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DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v28n2e272029 ORIGINAL ARTICLE

Diazotrophic bacteria increase yield and profitability in organic cultivation of common bean[1]

Bactérias diazotróficas aumentam produtividade e rentabilidade no cultivo orgânico do feijão comum

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HIGHLIGHTS:
Common bean can be grown efficiently in an organic system with diazotrophic bacteria as nitrogen (N) source.
Application of poultry manure is not only expensive, but the nutrient content is also inadequate.
Seed inoculation, co-inoculation and additional inoculation provided higher yields and profitability in common bean crop.

ABSTRACT: The symbiosis of common beans with nitrogen-fixing bacteria provides an efficient approach to sustainable and economical food production. Therefore, this study aimed to evaluate the application of cost-effective nitrogen management strategies in organic common bean cultivation, including the application of poultry manure and organic liquid fertilizer, seed and co-inoculation with diazotrophic bacteria (*Azospirillum brasilense* and/or *Rhizobium tropici*), and supplementary *Rhizobium tropici* inoculation. The study spanned three years in a well-established organic cultivation field (2018) and an initial organic cultivation area (2019 and 2020) in Brazil. It was arranged in a randomized blocks design in a 2 × 5 (2018) and 2 × 6 (2019 and 2020) factorial scheme, with four replicates. The most profitable strategy involves seed inoculation with *Azospirillum brasilense* and additional inoculation with *Rhizobium tropici* at stage V_{4-5} (fifth trifoliate leaf fully expanded), while the most costly strategy was the application of poultry manure at the V_3 stage (first trifoliate leaf fully expanded). Thus, the use of diazotrophic bacteria for seed inoculation and co-inoculation (*Azospirillum brasilense* and/or *Rhizobium tropici*) ensured financial returns and system profitability in common bean cultivation.

Key words: *Phaseolus vulgaris* L., *Azospirillum brasilense*, *Rhizobium tropici*, economic performance

RESUMO: A simbiose do feijão comum com bactérias fixadoras de nitrogênio proporciona uma abordagem eficiente para a produção de alimentos sustentável e econômica. Portanto, este estudo teve como objetivo avaliar a aplicação de estratégias custo-efetivas de manejo de nitrogênio no cultivo orgânico do feijão comum, incluindo a aplicação de esterco de aves e fertilizante orgânico líquido, inoculação de sementes e coinoculação com bactérias diazotróficas (*Azospirillum brasilense* e/ou *Rhizobium tropici*), e inoculação suplementar com *Rhizobium tropici*. O estudo durou três anos em um campo de cultivo orgânico bem estabelecido (2018) e uma área inicial de cultivo orgânico (2019 e 2020) no Brasil. O delineamento foi em blocos casualizados em esquema fatorial 2 × 5 (2018) e 2 × 6 (2019 e 2020), com quatro repetições. A estratégia mais lucrativa envolve a inoculação de sementes com *Azospirillum brasilense* e inoculação adicional com *Rhizobium tropici* no estádio V_{4-5} (quinta folha trifoliada totalmente expandida), enquanto a estratégia mais cara foi a aplicação de esterco de aves no estádio V_3 (primeira folha trifoliada totalmente expandida). Assim, o uso de bactérias diazotróficas para inoculação e coinoculação de sementes (*Azospirillum brasilense* e/ou *Rhizobium tropici*) garantiu retorno financeiro e rentabilidade do sistema no cultivo do feijão comum.

Palavras-chave: *Phaseolus vulgaris* L., *Azospirillum brasilense, Rhizobium tropici,* desempenho econômico

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Introduction

Common bean (*Phaseolus vulgaris* L.), an annual grain legume rich in protein, is one of the most important food crops in Brazil, and is the country's staple food along with rice (Rezende et al., 2017; Los et al., 2020). The crop can be sown at three different times in an agronomic calendar, resulting in a constant supply throughout the year. Furthermore, Brazil is the second largest producer of common bean globally, and accounts for 68% of its total global yield with India and Myanmar (FAOSTAT, 2021).

In addition to being an excellent source of food for human consumption, organic crop cultivation plays an important role in sustainable food production by prohibiting the use of synthetic fertilizers, pesticides, and genetically modified products (Le Campion et al., 2020), while relying on the rational and sustainable utilization of natural resources. However, research on the production of common beans in organic systems in Brazil, especially on the economic evaluation of sustainable nitrogen (N) management techniques, is limited. As the mineral fertilizers used in Brazil are mostly imported (Conceição et al., 2022), the use of diazotrophic bacteria as a N source is crucial in preventing economic loss and environmental problems. However, one of the main limitations in organic crop production is the inaccurate and unsystematic data because of the absence of a systematic database that approaches the indicators of organic production (area, yield, number of farmers, retail sales, and international sales), which makes it difficult to follow and elaborate the history of yield and commercialization (Lima et al., 2019).

Therefore, the present study aimed to evaluate the economic potential, in terms of yield cost, profitability of crop management, and N supply, in organic common bean cultivation using poultry manure, organic liquid fertilizer, and seed inoculation and co-inoculation with diazotrophic bacteria, with or without additional *Rhizobium tropici* inoculation.

Material and Methods

The study was conducted in two different fields over three agronomic years. In 2018, the experiment was conducted in a consolidated organic field under organic cultivation for more than ten consecutive years. The 2018 study was conducted in the 'Agência Paulista de Tecnologia dos Agronegócios' – APTA, Andradina–SP, Brazil (longitude 51°23'11" W, latitude 20°55'57" S, altitude 379 m). The soil in the experimental area is an oxisol with sandy texture, which has been cultivated with annual crops. In previous years, maize, cover crops [*Urochloa decumbens* and *Sorghum* spp.), and cowpea (*Vigna unguiculata* (L.) Walp.] were cultivated in the experimental area. According to the Köppen classification, the regional climate is tropical, comprising rainy summers and dry winters. The climatic data recorded during the experimental period are displayed in Figure 1.

In 2019 and 2020, the experiment was conducted in the municipality of Selvíria-MS, Brazil (longitude 51°24'10" W, latitude 20°20'28" S, altitude 335 m), in an area of the São Paulo State University (UNESP) farm. The soil is an oxisol with a clayey texture, prior to the experiment was fallow for over five years, with spontaneous vegetation and without any chemical or physical interference, similar to areas in transition to an organic system. According to the Köppen classification, the regional climate is Aw type, denoting a humid tropical climate with a pronounced rainy season in summer and dry season in winter. Comprehensive data on the maximum and minimum temperatures, and rainfall, were systematically collected during the experimental period (Figure 2).

