of three strains of *Rhizobium* (P4, P8, and P14), and two

inoculum of mycorrhiza MVA (*Rhizoglyphus occultum* and *Acaulospora* spp.) were evaluated on the yield of bush bean varieties, ICA-Rovirense and Radical-J1J1. Each experimental unit consisted of six rows, 10 m long and 0.6 m wide. A randomized complete block experimental design with four replications was used. The study consisted in the evaluation of seven treatments; in Curití was included a control, that involved the application of the combination of *Trichoderma lignorum*, and a mixture of mycorrhizal fungi (*Rhizoglyphus occultum* and *Acaulospora* spp.), plus the inoculation of the seeds with *Rhizobium* sp.

RESULTS AND DISCUSSION

At C.I. La Selva, when performing a combined analysis during two consecutive cycles, in Corpoica 106 and ICA-Viboral, significant differences were present among treatments. As it can be seen in Table 1, the yield obtained with chemical fertilization in the variety Corpoica 106 was equal to that obtained with organic and biological fertilization, either with double inoculation, mycorrhizae plus *Rhizobium*, and/or with the application of PR. This agrees with several authors who report a positive effect of the different strains, both in their simple as in its combined forms, presenting the greatest effects when double inoculations were used (Saravesi *et al.*, 2014; Galindo and Clavijo, 2009; Caldera *et al.*, 2013; Clua *et al.*, 2013; Granda *et al.*, 2016; Romero *et al.*, 2016).

Table 1. Yield of climbing beans Corpoica-LAS 106 and ICA-Viboral, during two consecutive cycles. CI La Selva.

Treatments	Corpoica LAS-106 (kg ha ⁻¹)	ICA Viboral (kg ha ⁻¹)
Control (chemical farmer treatment)	1527.0 a*	2033.2 a
Poultry manure plus inoculation with mycorrhizae	1602.9 a	1609.3 b
Poultry manure plus inoculation with <i>Rhizobium</i>	1439.6 a	1502.2 bc
Poultry manure plus phosphate rock	1585.1 a	1642.1 b
Poultry manure plus inoculation with mycorrhizae and <i>Rhizobium</i>	1480.3 a	1529.3 bc
Poultry manure plus inoculation with <i>Rhizobium</i> and phosphate rock	1518.2 a	1502.0 bc
Without poultry manure-inoculation with <i>Rhizobium</i> and mycorrhizae	1169.9 b	1157.0 c
CV	14.5%	22.0%

* Means followed by the same letter do not differ statistically at the level of 5%, according to Tukey's test.

It should be noted that the treatment with less yield was the one in which no poultry manure was applied, for both bean materials. This aspect is important due to the fact that, when the poultry manure is combined with inoculations

of *Rhizobium* and mycorrhizae, the first one can act as a stimulator. In the variety Corpoica LAS-106, chemical fertilization can be replaced with the use of biofertilizers; contrary, the ICA-Viboral variety, responded better to the

application of chemical fertilizer (350 kg ha⁻¹ of 10-30-10) than to the application of biofertilizers. According to Osorio (2016), arbuscular mycorrhizal fungi can improve the ability of the root system to absorb nutrients and improve the effect of phosphate amendments. Likewise, the rhizobium-legume association is considered a highly efficient process in biological fixation of atmospheric nitrogen (BNF); it is estimated that nitrogen fixation varies from 24 to 584 kg ha⁻¹; it has the capacity to supply up to 90% of the needs of the plant (Ángeles-Núñez and Cruz-Acosta, 2015). However, Osorio (2018) reports that there are differences in mycorrhizal dependence among cultivars of the same species.

