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Agroeconomic response of inoculated common bean as affected by nitrogen application along the growth cycle[1]

Resposta agroeconômica do feijão-comum inoculado em função da aplicação de nitrogênio ao longo do ciclo de crescimento

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Highlights

Increased nodulation in inoculated common bean.
N-fertilizer decreases nodulation.
Inoculation promotes high net revenue.

Abstract

Biological nitrogen fixation (BNF) is an alternative for the supply of N, aiming at reducing production costs and environmental impacts of common bean crops. This work aimed to evaluate the agroeconomic performance of the inoculated common bean subjected to N-fertilizer application at different phenological phases. N-fertilizer, in a total of 90 kg ha^{-1} as urea, was applied at 3 phases: planting (P), phenological phase V4 (V4), and phenological phase R5 (R5) of the common bean, in two field experiments. The used treatments were: $P_0V4_0R5_0$, $P_0V4_{45}R5_{45}$, $P_0V4_{90}R5_0$, $P_0V4_0R5_{90}$, $P_{30}V4_{30}R5_{30}$, $P_{30}V4_{60}R5_0$, $P_{30}V4_0R5_{60}$, $P_{60}V4_{30}R5_0$, $P_{60}V4_0R5_{30}$, and $P_{90}V4_0R5_0$. All treatments were inoculated with peat inoculum containing the commercial strain SEMIA 4077 (*Rhizobium tropici*). The number of nodules (NN), nodule dry mass (NDM), leaf area index (LAI), root dry mass (RDM), shoot dry mass (SDM), grain yield (GY), production cost (PC), gross revenue (GR), net revenue (NR), and benefit-cost ratio (BCR) were determined. Inoculated treatment

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($P_0V4_0R5_0$) showed higher NN and NDM. Although inoculated treatment ($P_0V4_0R5_0$) showed lower values of LAI, RDM, SDM, and GY, inoculation can result in GR, NR, and BCR equal to N-fertilized treatments, depending on the prices achieved for grains sale.

Key words: Urea. Biological nitrogen fixation. Inoculant. *Phaseolus vulgaris* L.

Resumo

A fixação biológica de nitrogênio (FBN) é uma alternativa para o fornecimento de N, visando reduzir os custos de produção e os impactos ambientais da cultura do feijoeiro. Este trabalho teve como objetivo avaliar o desempenho agroeconômico do feijão inoculado submetido à aplicação de N-fertilizante em diferentes fases fenológicas. O fertilizante N, em um total de 90 kg ha^{-1} na forma de ureia, foi aplicado em 3 fases: plantio (P), fase fenológica V4 (V4) e fase fenológica R5 (R5) do feijoeiro, em dois experimentos de campo. Os tratamentos utilizados foram: $P_0V4_0R5_0$, $P_0V4_{45}R5_{45}$, $P_0V4_{90}R5_0$, $P_0V4_0R5_{90}$, $P_{30}V4_{30}R5_{30}$, $P_{30}V4_{60}R5_0$, $P_{30}V4_0R5_{60}$, $P_{60}V4_{30}R5_0$, $P_{60}V4_0R5_{30}$ e $P_{90}V4_0R5_0$. Todos os tratamentos foram inoculados com inóculo de turfa contendo a cepa comercial SEMIA 4077 (*Rhizobium tropici*). O número de nódulos (NN), massa seca do nódulo (NDM), índice de área foliar (IAF), massa seca da raiz (RDM), massa seca da parte aérea (SDM), rendimento de grãos (GY), custo de produção (PC), receita bruta (GR), receita líquida (RL) e relação custo-benefício (BCR) foram apurados. O tratamento inoculado ($P_0V4_0R5_0$) apresentou maior NN e NDM. Embora o tratamento inoculado ($P_0V4_0R5_0$) tenha apresentado menores valores de LAI, RDM, SDM e GY, a inoculação pode resultar em GR, NR e BCR semelhantes aos tratamentos fertilizados com N, dependendo dos preços obtidos para a venda dos grãos.

Palavras-chave: Ureia. Fixação biológica de nitrogênio. Inoculante. *Phaseolus vulgaris* L.

Introduction

The common bean (*Phaseolus vulgares* L.) has great socioeconomic and nutritional importance in Brazil. It is one of the main components of the Brazilian diet, especially for the poorest population that has this food as their main protein source (Nalepa & Ferreira, 2013; Carvalho et al., 2014). According to Mitidiero et al. (2017), 70% of the national common bean production comes from family farming systems, making this crop important for this productive segment.

In Brazil, common bean is grown in three different cropping seasons. The first cropping season takes place during spring-summer, mainly in the South and Southeast regions. The second cropping season happens during summer-autumn in the South, Southeast and Midwest regions. Finally, the third cropping season is grown during winter in tropical areas under sprinkler irrigation, mainly in the states of Minas Gerais, São Paulo, Goiás, Distrito Federal, Tocantins, Mato Grosso and the western region of Bahia state (Silva et al., 2012).

A large part of family farming producers of common bean is concentrated in the first cropping season, also known as water-cropping season, which occurs during the rainy period. In this season, the crop is conducted with low use of technologies, such as fertilizers, insecticides, fungicides, and mechanization. The water-cropping season occupies approximately 519 thousand hectares, with an average productivity of 1419 kg ha^{-1}. In Goiás state 40 thousand hectares are cultivated in the water-cropping season, with an average productivity of 2400 kg ha^{-1} (Companhia Nacional de Abastecimento [CONAB], 2022).

Considering that the Brazilian common bean yield comes predominantly from family farming and that these farmers have difficulties in accessing agricultural credit (Zani & Costa, 2014), national bean productivity is negatively impacted. One of the main problems faced by these producers is the high cost of inputs, mainly nitrogen fertilizers (Martins et al., 2013).