Prior to the experiment, soil samples were collected at 0–20-cm depth. The soil chemical characteristics were determined according to Raij et al. (2001). In 2018, 2019, and 2020, the soil chemical characteristics were as follows: P-resin (phosphorus) = 13, 64, 54 mg dm^{-3}; OM (organic matter) = 20, 24, 24 g dm^{-3}; pH ($CaCl_2$ (calcium chloride)) = 5.1, 5.2, 5.7; K (potassium) = 3.8, 4.1, 5.2; Ca (calcium) = 22, 32, 23; Mg (magnesium) = 10, 16, 14; H + Al (hydrogen + aluminum) = 25, 38, 25; SB (sum of basic cations) = 35.8, 52.1, 42.2; CEC (cation exchange capacity at pH 7.0) = 60.8, 90.1, 67.2 mmol$_c$ dm^{-3}; V (base saturation) = 59, 58, 63%, respectively.

In 2018, before common bean sowing, the area was prepared according to conventional management using one plowing harrow, followed by a leveling harrow. In 2019, a

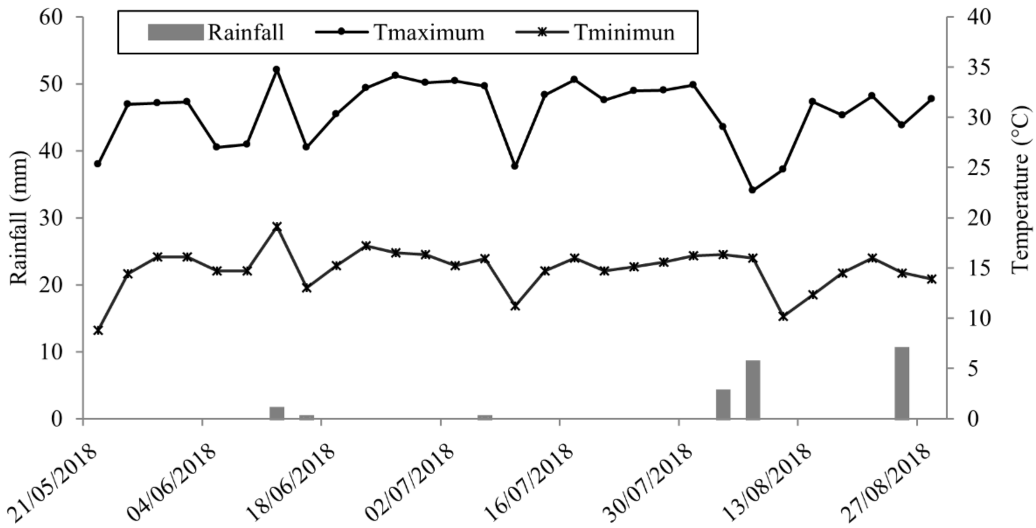
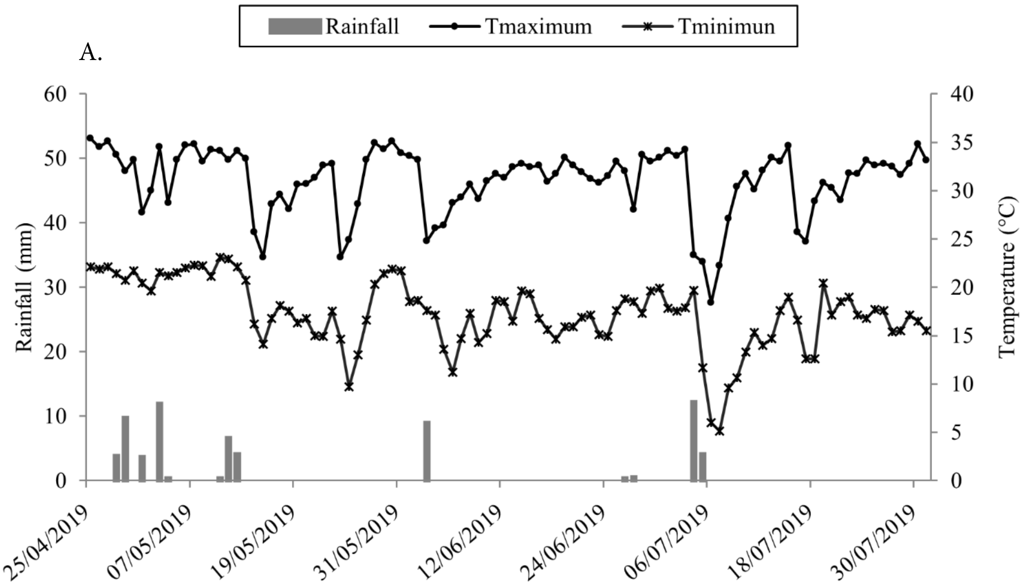


Figure 1. Rainfall, and maximum (T maximum) and minimum (T minimum) air temperatures obtained from the weather station located at APTA, Andradina-SP, Brazil, during the experiment in 2018



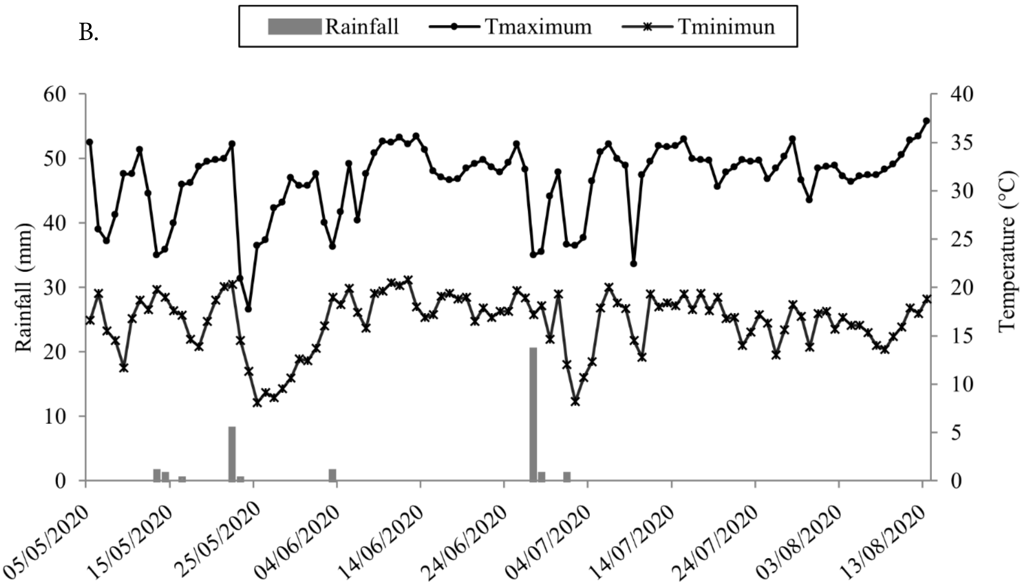


Figure 2. Rainfall and maximum (Tmaximum) and minimum (Tminimum) air temperatures obtained from the weather station at the station at the São Paulo State University (UNESP) farm during the experimental period in 2019 (A) and 2020 (B)

field shredder was used because of the dense spontaneous vegetation. To control the spontaneous growth of plants, millet was sown in the fallow area and crop straw was incorporated via plowing before plant flowering. Before 2020, organic corn was cultivated. The crop was incorporated into the soil via field shredding, plowing, and harrowing, followed by the 2020 common bean cultivation.