The bean yield with this treatment was statistically superior to the different combinations of *Rhizobium*, phosphate rock and mycorrhizae (Table 1). As in the variety Corpoica LAS-106, in the ICA-Viboral, there was a significant response when poultry manure was applied, being this an activator of the biological-mineral fertilization. Organic fertilizers are a crucial element for the regulation of many processes related to agricultural productivity and can be a complement or replacement of synthetic fertilizers (Ramos and Terry, 2014). It may be argued that in the poultry manure, the microorganisms producers of organic acids can make more available the phosphate ions released from the phosphate rock, and thus improve yield (Osorio and Habte, 2013; Ramírez *et al.*, 2013; Tamayo and Osorio, 2017). In both

materials, yield per hectare during the two growing cycles was acceptable and, in some cases, exceeded the yields of the region (1.2 t ha⁻¹).

In medium climate conditions (CI El Nus) (Table 2), the Quimbaya and Citara bean materials showed a better yield response, when the control treatment (chemical) was applied, due to the soils of this area are low in fertility, very low in organic matter and exchangeable bases, and with acid pH. Although, it has been reported that in soils with very low organic matter there is a better response to organic applications than when applying chemical sources (Ramírez *et al.*, 2008; Ramos and Terry, 2014; Hartmann *et al.*, 2014; Guénon and Gros, 2015). In this study, the application of the biofertilizers was not enough to obtain the yields that were achieved with the chemical treatment, possibly because the applied doses were low. The treatments without poultry manure produced the lowest yields (936 and 352 kg ha⁻¹) for the bush varieties Citara and Quimbaya, respectively. A similar situation occurred in the locality of C.I. La Selva with climbing materials. The Quimbaya variety did not respond as significantly to the biological-mineral sources as did the climbing beans of moderate cold climate; however, there are reports of other mid-climate locations where their response has been positive. In all the varieties, the effect of the poultry manure on the yields is substantial (Table 2).

Table 2. Effect of biological-mineral fertilization on yield of bush bean in soils of medium climate. CI El Nus.

Treatments	Quimbaya (kg ha ⁻¹)	Citará (kg ha ⁻¹)
Control (chemical farmer treatment)	1264.0 a*	1583.9 a
Poultry manure plus inoculation with mycorrhizae	941.0 b	1400.0 ab
Poultry manure plus inoculation with <i>Rhizobium</i>	890.0 b	1022.8 bc
Poultry manure plus PR ²	910.0 b	894.2 bc
Poultry manure plus inoculation with mycorrhizae and <i>Rhizobium</i>	850.0 b	755.6 c
Poultry manure plus inoculation with <i>Rhizobium</i> and PR	800.0 b	846.1 c
Without poultry manure–inoculation with <i>Rhizobium</i> and mycorrhizae	332.0 c	936.1 bc
CV	22%	12%

* Means with different letters in each column indicate significant differences according to the Tukey's test ($P \leq 0.05$).

In Pasca, the yield in the bean "Cargamanto Rojo" fluctuated between 568 and 2000 kg ha⁻¹. Table 3 shows significant differences among the treatments;

the chemical farmer treatment (control), does not differ statistically from the treatments of poultry manure plus *Rhizobium*, phosphate rock and mycorrhizae and

Rhizobium. These yields, despite being from medium to low, the trend they present is the same of that obtained in C.I. La Selva with the ICA-Viboral bean, probably because poultry manure could improve the physical and biological conditions and help the activity of mycorrhiza and *Rhizobium* in the soil.

Table 3. Effect of organic and biological fertilization on the yield of climbing bean. Municipality of Pasca.

Treatments	Cargamanto Rojo (kg ha ⁻¹)
Control (chemical farmer treatment)	2000.0 a*
Poultry manure plus inoculation with mycorrhizae	941.0 bc
Poultry manure plus inoculation with <i>Rhizobium</i>	1199.0 abc
Poultry manure plus phosphate rock	1467.0 ab
Poultry manure plus inoculation with mycorrhizae and <i>Rhizobium</i>	1331.0 abc
Poultry manure plus inoculation with <i>Rhizobium</i> and phosphate rock	952.0 bc
Without poultry manure–inoculation with <i>Rhizobium</i> and mycorrhizae	568.0 c
CV	25%

*Means with different letters in each column indicate significant differences according to the Tukey's test ($P \leq 0.05$) (n=4).