In this context, biological nitrogen fixation (BNF) is an alternative for the N supply aiming at reducing production costs and increasing the productivity of the common bean (Mingotte et al., 2014). Studies with BNF in common bean have shown positive results in increasing the yield (Hungria et al., 2000, 2003). Also, the low cost of inoculant facilitates the use of BNF in the family farming systems, also enabling the reduction of N-fertilizer use (Oliveira et al., 2014).

Besides its benefits on reducing production costs, BNF is also a key factor under environmental aspects, since the use of N-fertilizers contributes to increased environmental risks, such as groundwater contamination with nitrite (Bortolotto et al., 2012) and greenhouse gas emission increasing (Siqueira et al., 2011).

Although advantages of the use of BNF over N fertilizers have been pointed out, noneconomic analysis for the water cropping season is available. Thus, this study aimed to evaluate the agroeconomic performance of N-fertilizer splitting at different phenological phases and its influence on the development and production of the common bean cultivated in the water-cropping season with inoculation.

Material and Methods

Site description

The experiments were carried out in the water-cropping season in the experimental area of Embrapa Arroz e Feijão, located in the municipality of Santo Antonio de Goiás, Goiás State, Brazil, under the coordinates 16º29`11"S, 49º17`59"O and altitude of 823m.

According to Köppen's classification, the climate of the region is Aw, tropical savanna, with a dry season in the winter and a rainy season in the summer. The temperature and precipitation conditions that occurred during the conduction of the experiments are shown in Figure 1.

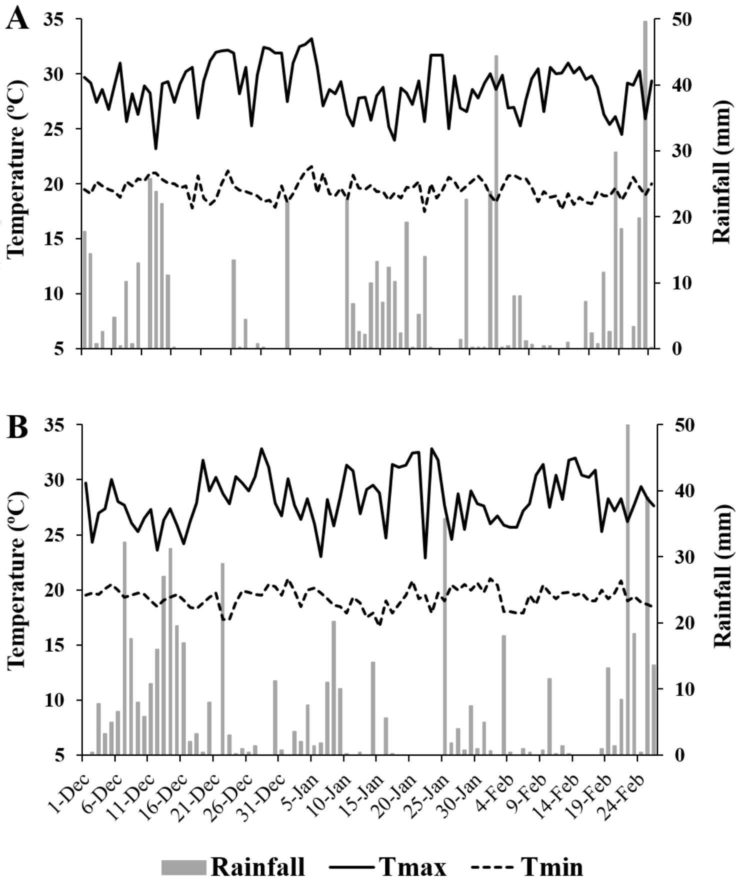

Figure 1. Rainfall, maximum temperature (Tmax), and minimum temperature (Tmin) during the conduction of the experiments in the water-cropping seasons of 2016-2017 (A) and 2017-2018.

Soil chemical and granulometry analysis

In each site, at the onset of experimentation, 10 soil subsamples (0–20 cm) were taken to evaluate soil chemical properties and soil granulometry. Soil chemical analysis followed basic procedures (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2017). Before being analyzed, soil samples were dried (60 °C for 48 h) and sieved (2-mm). Soil pH was determined in 0.01 M CaCl2 (1:2.5; soil/solution), after agitation for 1 h. Exchangeable Ca^{2+}, Mg^{2+}, and Al^{3+} were determined in the extract obtained with 1.0 mol L^{-1} KCl (1:10; soil/solution) after agitation for 10 min. P and K contents were evaluated in the Mehlich-1 (0.05 mol L^{-1} HCl+0.0125 mol L^{-1} H_2SO_4) extract (1:10; soil/solution) after agitation for 10 min. Aluminum was determined by titration with 0.015 Mo L^{-1} standardized NaOH, using bromothymol blue as indicator. Concentrations of Ca^{2+} and Mg^{2+} were determined in an atomic absorption spectrophotometer, K in a flame photometer and P by colorimetry, using the molybdenum-blue method and ascorbic acid as reducing agent. Organic matter was determined by Walkley & Black method. On the granulometry analysis the quantities of clay, silt and sand were determined according to the methodology described in EMBRAPA (2017). Soil characteristics before sowing at each site are shown in Table 1.