During the three cultivation years, organic compost was applied after soil preparation. In 2018, 1.5 t ha^{-1} of mash and granulated compost was applied to the total area and incorporated using a leveling harrow. In 2019 and 2020, 750 kg ha^{-1} of mash compost was applied to the total area, and 750 kg ha^{-1} of granulated compost was applied to the sowing furrow. The organic compost was produced from agro-industrial wastes using the composting method; the raw material was acquired from a local company, and presented the following characteristics: organic matter 35.15, N 0.43, total P 3.05, K 0.62, and moisture 43.22% (65 °C).

Irrigation was provided via sprinkler systems installed in the two fields with a precipitation rate of 3.3 mm h^{-1}, applied as required. The average irrigation depth was standardized to 15 mm, and was performed based on the rainfall data recorded during common bean cultivation. In 2018, irrigation was provided at approximately four-day intervals, whereas in 2019 and 2020, the intervals averaged approximately three days.

The experimental design was a randomized block with four replicates in a 2 × 5 factorial scheme in 2018, and 2 × 6 in 2019 and 2020. The treatments were as follows: with and without additional inoculation with *R. tropici* at V_{4-5} (fifth trifoliate leaf fully expanded), to reduce losses in case of seed inoculation failure; interacting with the following N supply methods: T_1 – no inoculation (control); T_2 – no inoculation + poultry manure application as topdressing (V_3 stage: first trifoliate leaf fully expanded); T_3 – seed inoculation with *A. brasilense*; T_4 – seed inoculation with *R. tropici*; T_5 – seed co-inoculation with *A. brasilense* + *R. tropici*, and T_6 (2019 and

2020 only) – seed inoculation and leaf application with organic liquid fertilizer. Each experimental plot comprised five rows, 8 m in length with 0.45 m interrow spacing.

Seed inoculation and co-inoculation were performed with liquid *A. brasilense* (strains AbV_5 and AbV_6 at 2 × 10^8 CFU mL^{-1}) and *R. tropici* (strain Semia 4080 at 2 × 10^9 CFU mL^{-1}) at an application rate of 200 mL 50 kg^{-1} of common bean seeds. Additional inoculation with *R. tropici* was performed using a backpack sprayer with a full-cone spray tip nozzle at stage V_{4-5}, when the 5th trifoliate leaf was completely expanded and the branching process began. Additional inoculation was performed using the liquid inoculant strain Semia 4080 at 2 × 10^9 CFU mL^{-1}, at an application rate of 200 mL ha^{-1} and spraying volume of approximately 200 L ha^{-1}.

The poultry manure was applied manually via topdressing near the sowing line at an application rate of 2.5 t ha^{-1}. In all the three years, the manure was applied at the V_3 stage. The application rate corresponded to N application of 48 kg ha^{-1} (considering an expected yield of 1.5–2.5 t ha^{-1}), according to Pereira et al. (2015). Poultry manure was acquired from a local poultry farm that prioritized animal welfare and does not use antibiotics or chemicals during animal development. The estimated composition of the manure was as follows: 48 kg ha^{-1} N; 20 kg ha^{-1} P; 46 kg ha^{-1} K; 44 kg ha^{-1} Ca; 7 kg ha^{-1} Mg; 25 kg ha^{-1} S (Sulphur); 2,5 kg ha^{-1} Fe (Iron); 1 kg ha^{-1} Mn (Manganese); 125 g ha^{-1} Cu (Copper); and 950 g ha^{-1} Zn (Zinc).

The organic liquid fertilizer used was a commercial product comprising 30 g L^{-1} organic carbon and 2 g L^{-1} K_2O (Potassium oxide). It is certified for organic systems by Ecocert Brazil and is commonly used by organic farmers in the region. Seed inoculation with organic liquid fertilizer was performed at an inoculation rate of 200 mL 50 kg^{-1} common bean seeds, and foliar application was performed at an rate of 750 mL ha^{-1} at the V_{4-5} stage, followed by a second application 10 days later, as recommended by the product manufacturer.

Sowing was performed on 05/21/2018, 04/25/2019, and 05/05/2020, at a plant density of 12 plants m^{-1}, resulting in 72 kg ha^{-1} of common bean seeds. The cultivar BRS Estilo was used for the 2018 and 2020 experiments and the IAC Sintonia cultivar was used for the 2019 experiment. Both cultivars are in the 'carioca' commercial group and present growth habit type II.

The experiments were performed following the Brazilian criteria of regulation for organic system production, according to Law No. 10,831 of 2003, from The Brazilian Ministry of Agriculture, Livestock, and Food Supply, and all its current regulatory instructions. Two applications of 0.5% neem oil (*Azadirachta indica*) and two foliar applications of the biofertilizer Supermagro I at an application rate of 2% were performed to control pests and diseases. The biofertilizer was prepared using the material available in the experimental area, and comprised a mixture of micronutrients anaerobically fermented in an organic medium with fresh bovine manure (40 L), water (180 L), brown sugar (0.5 kg), milk (1 L), and micronutrients, according to Rodrigues et al. (2009), to provide protection and nutrients for plants. The biofertilizer was anaerobically fermented and used after 45 days. All applications were performed using a backpack sprayer, with a full cone spray tip nozzle and application volume of 200 L ha^{-1}. Pulverization was performed in the afternoon (5–6 pm) under moderate temperatures and low wind incidence.

Spontaneous plant control was achieved using a weeder. In 2018, weed control was performed at 24 and 47 days after sowing (DAS), and in 2019 and 2020, weed control was performed at 22 and 20 DAS, respectively, in a single operation. Harvesting was performed manually at 98, 96, and 100 DAS in 2018, 2019, and 2020, respectively. In 3-m of two lines of each plot, all the plants were uprooted and dried in the sun; the material was manually threshed and the grains dry weight (DW) was recorded. The data was converted to kg ha^{-1} at 13% moisture.

The economic analysis was performed based on the total operational expenses (TOE) structure used by the Instituto de Economia Agrícola (IEA) and proposed by Matsunaga et al. (1976). The effective operational expenses (EOE) comprise the sum of expenses for mechanical operations (including depreciation), irrigation, manual operations, and agricultural inputs used during crop management and N supply. The mean expenses of the mechanical operations up to September 2021 were updated and indexed by the general market price index (IGP-M).

For manual operations, the requirements of labor in the different stages of management in organic common bean cultivation was assessed; for each operation, the number of worker/day was multiplied by the technical labor force coefficient and payment in each region. The input expenses were calculated based on a multiplicative factor, considering the amount of material and market prices updated in August 2021.