In Table 4, it is observed that in the locality C.I. "El Arsenal", there were statistical differences ($P \leq 0.05$) among treatments, with a mean of 2354.5 kg ha⁻¹ and a coefficient of variation of 14.67%.

The combination of AMF mycorrhizae (*Rhizoglyphus* spp. + *Acaulospora*) and *Rhizobium* P14 strain, presented the highest yield (2839.5 kg ha⁻¹), while the lowest yield was shown in the treatment that included the *Acaulospora*

combination and the *Rhizobium* P8 strain, with 1992.7 kg ha⁻¹. The combined use of both types of microorganisms (*Rhizobium* and mycorrhizal fungi) produces better effects than the individual use of them, the use of microorganisms in the form of biofertilizers improves soil nutrition and plant growth (Grageda *et al.*, 2012; Elein *et al.*, 2013; Lozano *et al.*, 2015; Gardezi *et al.*, 2016). In the locality of Curití, no significant differences among treatments were observed, in relation to the average yield of bean in kg ha⁻¹.

Table 4. Average yield (kg ha⁻¹) in Santander with regional bean varieties.

Treatments		CI EI Arsenal ICA-Rovirense (kg ha ⁻¹)	Curití Radical-J1J1 (k ha ⁻¹)
Micorriza VA	<i>Rhizobium</i>		
<i>Rhizoglyphus</i> spp. ¹	Strain P14	2086.4 cd *	1558.3 ab
<i>Rhizoglyphus</i> spp.	Strain P4	2451.7 b	1918.0 a
<i>Rhizoglyphus</i> spp.	Strain P8	2463.3 b	1827.3 ab
<i>Acaulospora</i> spp.	Strain P14	2338.4 bc	1488.0 ab
<i>Acaulospora</i> spp.	Strain P4	2309.4 bc	1782.3 ab
<i>Acaulospora</i> spp.	Strain P8	1992.7 d	1846.5 ab
<i>Rhizoglyphus</i> spp + <i>Acaulospora</i>	Strain P14	2839.5 a	----
<i>Acaulospora</i> spp + <i>Trichoderma</i> + <i>Rhizoglyphus</i> (control)		---	1955.7 a
CV		14.67%	14.09%

* Means with different letters in each column indicate significant differences according to the Tukey's test ($P \leq 0.05$) (n=4).

¹ *Rhizoglyphus*=*Glomus* (Sieverding *et al.*, 2014).

The highest effectiveness with respect to the yield was detected in the locality CI "El Arsenal", probably due to the quality of the organic medium, to the presence of existing beneficial microorganisms, which give the root greater capacity to explore the soil in search of water and nutrients, that results in higher yields; these results are similar to those obtained by Flores *et al.* (2014) in *Stylosanthes guianensis*. This allows to consider, that the combination of compost and biological agents in the management of the nutrition of the cultivated plants is beneficial, which represents for the farmers of bean, to produce more quantity and quality of food at a lower cost, preserving the environment.

CONCLUSIONS

The use of biofertilizers (mycorrhizae fungi and *Rhizobium*) improved yields in the bean crop, with the materials used (climbing and bush beans) and in the localities studied.

There is an additive effect in the applications of the biofertilizers evaluated, since a higher yield was observed in the bean crop when these were applied combined than individually.

ACKNOWLEDGEMENTS

The authors thank farmers in the municipalities where the evaluations were carried out, for their participation and collaboration in the research trials.

Disclaimer of Liability

The source of research funding was obtained by the Corporación Colombiana de investigación Agropecuaria. The authors state that the research was carried out in the absence of commercial or financial relationships that could be interpreted as a possible conflict of interests.

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