Table 1
Result of chemical and physical analysis of soil related to experiments conducted in the water-cropping seasons of 2016-2017 and 2017-2018

Season	pH	P	K	Ca	Mg	Al	H+Al	MO
	Chemical attributes							
	H_2O	mg dm^{-3}		mmol$_c$ dm^{-3}				g kg^{-1}
2016/17	5.50	9.60	69.00	22.00	12.00	1.00	31.00	37.20
2017/18	5.70	8.50	114.00	35.60	18.00	0.00	24.00	39.34
	Physical attributes							
	Clay	Silt	Sand	Soil classification				
	g kg^{-1}							
2016/17	385.00	248.00	367.00	Ferralsol				
2017/18	496.00	265.00	239.00	Ferralsol				

Field experiments settlement

The cultivar of common bean Pérola was used in winter crop experiments in 2017 and 2018, which were conducted in a randomized block design with four replicates. The plots were composed by 6 lines of 4.0 meters in length, 0.45m between line and 1.0 meter between plots. Sowing occurred by placing 16 seeds per meter manually. Both years the experiments were installed in areas with central pivot irrigation.

Phosphorus and K fertilization were performed according to the results of soil analysis and crop needs using the dose of 360 kg ha^{-1} of formula 00-30-10 (N-P-K) applied in furrow. Besides the inoculated treatment without N-fertilizer ($P_0V4_0R5_0$), nine treatments were composed by the inoculation plus the N-fertilizer application. A total of 90 kg ha^{-1} of N in the form of urea was applied at three times: planting (P), phenological phase V4 (V4) and phenological phase R5 (R5) and, in each of these times, the combination or sole rate corresponding to 0, 30, 45, 60 or 90 kg ha^{-1}. Thus, the treatments used were: $P_0V4_0R5_0$, $P_0V4_{45}R5_{45}$, $P_0V4_{90}R5_0$, $P_0V4_0R5_{90}$, $P_{30}V4_{30}R5_{30}$, $P_{30}V4_{60}R5_0$, $P_{30}V4_0R5_{60}$, $P_{60}V4_{30}R5_0$, $P_{60}V4_0R5_{30}$, and $P_{90}V4_0R5_0$, where the N rates used are represented by the subscribed numbers.

All treatments were inoculated with peat inoculum, containing the commercial strain SEMIA 4077 (*Rhizobium tropici*), using two rates ha^{-1}, corresponding to 500 g of peat inoculum for each 50 kg of seeds. To facilitate the inoculum adhesion to the seeds, 300 mL of a 10% sugar solution (100 g of sugar in 1 liter of water) were used for each 50 kg of seeds.

When necessary, herbicides based on Fomesafen and Flumioxazine were used at the dosage indicated for common bean crop. It was also necessary to use Metconazole-based fungicide and Imidacloprid + Beta-cyfluthrin-based insecticide at the recommended doses for culture.

Data collection

For both water-cropping seasons, 2016-2017 and 2017-2018, determination of nodulation and plant growth parameters were performed at V4 and R5 phenological phases, except in 2017-2018 when these parameters were only evaluated at V4. Five plants were randomly collected from each plot using a straight shovel, by removing a 25 cm radius soil block. The roots were separated from the shoots and placed in plastic bags. After washing, the roots were left in the shade to dry until the detachment of the nodules, which were counted to determine the number of nodules (NN). The shoots were packed in paper bags and taken to the laboratory where the leaves were detached and passed in equipment to determine the leaf area index (LAI). Nodules, roots and shoots were then placed in an air-forced dryer at 65 ºC until constant weight was obtained (approximately 72 h) and then weighed to determine nodule dry mass (NDM), root dry mass (RDM) and shoot dry mass (SDM).

At the R9 phenological phase a useful area of 4.05 m^2 per plot was collected to determine grain yield (GY), being eliminated lines 1, 5, and 6, as well as 0.50 m from each end of each plot. The grains were weighed, and the moisture corrected to 13% and GY expressed in kg ha^{-1}.

Economic analysis

All costs related to the acquisition of inputs, planting operations, management and harvesting were computed to determine the production cost (PC). Data for evaluation of the production cost and value of the common bean bag in the Goiás state were obtained from the Federação da Agricultura e Pecuária de Goiás [FAEG] (2018). All the values were obtained in Brazilian Reais (R$) and converted to American Dollar (US$). December-2016 was used as a reference to obtain the planting and management costs of the 2016/17 experiment, and December-2017 for the 2017-2018 experiment as well. For the sale values of the common bean bag, March-2017 was used as the reference month for the 2016-2017 experiment, and March-2018 for the 2017-2018 experiment as well.

On the economic analysis Gross Revenue (GR), Production cost (PC), Net Revenue (NR), and Benefit-Cost Ratio (BCR) were evaluated. GR was obtained for each treatment by selling grain production, transformed into 60 kg bags, using as index the values of R$ 146.82 (=US$ 47.05) bag^{-1} for the 2016-2017 cropping season and R$ 80,47 (=US$ 24.60) bag^{-1} to 2017-2018 one (FAEG, 2018). For the determination of the PC, it was considered all the consumed inputs and operations carried out from pre-planting to harvest, with the values expressed in US$ ha^{-1}. The NR was obtained subtracting from GR the value of PC. Finally, the BCR ratio was calculated by dividing the value of GR by the PC, expressing how much US$ return for each US$ invested.

Statistical analysis

Data from each experiment were first submitted to tests of normality and homogeneity of variances for each variable and then to analysis of variance (ANOVA). When confirming a statistically significant value in the F test ($p \leq 0.05$), mean values were compared by Skott-Knott test at 5% of significance using the software SISVAR (Ferreira, 2019).