The costs for the inoculation were approximately R$ 8.00 and R$ 23.00 for *R. tropici* and *A. brasilense*, respectively, at an application rate of 200 mL ha^{-1}, considering the total amount for each treatment. The cost of poultry manure was R$ 350.00 per ton. For the organic liquid fertilizer, the cost for leaf application at 750 mL ha^{-1} was R$ 69.00 and for the seed inoculation was approximately R$ 33.00 at an inoculation rate of 360 mL ha^{-1}. To calculate the TOE, we considered other operational expenses to represent 5% of the EOE (Matsunaga et al., 1976). Interest in agricultural loans was calculated using an annual interest rate of 6% (the interest rate for rural credit operations for medium-sized farmers), calculated as 50% of the EOE. This methodology has been used in several studies for the economic evaluation of crops (Galindo et al., 2018; Galindo et al., 2020; Elejalde et al., 2023; Turco et al. 2023).

The profitability of the treatments was estimated according to Martin et al. (1998), considering the following: gross revenue (GR) in R$ per hectare, calculated by multiplying the common bean yield (in number of 60 kg sacks) with the mean price received by farmers; operational income (OI), calculated as the difference between GR and TOE; income index (II), which is the ratio between OI and GR in percentage; the equilibrium price (EP) given a certain operational production cost, as the minimum price calculated to cover this cost, considering the average yield obtained; and the equilibrium yield (EY) given a certain total operating production cost, as the minimum yield necessary to cover this cost, considering the mean price received by the farmers.

The treatment yield was converted to 60 kg sacks (sc), which is the traditional commercial unit in the region. In July 2021, the mean price of common bean sacks received by farmers in São Paulo, Brazil, was R$ 295.66 sc^{-1}. According to the Food Acquisition Program ('Programa de Aquisição de Alimentos – PAA') and National Program of School Feeding ('Programa Nacional de Alimentação Escolar – PNAE'), which articulates the public purchase of food from family farming production, the price of organic and agroecological products can increase up to 30% of that of conventional products (Lima et al., 2019). Thus, in the present study, by increasing the common bean sack price by 30%, the value considered was R$ 384.36 sc ha^{-1} for organic common bean.

Results and Discussion

The TOE of winter common bean crop cultivated in an organic system in Selvíria-MS, Brazil, 2019, was R$ 4,399.93 ha^{-1} (Table 1). This TOE structure model was used individually for all treatments in the three cultivation years, although the reference table presents only one of the studied treatments, seed inoculation with *A. brasilense* and additional inoculation with *R. tropici* at V_{4-5} stage.

Manual operations and input expenses were higher (38.03 and 32.67% of the TOE, respectively) because organic cultivation is usually performed by family farming, which incurs a larger labor force to execute manual operations. Among the mechanical operations, irrigation incurred the highest expense (10.00% TOE), followed by sowing (4.67% TOE). Regarding inputs, the highest expenses were recorded for granulated organic compounds and seeds (11.08 and 13.09% of TOE, respectively).

In studies involving the BRS Estilo cultivar, Silva & Wander (2015) reported that inputs (57.48% of TOE) and mechanized operations (27.36% of TOE) accounted for the highest expenses for conventional production, on average over the four agricultural years analyzed. Regarding inputs, fertilizers, pesticides, and seeds accounted for 19.18, 16.36, and 12.28% of the expenses. Galindo et al. (2020) reported that the highest expenses in conventional cowpeas [*Vigna unguiculata* (L.) Walp.] production under the control treatment (0 kg ha^{-1} of N) were for mechanical operations (24.9% of TOE) and agricultural chemicals, such as fertilizers, insecticides, fungicides, and herbicides (21% of TOE).

The results of the present study reiterate that the expenses related to operations are recovered by the winter common bean crop yield, thereby demonstrating overall profitability across the three cultivation years. Thus, the operating income remained positive in all treatments, even in 2018, which had lower yields and higher TOE due to the increased costs of additional weeder operations and fertilization (organic compounds). This was in contrast to 2019 and 2020, when the natural soil fertility was better (as indicated in Table 2). The use of different cultivars may have also influenced yield owing to the influence of genetic variability.

Comparing the profitability of organic and conventional systems is valuable because, unlike conventional methods,

Table 1. Total operational expense (TOE) per hectare and percentage of each expense for winter common bean crop cultivated in an irrigated organic system. Calculations based on expenses for treatment 6 (T_6) [seed inoculation with *A. brasilense* + additional inoculation (AI) with *R. tropici* at V_{4-5}]. Selviria-MS, Brazil. 2019

Description	Esp.	nº times	Amount	Unitary cost (R$)	Total (R$)	%
A) Mechanical operations						
Field shredder	HM	1	0.50	111.45	55.73	1.27
Plowing	HM	1	0.77	143.95	110.84	2.52
Total area of fertilization	HM	1	0.38	161.92	61.53	1.40
Leveling harrow	HM	1	0.73	123.46	90.13	2.05
Sowing + fertilization	HM	1	1.34	153.20	205.29	4.67
Irrigation	kWh	1	2.200	0.20	440.00	10.00
Subtotal A					963.51	21.90
B) Manual operations						
Foliar applications		5	1.00	73.85	369.25	8.39
Weeder		1	3.00	90.00	270.00	6.14
Common bean harvesting		1	8.00	73.85	590.80	13.43
Common bean threshing		1	6.00	73.85	443.10	10.07
Subtotal B					1,673.15	38.03
C) Inputs						
Granulated organic compound	kg	1	750.00	0.65	487.5	11.08
Mash organic compound	kg	1	750.00	0.15	112.50	2.56
Common bean seed 'IAC Sintonia'	sc	1	72.00	8.00	576.00	13.09
Neem oil	L	2	1.00	75.00	150.00	3.41
Biofertilizer Supermagro I	L	2	4.00	8.68	69.42	1.58
Poultry manure	t	1	0.00	350.00	0.00	0.00
Organic liquid fertilizer	L	3	0.00	92.00	0.00	0.00
Azospirillum brasilense	L	1	0.29	116.67	33.60	0.76
Rhizobium tropici (AI)	L	1	0.20	41.67	8.33	0.19
Subtotal C					1,437.35	32.67
Effective operational expenses (EOE)					4,074.01	92.59
Other expenses (5% EOE)					203.70	4.63
Interest of agriculture loan					122.22	2.78
Total operational expense (TOE)					4,399.93	100.00

HM - hour machine

organic agriculture aims to enhance ecological processes that foster plant nutrition while conserving soil and water resources. Organic systems eliminate agrichemicals and minimize external inputs, thereby contributing to environment improvement and enhancing farm economics (Uematsu & Mishra, 2012). In addition to the economic aspect, the use of N fertilizer in tropical soil has a high potential of environment harm because fertilizer leaching and surface runoff can contaminate groundwater (Sousa et al., 2020).