Results and Discussion

Nodulation of inoculated common bean under N-fertilizer splitting

The number of nodules (NN) at V4 and R5 phenological phases was affected by treatments. In 2016-2017, at V4 phenological phase and, in 2016-2017 at R5 phenological phases the inoculated treatment ($P_0V4_0R5_0$) presented higher NN than treatments with N-fertilizer application (Table 2). The results observed for nodule dry mass (NDM) were very similar to those observed for NN, with the inoculated treatment ($P_0V4_0R5_0$) showing higher NDM than most of the evaluated treatments, except at R5 in 2017/18, when greater values of NDM were observed for the treatments $P_0V4_{45}R5_{45}$, $P_0V4_{90}R5_0$, and $P_0V4_0R5_{90}$ (Table 2).

Table 2

Number of nodules (NN) and nodule dry mass (NDM) of common bean in the phenological phases V4 and R5 as affected by inoculation and N-fertilizer splitting in field experiments conducted in the water cropping season (Wc) of 2016-2017 and 2017-2018

Treatments (T)		NN (n^o plant^{-1})			NDM (mg plant^{-1})		
		V4	R5		V4	R5	
		2017/18	2016/17	2017/18	2017/18	2016/17	2017/18
$P_0V4_0R5_0$		61.17 a	5.42	86.08 a	51.55 a	0.79 b	74.22 a
$P_0V4_{45}R5_{45}$		44.75 b	2.83	47.08 b	32.45 b	1.43 a	27.37 b
$P_0V4_{90}R5_0$		43.00 b	4.67	48.33 b	44.73 b	3.23 a	18.07 c
$P_0V4_0R5_{90}$		33.42 c	4.83	48.33 b	22.60 c	4.21 a	17.07 c
$P_{30}V4_{30}R5_{30}$		18.33 d	1.50	44.75 b	10.46 c	0.44 b	18.13 c
$P_{30}V4_{60}R5_0$		32.42 c	0.75	18.00 d	30.37 b	0.23 b	10.05 c
$P_{30}V4_0R5_{60}$		45.00 b	1.08	41.00 b	32.45 b	0.77 b	26.09 b
$P_{60}V4_{30}R5_0$		26.33 c	2.92	42.33 b	16.33 c	0.14 b	21.42 b
$P_{60}V4_0R5_{30}$		19.67 d	0.75	10.42 d	17.60 c	0.25 b	1.73 d
$P_{90}V4_0R5_0$		13.00 d	0.92	30.75 c	7.44 c	0.22 b	14.34 c
Average		33.71	2.56 B	41.70 A	26.6	1.17 B	22.85 A
CV%		39.49	39.65	19.3	68.34	34.29	22.47
F values	T	16.90*	1.44^{ns}	12.57*	38.16*	2.68**	25.84*
	Wc	-	146.33*		-	36.49*	
	TxWc	-	3.61*		-	12.65*	

"F" test significance *(p<0.01); **(p<0.05); ***(p<0.001); ^{ns}(non significant). Means from a same column followed by different lowercase letters are significantly different (p≤0.05, Skott-Knott test). Means from a same row followed by different capital letters are significantly different (p≤0.05, "F" test). CV: coefficient of variation (%).

N-fertilizer, mainly in the form of urea, is an input widely used in Brazilian agriculture. Like other crops, common bean requires great amounts of N for good development. Thus, is very common high quantities of N-fertilizer been applied in common bean crop, affecting many ways the environment, plants, and plant-microbe interaction.

A direct effect of the N-fertilizer use was observed in our work over the common bean nodulation. In N-fertilized treatments, the number and mass of nodules were decreased in comparison to inoculated treatment, corroborating results of Kaneko et al. (2010), Rufini et al. (2011) and Souza et al. (2011), who reported a reduction in NN and NDM due to the use of N-fertilizer and, consequently, a decrease in BNF activity in common bean. This occurs because the plant prefers to absorb N from the fertilizer (Cassini & Franco, 2011; Couto et al., 2013) since the energy expenditure is lower as compared to BNF. While for the assimilation of two NH3 molecules through BNF 16 ATP is spent, the absorption of the same amount from the fertilizer through glutamine synthetase and glutamate synthase, or asparagine synthetase, has a two ATP expense (Marenco & Lopes, 2009).

Growth of inoculated common bean under N-fertilizer splitting

The leaf area index (LAI) in the phenological phases V4 and R5 were affected by the year and the treatments, being observed interaction of these factors. At V4 in 2017/18 the treatments $P_{60}V4_{0}R5_{30}$ and $P_{60}V4_{30}R5_{0}$ showed greater LAI values. At R5, considering both seasons, greater LAI values were observed in the treatments where N-splitting was done with at least a dose at sowing, except for the $P_{0}V4_{90}R50$ treatment (Table 3).

Root dry mass (RDM) and shoot dry mass (SDM) were also affected by the year and the treatments, being observed interaction of these factors. Greater values of RDM and SDM at the V4 phenological phase were observed for the treatments $P_{60}V4_{30}R5_{0}$, $P_{60}V4_{0}R5_{30}$, and $P_{90}V4_{0}R5_{0}$ in 2017/18. However, at R5, considering 2016-2017 and 2017-2018 seasons, best result of RDM was observed for the treatment $P_{30}V4_{0}R5_{60}$, while for SDM the treatments $P_{30}V4_{60}R5_{0}$, $P_{60}V4_{0}R5_{30}$, and $P_{90}V4_{0}R5_{0}$ stood out (Table 3).