The highest yields led to higher GR and II in 2018 (33.8 sc ha^{-1}), 2019 (66.3 sc ha^{-1}), and 2020 (59.9 sc ha^{-1}). Thus, the highest II was observed under N supply with *R. tropici* seed inoculation in 2018, *A. brasilense* seed inoculation + additional inoculation with *R. tropici* at V_{4-5} in 2019, and *A. brasilense* + *R. tropici* seed co-inoculation in 2020, with II values of 59.59, 82.74, and 81.20%, respectively (Table 2). In contrast, the lowest II values were observed for the poultry manure application without additional inoculation in all three years, with II values of 14.44, 70.03, and 74.79% in 2018, 2019, and 2020, respectively (Figures 3, 4, and 5).

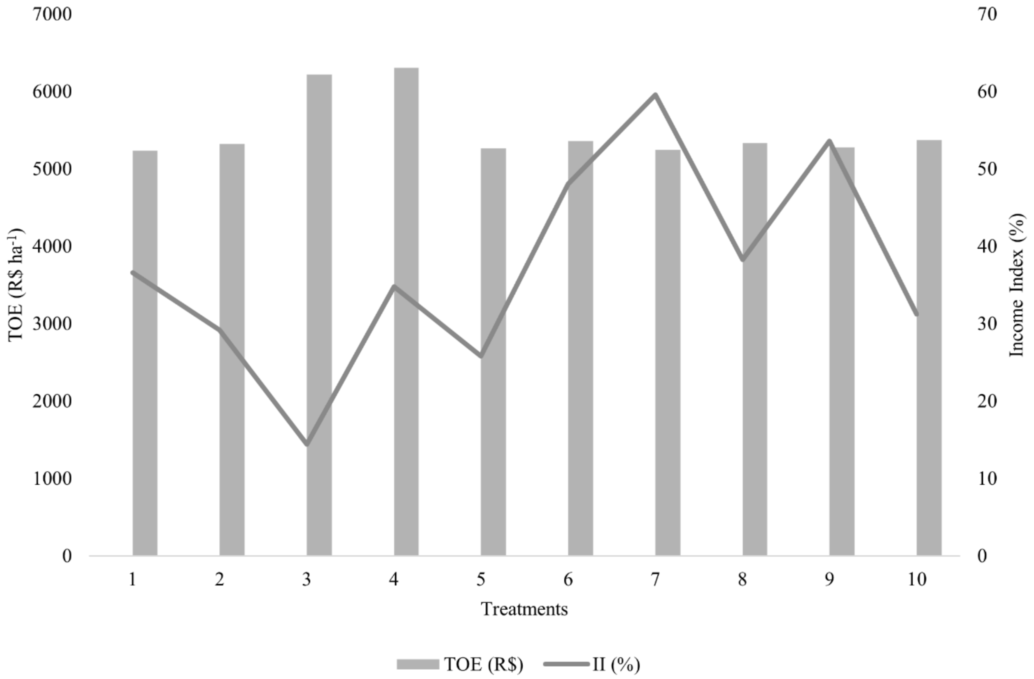
Regarding the minimum yield, farmers had to cover their expenses (EY) every year for all treatments; however, the winter common bean crop yield was higher than the EY. The application of poultry manure with or without additional inoculation led to the highest TOE and EY (Table 2); thus, in these treatments, higher yields were necessary to cover the operating expenses.

In addition to the high quantities of poultry manure required, e.g. 2.5 t ha^{-1} to achieve an expected yield of 1.5 to 2.5 t ha^{-1}, the manure also got scarcer over time due to the decrease in poultry production under organic systems (Padovan et al., 2002); and the inadequate nutrient proportions result in a non-viable production system. Diazotrophic bacteria can provide N to support crop yields above 3,500 kg ha^{-1}; therefore, it is a low-cost and easily applicable technology, leading to higher incomes for farmers cultivating winter common bean crops under an organic system. The use of diazotrophic bacteria is a

Table 2. Winter common bean crop profitability index in organic cultivation system, under different N supplies, in 2018, 2019, and 2020

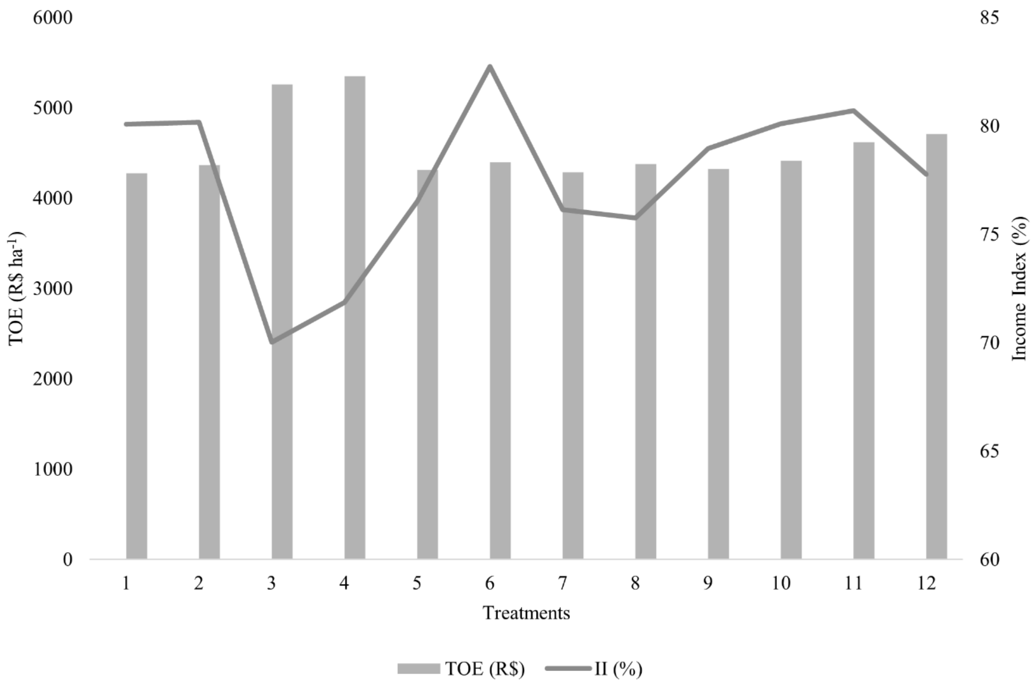
Treat.	AI	Yield (kg ha^{-1})	Yield (sc ha^{-1})	TOE	GR	OI	II (%)	EP (R$ sc^{-1})	EY (sc ha^{-1})
				(R$)					
2018 (Andradina-SP, Brazil)									
1	No	1287	21.5	5230.34	8245.38	3015.04	36.57	243.81	14
2	Yes	1172	19.5	5319.10	7506.93	2187.83	29.14	272.34	14
3	No	1134	18.9	6215.22	7263.97	1048.75	14.44	328.87	16
4	Yes	1509	25.2	6303.98	9667.95	3363.97	34.80	250.62	16
5	No	1108	18.5	5266.63	7095.78	1829.15	25.78	285.28	14
6	Yes	1608	26.8	5355.39	10299.87	4944.48	48.01	199.85	14
7	No	2025	33.8	5243.30	12974.78	7731.48	59.59	155.33	14
8	Yes	1348	22.5	5332.06	8636.35	3304.28	38.26	237.30	14
9	No	1774	29.6	5279.59	11366.72	6087.13	53.55	178.53	14
10	Yes	1218	20.3	5368.35	7802.32	2433.97	31.20	264.46	14
2019 (Selvíria-MS, Brazil)									
1	No	3347	55.8	4274.89	21444.02	17169.13	80.06	76.62	11
2	Yes	3433	57.2	4363.65	21990.25	17626.60	80.16	76.27	11
3	No	2739	45.7	5259.77	17547.94	12288.18	70.03	115.21	14
4	Yes	2967	49.5	5348.52	19007.37	13658.84	71.86	108.16	14
5	No	2865	47.7	4311.18	18353.18	14042.00	76.51	90.29	11
6	Yes	3978	66.3	4399.93	25486.26	21086.32	82.74	66.36	11
7	No	2805	46.8	4287.85	17971.40	13683.55	76.14	91.71	11
8	Yes	2818	47.0	4376.61	18054.73	13678.12	75.76	93.17	11
9	No	3206	53.4	4324.14	20537.94	16213.81	78.95	80.92	11
10	Yes	3461	57.7	4412.89	22173.96	17761.07	80.10	76.49	11
11	No	3735	62.2	4619.21	23923.93	19304.71	80.69	74.21	12
12	Yes	3307	55.1	4707.97	21185.76	16477.79	77.78	85.41	12
2020 (Selvíria-MS, Brazil)									
1	No	2822	47.0	4274.89	18076.39	13801.50	76.35	90.90	11
2	Yes	3084	51.4	4363.65	19758.67	15395.02	77.92	84.88	11
3	No	3256	54.3	5259.77	20861.00	15601.23	74.79	96.91	14
4	Yes	3501	58.3	5348.52	22425.70	17077.17	76.15	91.67	14
5	No	3552	59.2	4311.18	22751.01	18439.84	81.05	72.83	11
6	Yes	3498	58.3	4399.93	22408.64	18008.70	80.37	75.47	11
7	No	3453	57.6	4287.85	22123.04	17835.19	80.62	74.50	11
8	Yes	2998	50.0	4376.61	19207.74	14831.14	77.21	87.58	11
9	No	3591	59.9	4324.14	23005.91	18681.77	81.20	72.24	11
10	Yes	3344	55.7	4412.89	21424.19	17011.30	79.40	79.17	11
11	No	3266	54.4	4539.45	20924.19	16384.74	78.31	83.39	12
12	Yes	3479	58.0	4628.21	22285.77	17657.56	79.23	79.82	12

Treatments (Treat.); Additional inoculation (AI); yes - with additional inoculation; no - without additional inoculation; 1 - no inoculation (control); 2 - no inoculation + AI with *R. tropici*; 3 - no inoculation + poultry manure as top dressing; 4 - no inoculation + poultry manure as top dressing + AI with *R. tropici*; 5 - seed inoculation with *A. brasilense*; 6 - seed inoculation with *A. brasilense* + AI with *R. tropici*; 7 - seed inoculation with *R. tropici*; 8 - seed inoculation with *R. tropici* + AI with *R. tropici*; 9 - seed co-inoculation with *A. brasilense* + *R. tropici*; 10 - seed co-inoculation with *A. brasilense* + *R. tropici*+ AI with *R. tropici*; 11 - seed inoculation and leaf application with organic liquid fertilizer; 12 - seed inoculation and leaf application with organic liquid fertilizer + AI with *R. tropici*. Common bean yield (YIELD), total operational expenses (TOE), gross revenue (GR), operational income (OI), income index (II), equilibrium price (EP), and equilibrium yield (EY)



1 - No inoculation (control); 2 - no inoculation + AI with *R. tropici*; 3 - no inoculation + poultry manure as top dressing; 4 - no inoculation + poultry manure as top dressing + AI with *R. tropici*; 5 - seed inoculation with *A. brasilense*; 6 - seed inoculation with *A. brasilense* + AI with *R. tropici*; 7 - seed inoculation with *R. tropici*; 8 - seed inoculation with *R. tropici* + AI with *R. tropici*; 9 - seed co-inoculation with *A. brasilense* + *R. tropici*; 10 - seed co-inoculation with *A. brasilense* + *R. tropici*+ AI with *R. tropici*

Figure 3. Winter common bean crop total operational expense (TOE) and income index (II) under different N supplies, Andradina-SP, Brazil. 2018

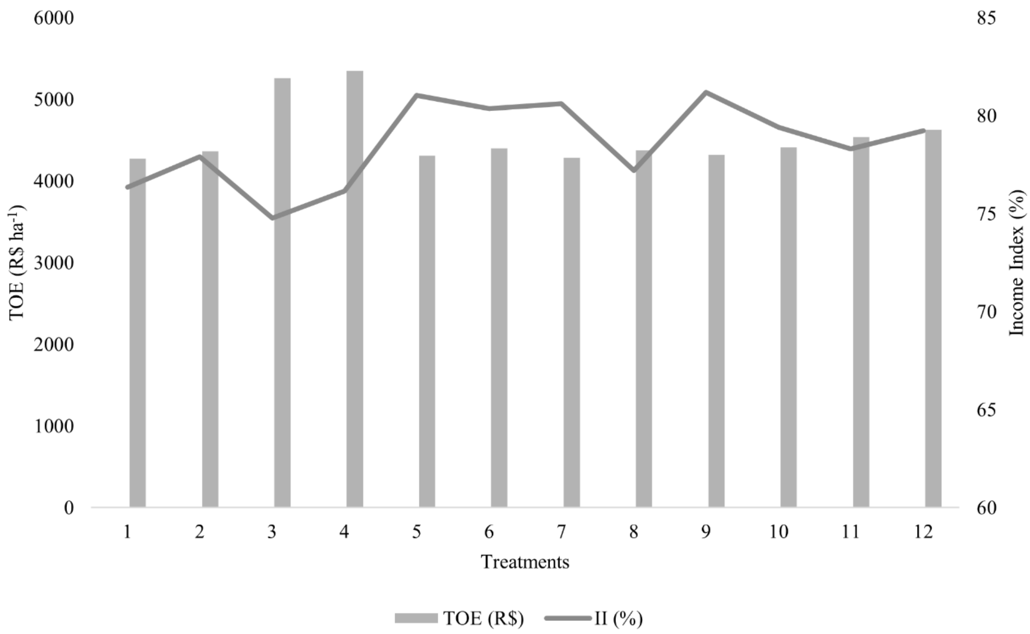


1 - No inoculation (control); 2 - no inoculation + AI with *R. tropici*; 3 - no inoculation + poultry manure as top dressing; 4 - no inoculation + poultry manure as top dressing + AI with *R. tropici*; 5 - seed inoculation with *A. brasilense*; 6 - seed inoculation with *A. brasilense* + AI with *R. tropici*; 7 - seed inoculation with *R. tropici*; 8 - seed inoculation with *R. tropici* + AI with *R. tropici*; 9 - seed co-inoculation with *A. brasilense* + *R. tropici*; 10 - seed co-inoculation with *A. brasilense* + *R. tropici*+ AI with *R. tropici*; 11 - seed inoculation and leaf application with organic liquid fertilizer; 12 - seed inoculation and leaf application with organic liquid fertilizer + AI with *R. tropici*