In spite of reducing nodulation, N-fertilized treatments increased the plant growth, as already reported by Gubiani et al. (2014), providing greater values of LAI, RDM, and SDM, which are positively affected by N availability in the soil, as reported by Albuquerque et al. (2012). The effects of N-fertilizer over plant growth also influenced the grain yield (GY), but only in the 2016-2017 water-cropping season, when four of the five N-fertilized treatments showed GY greater than the inoculated treatment ($P_{0}V4_{0}R5_{0}$). In the 2017-2018 water-cropping season, the inoculated treatment showed GY values statistically equal to six of the nine N-fertilized treatments. These results are similar to those of Hungria et al. (2013), who found no significant difference for GY between the inoculated treatment and the N-fertilized treatment corresponding to 80 kg ha^{-1} of N application. Brito et al. (2015), also did not find statistical difference between the inoculated treatment and the N-fertilized treatment corresponding to 120 kg ha^{-1} of N application.

Table 3

Leaf area index (LAI), root dry mass (RDM) and shoot dry mass (SDM) of common bean in the phenological phases V4 and R5 as affected by inoculation and N-fertilizer splitting in field experiments conducted in the water cropping season (Wc) of 2016-2017 and 2017-2018

Treatments (T)		LAI (cm² plant⁻¹)			NDM (mg plant⁻¹)			SDM (g plant⁻¹)		
		V4	R5		V4	R5		V4	R5	
		2017/18	2016/17	2017/18	2017/18	2016/17	2017/18	2017/18	2016/17	2017/18
$P_0V4_0R5_0$		472.46 c	856.75 b	663.88 b	0.23 b	0.47 a	0.57 c	4.28 b	4.98 b	6.75 c
$P_0V4_{45}R5_{45}$		574.20 b	828.83 b	775.85 b	0.21 b	0.34 b	0.71 b	4.56 b	3.43 b	7.72 c
$P_0V4_{90}R5_0$		379.20 c	697.83 b	924.20 a	0.15 b	0.42 b	0.45 c	3.98 b	4.55 b	9.10 b
$P_0V4_0R5_{90}$		451.15 c	931.08 b	500.14 b	0.16 b	0.36 b	0.46 c	4.35 b	4.64 b	5.23 c
$P_{30}V4_{30}R5_{30}$		533.12 b	820.50 b	1.124.55 a	0.19 b	0.36 b	0.74 b	3.78 b	3.88 b	10.83 a
$P_{30}V4_{60}R5_0$		355.57 c	1.365.08 a	1.127.17 a	0.20 b	0.38 b	0.78 b	3.57 b	6.35 a	13.52 a
$P_{30}V4_0R5_{60}$		386.67 c	636.00 b	1.121.45 a	0.19 b	0.60 a	0.95 a	3.88 b	3.16 b	13.19 a
$P_{60}V4_{30}R5_0$		674.73 a	655.00 b	748.77 b	0.43 a	0.34 b	0.67 b	5.28 a	3.41 b	9.79 b
$P_{60}V4_0R5_{30}$		726.29 a	1.126.83 a	1.088.20 a	0.52 a	0.44 b	0.77 b	6.06 a	5.54 a	12.45 a
$P_{90}V4_0R5_0$		583.91 b	1.293.75 a	1.083.42 a	0.44 a	0.48 a	0.76 b	5.05 a	6.55 a	12.77 a
Average		513.75	921.16	915.76	0.27	0.42 B	0.69 A	4.48	4.65 B	10.13 A
CV%		23.1	23.01	16.17	25.08	19.25	16.9	19.57	20.62	17.4
F values	T	2.81*	8.02*	6.28*	4.58*	2.73*	9.61*	4.66*	2.93*	16.76*
	Wc	-	0.00^{ns}		-	37.71*		-	39.38*	
	TxWc	-	4.76*		-	3.74*		-	7.59*	

"F" test significance *(p<0.01); **(p<0.05); ***(p<0.001); ^ns^(non significant). Means from a same column followed by different lowercase letters are significantly different (p≤0.05, Skott-Knott test). Means from a same row followed by different capital letters are significantly different (p≤0.05, "F" test). CV: coefficient of variation (%).

Productivity and Economics of inoculated common bean under N-fertilizer splitting

Grain yield was influenced by year and treatments, with interaction of two factors. The treatments $P_0V4_{45}R5_{45}$, $P_0V4_0R5_{90}$, $P_{60}V4_0R5_{30}$, and $P_{90}V4_0R5_0$ presented the highest averages in 2016-2017, while the treatments $P_0V4_0R5_0$, $P_0V4_{45}R5_{45}$, $P_0V4_{90}R5_0$, $P_0V4_0R5_{90}$, $P_{30}V4_{60}R5_0$, $P_{60}V4_{30}R5_0$, and $P_{90}V4_0R5_0$ showed higher GY in 2017-2018 (Table 4).

The production cost (PC) values varied due to the use or not of N in the form of urea, being higher with the use of N-fertilizer as compared to the inoculated treatment ($P_0V4_0R5_0$). When using the N-fertilizer, the PC was affected by the splitting of application. The lowest PC was observed in the inoculated treatment ($P_0V4_0R5_0$), being 572.67 US\$ ha^{-1} in 2016/17 and 499.44 US\$ ha^{-1} in 2017/18 (Table 4). Among the nine treatments in which there was N fertilization, the lowest cost was in the $P_{90}V4_0R5_0$ treatment, equivalent to 597.08 US\$ ha^{-1} in 2016-2017 and 531.34 US\$ ha^{-1} in 2017-2018 (Table 4).

The treatments with higher PC were: $P_0V4_{45}R5_{45}$ and $P_{30}V4_{30}R5_{30}$, which showed the same PC within each year (Table 4). In both treatments, the expense of three applying operations was computed due to the urea splitting. In treatment $P_0V4_{45}R5_{45}$ even with no application at sowing, the operational expense is computed, because of P and K fertilization. The PCs for these treatments ($P_0V4_{45}R5_{45}$ and $P_{30}V4_{30}R5_{30}$) were 633.43 US\$ ha^{-1} in 2016-2017 and 566.21 US\$ ha^{-1} in 2017-2018 (Table 4).