Figure 4. Winter common bean crop total operational expense (TOE) and income index (II) under different N supplies, Selvíria-MS, Brazil. 2019

well-established technology that is environmentally friendly and ensures food security, as observed in recent studies on grain legumes (Steiner et al., 2019; Bettiol et al., 2020; Moretti et al., 2020; Barbosa et al., 2021; Zilli et al., 2021; Martins et al., 2022).

As stated by Galindo et al. (2020), even in conventional systems, seed co-inoculation with diazotrophic bacteria (*Bradyrhizobium* spp. and *A. brasilense*) without N fertilizer application via topdressing provides higher economic and technical viability in cowpea. In irrigated common bean (*Phaseolus vulgaris* L.), Ferreira et al. (2020) observed higher income under diazotrophic bacteria application; *R. tropici* seed inoculation with 3 leaf applications of *A. brasilense* provided higher economic gains compared with 80 kg ha^{-1} of N applied



1 - No inoculation (control); 2 - no inoculation + AI with *R. tropici*; 3 - no inoculation + poultry manure as top dressing; 4 - no inoculation + poultry manure as top dressing + AI with *R. tropici*; 5 - seed inoculation with *A. brasilense*; 6 - seed inoculation with *A. brasilense* + AI with *R. tropici*; 7 - seed inoculation with *R. tropici*; 8 - seed inoculation with *R. tropici* + AI with *R. tropici*; 9 - seed co-inoculation with *A. brasilense* + *R. tropici*; 10 - seed co-inoculation with *A. brasilense* + *R. tropici*+ AI with *R. tropici*; 11 - seed inoculation and leaf application with organic liquid fertilizer; 12 - seed inoculation and leaf application with organic liquid fertilizer + AI with *R. tropici*

Figure 5. Winter common bean crop total operational expense (TOE) and income index (II) under different N supplies, Selvíria-MS, Brazil. 2020

as N fertilizer. Thus, the methods to intensify sustainability in farms and production systems depend on novel agricultural approaches that ensure consistent yields and ecological responsibility (Muhie, 2022).

The yield in the organic system was similar to that in the conventional system, thereby indicating that it is better to cultivate common beans in organic systems as it is safer for farmers, consumers, and the environment, and also because of the higher price of organic beans (Carvalho & Wanderley, 2007). Organic common beans in Brazil are sold at 30% higher prices than conventional beans, and government-assured purchases can stimulate the transition to the agroecological system (Darolt et al., 2016).

However, sustainability is a complex issue in economic analyses due to the difficulty in calculating the costs of organic certification, and the monetary value of the numerous ecological benefits of organic systems, called 'ecosystem services' (plant species diversity, soil formation, carbon sequestration, erosion, and pollution reduction) (Fess & Benedito, 2018).

Thus, studies acknowledging the profitability of organic systems in providing food are crucial, as natural resources are limited. The present study indicates that organic-irrigated common bean production with diazotrophic bacteria application is a well-established technology because of its low cost, easy application, and environmental sustainability.

Conclusions

1. Using diazotrophic bacteria in seed inoculation and co-inoculation (*Azospirillum brasilense* and *Rhizobium tropici*) provides higher yields and profitability over the years for winter common bean cultivation.

2. Seed inoculation with *A. brasilense* and additional inoculation with *R. tropici* at the V_{4-5} stage provides the highest yield, thereby providing the highest income index (83%).

3. Application of poultry manure topdressing at the V_3 stage is not recommended as a N supply method for organic systems because of its high cost and low yield and profitability.

Literature Cited

Barbosa, J. Z.; Hungria, M.; da Silva Sena, J. V.; Poggere, G.; dos Reis, A. R.; Corrêa, R. S. Meta-analysis reveals benefits of co-inoculation of soybean with *Azospirillum brasilense* and *Bradyrhizobium* spp. in Brazil. Applied Soil Ecology, v.163, p.103913, 2021.

Bettiol, J. V. T.; Filla, V. A.; Leal, F. T.; Coelho, A. P.; Meirelles, F. C.; Lemos, L. B.; Bossolani, J. W. Sustainable production of common beans: inoculation, co-inoculation and mineral fertilization in early-cycle cultivars. Journal of Plant Nutrition, v.44, p.16-28, 2020.

Carvalho, W. P. D.; Wanderley, A. L. Avaliação de cultivares de feijão (*Phaseolus vulgaris*) para o plantio em sistema orgânico no Distrito Federal. Ciência e Agrotecnologia, v.31, p.605-611, 2007. https://doi.org/10.1590/S1413-70542007000300002

Conceição, L. T.; Silva, G. N.; Holsback, H. M. S.; Oliveira, C. de F.; Marcante, N. C.; Martins, É. de S.; Santos, F. L. S.; Santos, E. F. Potential of basalt dust to improve soil fertility and crop nutrition. Journal of Agriculture and Food Research, v.10, p.1-8, 2022. https://doi.org/10.1016/j.jafr.2022.100443

Darolt, M. R.; Lamine, C.; Brandenburg, A.; Alencar, M. D. C. F.; Abreu, L. S. Redes alimentares alternativas e novas relações produção-consumo na França e no Brasil. Ambiente & Sociedade, v.19, p.1-22, 2016. https://doi.org/10.1590/1809-4422ASOC121132V1922016

Elejalde, D. A. G.; Soares, A. B.; de Lima, J. D.; Missio, R. L.; Assmann, T. S.; Tatto, W. H.; Deifeld, F. L. C.; Bortolli, M. A.; Bernadon, A.; Levinski-Huf, F.; Maccari, M.; Barriga, P. A. B; Rhoden, A. C. Economic viability in the integrated crop-livestock system with nitrogen fertilization system and sward canopy heights. Frontiers in Sustainable Food Systems, v.6, p.940946, 2023.

FAOSTAT - Food and Agriculture Organization of the United Nations. Crops 2021. Available on: http://www.fao.org/faostat/en/#data/QCL/visualize. Accessed on: Sep. 2023

Ferreira, E. P. B.; Silva, O. F.; Wander, A. E. Economics of rhizobia and azospirilla co-inoculation in irrigated common bean in commercial and family farming. Pesquisa Agropecuária Brasileira, v.55, p.1-9, 2020.