The remaining treatments ($P_0V4_{90}R5_0$, $P_0V4_0R5_{90}$, $P_{30}V4_{60}R5_0$, $P_{30}V4_0R5_{60}$, $P_{60}V4_{30}R5_0$, and $P_{60}V4_0R5_{30}$) have two N-fertilizer applications, or only one but at the phenological phase V4 or R5. Thus, the sowing cost was computed. The PCs of these treatments were 615.25 US\$ ha^{-1} in 2016-2017 and 547.40 US\$ ha^{-1} in 2017-2018 (Table 4).

Regarding the 2017/18 water-cropping season, where the GY of inoculated and N-fertilized treatments were quite similar, environmental, and economic issues could be considered by the producer to take the decision on the use of either inoculation or N-fertilization. In both agricultural seasons, our economic analysis showed production cost (PC) of the inoculated treatment about 8.0% lower than the N-fertilized treatments. Gerlach et al. (2013), studying the economics of common bean as a function of N rates and cover crops, stated that the 90 kg ha-1 N rate represents 14% of the total operational cost.

The economic parameters evaluated, such as gross revenue (GR), net revenue (NR) and benefit-cost ratio (BCR), presented similar results, being affected by the year, the treatments, occurring interaction of these factors. For 2016-2017 the highest values of GR, NR and BCR were observed in treatments $P_{60}V4_0R5_{30}$, $P_0V4_0R5_{90}$, $P_{90}V4_0R5_0$, and $P_0V4_{45}R5_{45}$. In 2018, the treatments with the highest averages of GR, NR and BCR were $P_{30}V4_0R5_{60}$, $P_{60}V4_0R5_{30}$, and $P_{30}V4_{30}R5_{30}$ (Table 5).

Table 4

Grain yield (GY) and production cost (PC) of common bean as affected by inoculation and N-fertilizer splitting in field experiments conducted in the water cropping season (Wc) of 2016-2017 and 2017-2018

Treatments (T)		GY (kg ha^{-1})		PC (US$ ha^{-1})	
		2016/17	2017/18	2016/17	2017/18
$P_0V4_0R5_0$		2.021.66 b	2.636.44 a	572.67	499.44
$P_0V4_{45}R5_{45}$		2.442.63 a	2.893.31 a	633.43	566.21
$P_0V4_{90}R5_0$		2.329.56 b	2.880.25 a	615.25	547.40
$P_0V4_0R5_{90}$		2.603.80 a	2.659.65 a	615.25	547.40
$P_{30}V4_{30}R5_{30}$		2.333.50 b	2.559.63 b	633.43	566.21
$P_{30}V4_{60}R5_0$		2.312.22 b	2.730.61 a	615.25	547.40
$P_{30}V4_0R5_{60}$		2.377.09 b	2.143.02 c	615.25	547.40
$P_{60}V4_{30}R5_0$		2.305.18 b	2.808.77 a	615.25	547.40
$P_{60}V4_0R5_{30}$		2.636.32 a	2.486.28 b	615.25	547.40
$P_{90}V4_0R5_0$		2.446.08 a	2.834.35 a	597.08	531.34
Average		2.380.81 B	2.663.23 A	-	-
CV%		9.06	6.32	-	-
	T	3.17*	5.56*	-	-
F values	Wc	9.00**		-	-
	TxWc	4.73*		-	-

"F" test significance *(p<0.01); **(p<0.05); ***(p<0.001); [ns](non significant). Means from a same column followed by different lowercase letters are significantly different (p≤0.05, Skott-Knott test). Means from a same row followed by different capital letters are significantly different (p≤0.05, "F" test). CV: coefficient of variation (%).

Table 5

Grain yield (GY), gross revenue (GR), net revenue (NR) and benefit-cost ratio (BCR) of common bean as affected by inoculation and N-fertilizer splitting in field experiments conducted in the water cropping season (Wc) of 2016-2017 and 2017-2018

Treatments (T)		GYa (Bags ha^{-1})		GRb (US$ ha^{-1})		NR (US$ ha^{-1})		BCR (US$ US$$^{-1}$ invested ha^{-1})	
		2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18
$P_0V4_0R5_0$		33.70 b	43.95 a	1,585.59 c	1,081.17 a	1,012.92 b	581.73 a	2.77 b	2.16 a
$P_0V4_{45}R5_{45}$		40.72 a	48.22 a	1,915.88 a	1,186.21 a	1,282.45 b	620.00 a	3.02 b	2.10 a
$P_0V4_{90}R5_0$		38.82 b	48.00 a	1,826.48 b	1,180.80 a	1,211.23 b	633.40 a	2.97 b	2.16 a
$P_0V4_0R5_{90}$		43.40 a	44.32 a	2,041.97 a	1,090.27 a	1,426.72 a	542.87 a	3.32 a	1.99 a
$P_{30}V4_{30}R5_{30}$		38.90 b	42.62 b	1,830.25 b	1,048.45 a	1,196.82 b	482.24 b	2.89 b	1.85 b
$P_{30}V4_{60}R5_0$		38.52 b	45.50 a	1,812.37 b	1,119.30 a	1,197.12 b	571.90 a	2.95 b	2.04 a
$P_{30}V4_0R5_{60}$		39.60 b	35.72 c	1,863.18 b	878.71 b	1,247.23 b	331.31 c	3.03 b	1.61 c
$P_{60}V4_{30}R5_0$		38.42 b	46.80 a	1,807.66 b	1,151.28 a	1,192.41 b	603.88 a	2.94 b	2.10 a
$P_{60}V4_0R5_{30}$		43.92 a	41.42 b	2,066.44 a	1,018.39 a	1,451.19 a	471.53 b	3.36 a	1.86 b
$P_{90}V4_0R5_0$		40.77 a	47.22 a	1,918.23 a	1,161.61 a	1,321.15 a	630.27 a	3.21 a	2.19 a
Average		39.68 B	44.38 A	1,866.80 A	1,091.67 B	1,253.99 A	546.91 B	3.05 A	2.01 B
CV%		39.49	6.32	9.06	6.32	14.00	12.57	9.04	6.43
F values	T	3.17*	5.56*	4.31*	2.27**	3.68*	7.61*	3.02*	8.24*
	Wc	9.00**		172.77*		463.75*		320.62*	
	TxWc	4.73*		3.57*		3.52*		3.72*	

[a]Grain yield of the Table 4 (kg ha^{-1}) divided by 60 kg. [b]Grain yield (Bags ha^{-1}) multiplied by US$ 47.05 in 2016/17 and by US$ 24.60 in 2017/18. "F" test significance *(p<0.01); **(p<0.05); ***(p<0.001); [ns](non significant). Means from a same column followed by different lowercase letters are significantly different (p≤0.05, Skott-Knott test). Means from a same row followed by different capital letters are significantly different (p≤0.05, "F" test). CV: coefficient of variation (%).

In our study, the selling prices of grains affected gross revenue (GR), net revenue (NR), and benefit-cost ratio (BCR) within each cropping season. On the 2016-2017 cropping season, the 60 kg bag was being sold by US$ 47.05, about 48% more than in 2017-2018 (US$ 24.60). In this situation, even showing greater PC, the GR, NR, and BCR of some N-fertilized treatment ($P_0V4_0R5_{90}$, $P_{60}V4_0R5_{30}$, and $P_{60}V4_0R5_{30}$) were statically greater than the inoculated treatment ($P_0V4_0R5_0$). However, in 2017/18 cropping season, when the selling price was lower, the inoculated treatment showed GR, NR, and BCR statistically equal to the most N-fertilized treatments.

Conclusions

Under the evaluated edaphoclimatic conditions N-fertilizer, applied at any phenological phase, negatively affects common bean nodulation, reducing the number and the dry mass of nodules.

In general, the inoculated treatment shows lower leaf area index, root dry mass, shoot dry mass, grain yield, and production cost.

Although the inoculated treatment shows lower values for growth parameters, negatively influencing GY of the common bean, inoculation can result in NR and BCR equal to N-fertilized treatments.

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References

Albuquerque, H. C., Pegoraro, R. F., Vieira, N. M. B., Amorim, I. J. F., & Kondo, M. K. (2012). Nodulor capability and agronomic characteristics of common bean plants subjected to fragmented molybdenum and nitrogen fertilization. *Revista Ciência Agronômica, 43*(2), 214-221. doi: 10.1590/S1806-66902012000200002

Bortolotto, R. P., Bruno, I. P., Reichardt, K., Timm, L. C., Amado, T. J. C., & Ferreira, A. O. (2012). Nitrogen fertilizer (15N) leaching in a central pivot fertigated coffee crop. *Revista Ceres, 59*(4), 466-475. doi: 10. 1590/S0034-737X2012000400006

Brito, L. F., Pacheco, R. S., Souza, B. F., Fº., Ferreira, E. P. B., Straliotto, R., & Araújo, A. P. (2015). Response of Common Bean to Rhizobium Inoculation and Supplemental Mineral Nitrogen in Two Brazilian Biomes. *Revista Brasileira de Ciência do Solo, 39*(4), 981-992. doi: 10.1590/01000683rbcs20140322

Carvalho, J. J., Saad, J. C. C., Cunha, F. N., Silva, N. F., & Teixeira, M. B. (2014). Manejo da irrigação no feijoeiro, cultivado em semeadura direta e convencional. *Revista Brasileira de Agricultura Irrigada, 8*(1), 52-63. doi: 10.7127/rbai.v8n100198

Cassini, S. T. A., & Franco, M. C. (2011). Fixação biológica de nitrogênio: microbiologia, fatores ambientais e genéticos. In C. Vieira, T. J. Paula Jr., & A. Borém (Eds.), *Feijão* (pp. 143-170). Viçosa.

Companhia Nacional de Abastecimento (2022). *Acompanhamento da safra brasileira de grãos: 12° levantamento.* https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos/item/ download/44171_1d9f893d78f593b07d41887104acc43f

Couto, P. A., Jr., Silva, A. A., & Lana, R. M. Q. (2013). Aplicação de diferentes doses e adubação de micronutrientes via solo na cultura do feijoeiro. *Bioscience Journal, 29*(1), 8-14. http://www.seer.ufu.br/index.php/biosciencejournal/article/view/11659/11940

Empresa Brasileira de Pesquisa Agropecuária (1997). *Manual de métodos de análise de solos.* http://www.agencia.cnptia.embrapa.br/Repositorio/Manual+de+Metodos_000fzvhotqk02wx5ok0q43a0ram31wtr.pdf

Federação da Agricultura e Pecuária de Goiás (2018). *Index: custo de produção. Goiânia-GO.* http://ifag.org.br/custos-de-producao

Ferreira, D. F. (2019) SISVAR: A computer analysis system to fixed effects split plot type designs. *Revista Brasileira de Biometria, 37*(4), 529-535. doi: 10.28951/rbb.v37i4.450