Fess, T. L.; Benedito, V. A. Organic versus conventional cropping sustainability: a comparative system analysis. Sustainability, v.10, p.1-42, 2018. https://doi.org/10.3390/su10010272

Galindo, F. S.; Teixeira Filho, M.; Buzetti, S.; Ludkiewicz, M. G.; Rosa, P. A.; Tritapepe, C. A. Technical and economic viability of co-inoculation with *Azospirillum brasilense* in soybean cultivars in the Cerrado. Revista Brasileira de Engenharia Agrícola e Ambiental, v.22, p.51-56, 2018. https://doi.org/10.1590/1807-1929/agriambi.v22n1p51-56

Galindo, F. S.; Teixeira, M.; Silva, E. C. D.; Buzetti, S.; Fernandes, G. C.; Rodrigues, W. L. Technical and economic viability of cowpea co-inoculated with *Azospirillum brasilense* and *Bradyrhizobium spp.* and nitrogen doses. Revista Brasileira de Engenharia Agrícola e Ambiental, v.24, p.304-311, 2020. https://doi.org/10.1590/1807-1929/agriambi.v24n5p304-311

Le Campion, A.; Oury, F. X.; Heumez, E.; Rolland, B. Conventional versus organic farming systems: dissecting comparisons to improve cereal organic breeding strategies. Organic Agriculture, v.10, p.63-74, 2020.

Lima, S. K.; Galiza, M.; Valadares, A. A.; Alves, F. Produção e consumo de produtos orgânicos no mundo e no Brasil. Texto para discussão. Instituto de Pesquisa Econômica Aplicada - Ipea, 2019. https://repositorio.ipea.gov.br/bitstream/11058/9678/1/TD_2538.pdf

Los, F. G. B.; Demiate, I. M.; Dornelles, R. C. P.; Lamsal, B. Enzymatic hydrolysis of Carioca bean (*Phaseolus vulgaris* L.) protein as an alternative to commercially rejected grains. LWT, v.125, p.1-8, 2020. https://doi.org/10.1016/j.lwt.2020.109191

Martin, N. B.; Serra, R.; Oliveira, M. D. M.; Ângelo, J. A.; Okawa, H. Sistema integrado de custos agropecuários - "CUSTAGRI". Informações Econômicas: São Paulo, v.28, p.7-28, 1998. http://www.iea.sp.gov.br/ftpiea/ie/1998/tec1-0198.pdf

Martins, J. T.; Rasmussen, J.; Eriksen, J.; Arf, O.; De Notaris, C.; Moretti, L. G. Biological N fixation activity in soybean can be estimated based on nodule dry weight and is increased by additional inoculation. Rhizosphere, v.24, p.100589, 2022.

Matsunaga, M.; Bemelmans, P. F.; Toledo, P. N. E.; Dulley, R. D.; Okawa, H.; Pedroso, I. A. Metodologia de custo de produção utilizada pelo IEA. Agricultura em São Paulo, v.23, p.1-17, 1976.

Moretti, L. G.; Crusciol, C. A. C.; Bossolani, J. W.; Momesso, L.; Garcia, A.; Kuramae, E. E.; Hungria, M. Bacterial consortium and microbial metabolites increase grain quality and soybean yield. Journal of Soil Science and Plant Nutrition, v.20, p.1923-1934, 2020.

Muhie, S. H. Novel approaches and practices to sustainable agriculture. Journal of Agriculture and Food Research, v.10, p.100446, 2022.

Padovan, M. P.; Almeida, D. L.; Guerra, J. G. M.; Ribeiro, R. D. L. D.; Ndiaye, A. Avaliação de cultivares de soja, sob manejo orgânico, para fins de adubação verde e produção de grãos. Pesquisa Agropecuária Brasileira, v.37, p.1705-1710, 2002. https://doi.org/10.1590/S0100-204X2002001200005

Pereira, L. B.; Arf, O.; Belmiro dosSantos, N. C.; Oliveira, A. E. Z. de; Komuro, L. K. Fertilization management in bean crop under organic production system. Pesquisa Agropecuária Tropical, v.45, p.29-38, 2015.

Raij, B. Van; Andrade, J. C.; Cantarella, H.; Quaggio, J. A. Análise química para avaliação da fertilidade de solos tropicais. Campinas: Instituto Agronômico, 2001. 285p.

Rezende, A. A.; Pacheco, M. T. B.; Silva, V. S. N. D.; Ferreira, T. A. P. D. C. Nutritional and protein quality of dry Brazilian beans (*Phaseolus vulgaris* L.). Food Science and Technology, v.38, p.421-427, 2017. https://doi.org/10.1590/1678-457X.05917

Rodrigues, A. C.; Cavalcante, L. F.; Oliveira, A. P. D.; Sousa, J. T. D.; Mesquita, F. O. Produção e nutrição mineral do maracujazeiro-amarelo em solo com biofertilizante supermagro e potássio. Revista Brasileira de Engenharia Agrícola e Ambiental, v.13, p.117-124, 2009. https://doi.org/10.1590/S1415-43662009000200002

Silva, O. F.; Wander, A. E. Viabilidade econômica da cultivar de feijão-comum BRS Estilo. Revista Brasileira de Desenvolvimento Regional, v.3, p.223-242, 2015.

Sousa, M. A.; Oliveira, M. M.; Damin, V.; Brito Ferreira, E.P. Productivity and economics of inoculated common bean as affected by nitrogen application at different phenological phases. Journal of Soil Science and Plant Nutrition, v.20, p.1848-1858, 2020. https://doi.org/10.1007/s42729-020-00256-4

Steiner, F.; Ferreira, H. C. P.; Zuffo, A. M. Can co-inoculation of *Rhizobium tropici* and *Azospirillum brasilense* increase common bean nodulation and grain yield? Semina: Ciências Agrárias, v.40, p.81-98, 2019.

Turco, P. H. N.; Martins, A. N.; Firetti, R.; Pinatti, E.; Alves Neto, A.; Polis, K. T. F. Custos e lucratividade de Coffea arabica L. (cv. Catuaí IAC 144 e IAPAR 59) para a microrregião de Marília, São Paulo, Brasil. Revista de Economia e Sociologia Rural, p. e276484, 2023.

Uematsu, H.; Mishra, A. K. Organic farmers or conventional farmers: Where's the money? Ecological Economics, v.78, p.55-62, 2012.

Zilli, J. É.; Pacheco, R. S.; Gianluppi, V.; Smiderle, O. J.; Urquiaga, S.; Hungria, M. Biological N_2 fixation and yield performance of soybean inoculated with *Bradyrhizobium*. Nutrient Cycling in Agroecosystems, v.119, p.323-336, 2021.