Gerlach, G. A. X., Arf, O., Corsini, D. C. D. C., Silva, J. C., & Coletti, A. J. (2013). Economic analysis of bean yield according to nitrogen levels and cover crops. *Pesquisa Agropecuária Tropical, 43*(1), 42-49. doi: 10.1590/S1983-40632013000100005

Gubiani, P. I., Reichert, J. M., & Reinert, D. J. (2014). Interaction between water availability and soil compaction on common bean growth and yield. *Revista Brasileira de Ciência do Solo, 38*(3), 765-773. doi: 10.1590/S0100-06832014000300008

Hungria, M., Andrade, D. S., Chueire, L. M. O., Probanza, A., Gutierrez-Mañero, F. J., & Megías, M. (2000). Isolation and characterization of new efficient and competitive bean (Phaseolus vulgaris L.) rhizobia from Brazil. *Soil Biology and Biochemistry, 32*(11-12), 1515-1528. doi: 10.1016/S0038-0717(00)00063-8

Hungria, M., Campo, R. J., & Mendes, I. C. (2003). Benefits of inoculation of the common bean (*Phazeolus vulgaris* L.) crop with efficient and competitive Rhizobium tropici strains. *Biology and Fertility of Soils, 39*(2), 88-93. doi: 10.1007/s00374-003-0682-6

Hungria, M., Nogueira, M. A., & Araújo, R. S. (2013). Co-inoculation of soybeans and common beans with rhizobia and azospirilla: strategies to improve sustainability. *Biology and Fertility of Soils, 49*(7), 791-801. doi: 10.1007/s00374-012-0771-5

Kaneko, F. H., Arf, O., Gitti, D. C., Arf, M. V., Ferreira, J. P., & Buzetti, S. (2010). Furrow opening mechanisms, inoculation of seeds and nitrogen fertilization in no tillage common bean crop. *Bragantia, 69*(1), 125-133. doi: 10.1590/S0006-87052010000100017

Marenco, R. A., & Lopes, N. F. (2009). *Fisiologia vegetal: fotossíntese, respiração, relações hídricas e nutrição mineral.* Editora da UFV.

Martins, R. N., Nóbrega, R. S. A., Abrahão, R. S., Silva, A. F. T., Amaral, F. H. C., Costa, E. M., Lustosa, J. F., Fº., & Martins, L. V. (2013). Nitrogênio e micronutrientes na produção de grãos de feijão-caupi inoculado. *Semina: Ciências Agrárias, 34*(4), 1577-1586. doi: 10.5433/1679-0359.2013v34n4p1577

Mingotte, F. L. C., Yada, M. M., Jardim, C. A., Fiorentin, C. F., Lemos, L. B., & Fornasieri Filho, D. (2014). Sistemas de cultivo antecessores e doses de nitrogênio em cobertura no feijoeiro em plantio direto. *Bioscience Journal, 30*(2), 696-706. http://www.seer.ufu.br/index.php/biosciencejournal/article/view/18213/15229.

Mitidiero, M. A., Jr., Barbosa, H. J. N., & Sa, T. H. (2017). Quem produz comida para os brasileiros? 10 anos do censo agropecuário 2006. *Revista Pegada Eletrônica, 18*(3), 7-77. doi: 10.33026/peg.v18i3.5540

Nalepa, K. C., & Ferreira, S. M. R. (2013). Avaliação da qualidade do feijão preto. Demetra: *Alimentação, Nutrição & Saúde, 8*(2), 115-124. doi: 10.12957/demetra.2013.5984

Oliveira, A. L. M., Costa, K. R., Ferreira, D. C., Milani, K. M. L., Santos, O. J. A. P., Silva, M. B., & Zuluaga, M. Y. A. (2014). Aplicações da biodiversidade bacteriana do solo para a sustentabilidade da agricultura. *Biochemistry and Biotechnology Reports, 3*(1), 56-77. doi: 10.5433/2316-5200.2014v3n1p56

Rufini, M., Ferreira, P. A. A., Soares, B. L., Oliveira, D. P., Andrade, M. J. B., & Moreira, F. M. S. (2011). Simbiose de bactérias fixadoras de nitrogênio com feijoeiro-comum em diferentes valores de pH. *Pesquisa Agropecuária Brasileira, 46*(1), 81-88. doi: 10.1590/S0100-204X2011000100011

Silva, O. F., Wander, A. E., & Didonet, A. D. (2012). Sistema e custo de produção de feijão-comum de segunda safra para agricultura familiar em Goiás. In R. C. N. Guiducci, J. R. Lima Fº., & M. M. Mota (Eds.), *Viabilidade econômica de sistemas de produção agropecuários: metodologia e estudos de caso* (pp. 509-535). Brasília.

Siqueira, M., Neto, Piccoli, M. C., Costa, C., Jr., Cerri, C. C., & Bernoux, M. (2011). Emissão de gases do efeito estufa em diferentes usos da terra no bioma Cerrado. *Revista Brasileira de Ciências do Solo, 35*(1), 63-76. doi: 10.1590/S0100-06832011000100006

Souza, E. F. C., Soratto, R. P., & Pagani, F. A. (2011). Aplicação de nitrogênio e inoculação com rizóbio em feijoeiro cultivado após milho consorciado com braquiária. *Pesquisa Agropecuária Brasileira, 46*(4), 370-377. doi: 10.1590/S0100-204X2011000400005

Zani, F. B., & Costa, F. L. (2014). Avaliação da implementação do Programa Nacional de Fortalecimento da Agricultura Familiar - novas perspectivas de análise. *Revista de Administração Pública, 48*(4), 889-912. doi: 10.1590/0034-76121555