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Nitrogen management in common bean cultivars in soil infected by *Meloidogyne incognita*

Manejo do nitrogênio em cultivares de feijoeiro infectado por *Meloidogyne incognita*

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Highlights

Common bean cultivars are susceptible regardless of the nitrogen source used.
The use of inoculant does not minimize the negative effect of the phytonematode.
Nitrogen fertilization minimizes the negative effect of the Meloidogyne incognita.

Abstract

The selection of an appropriate nitrogen (N) source can mitigate the negative effect of root-knot nematodes on the yield of common beans. A greenhouse experiment was conducted to assess the application efficiency of four N sources (urea, ammonium sulfate, ammonium nitrate, and sodium nitrate) and inoculation with *Rhizobium tropici* on the yield components, chlorophyll, and total nitrogen (N) leaf contents of four common bean cultivars (IDR Curió, IDR Sabiá, IDR Tuiuiú, and IDR Bem-te-vi). These beans were cultivated in substrates both infected and uninfected with *Meloidogyne incognita.* In the soil containing phytonematodes, the IDR Curió cultivar exhibited the highest shoot and root dry weight yield, resulting in the greatest root volume, total N content, and grain yield. Among the N sources, the application of either urea or ammonium sulfate proved the most effective in enhancing common bean productivity in soil, irrespective of the cultivar or whether the soil was infected with *Meloidogyne incognita.*

Key words: *Phaseolus vulgaris.* Phytonematode. Nitrogen sources. Yield components.

Resumo

A escolha da fonte nitrogenada pode minimizar o efeito negativo dos fitonematoides das galhas sobre a produção do feijoeiro. Foi realizado um experimento em casa de vegetação para avaliar a eficiência da aplicação de quatro fontes de nitrogênio (ureia, sulfato de amônio, nitrato de amônio e nitrato de sódio)

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e inoculação com *Rhizobium tropici* sobre os componentes fitotécnicos e teores foliares de clorofila e nitrogênio (N) total de quatro cultivares de feijoeiro (IDR Sabiá, IDR Curió, IDR Tuiuiú e IDR Curió) cultivadas em substrato infectado e não infectado com o fitonematoide *Meloidogyne incognita.* No solo contendo fitonematoide, a cultivar IDR Curió apresentou maior produção de massa seca da parte aérea e de raízes acarretando o maior volume de raízes, teor de N total e produção de grãos. Entre as fontes nitrogenadas, a aplicação de ureia ou sulfato de amônio, independentemente da cultivar, foram as mais efetivas no aumento da produtividade do feijoeiro em solo infectado ou não por *Meloidogyne incognita.*
Palavras-chave: *Phaseolus vulgaris.* Fitonematoide. Fontes nitrogenadas. Componentes de produção.

Introduction

The common bean (*Phaseolus vulgaris* L.), particularly in its dry form, is a staple food in Latin America; in contrast, in Africa and developed countries they are majorly consumed as fresh or frozen green beans or as pods without threshing (Fageria et al., 2012; Canizella et al., 2017). This high consumption is attributed to its high palatability and protein content (20-25%), making it a valuable calorie source, especially for low-income populations (Fageria et al., 2012).

As the soybean (*Glycine max* [L.] Merrill) planted area in Brazil expands, common bean crops are migrating to less productive areas, characterized by sandy soils with low organic matter content (Baida et al., 2011). This shift has led to a decrease in productivity and an increase in production costs, primarily due to the significant presence of phytonematodes (Cunha et al., 2015), particularly those of the *Meloidogyne genus,* which can cause losses of up to 90% (Dutra & Campos, 2003). Plants infected with *Meloidogyne incognita* exhibit dense gall formation and a reduced root system, leading to restrictions in water and nutrient uptake and an overall decreased plant development (Fernandes & Kulczynski, 2009).

The common bean is recognized as a suitable host for this phytopathogen, with nearly all cultivated varieties exhibiting susceptibility (Dutra & Campos, 2003). Among nutrients, the role of nitrogen (N) is integral to the structure of amino acids, proteins, and the synthesis of chlorophyll, among other functions (Malavolta, 2006; Marschner, 2012). N is also the most demanded nutrient by the common bean plant, and 50% of the absorbed N is exported by the grains (Toledo et al., 2009). The presence of adequate N levels in infected areas can enhance photosynthetic efficiency and mitigate yield losses.

The high demand for N fertilizers necessitates careful selection of the N source (amidic, ammoniacal, nitric, and ammoniacal+nitric) for subsequent application, which can either mitigate or exacerbate the effects of phytonematodes on grain yield. Dias et al. (2021) found that in the absence of N, soybean crop yields were most negatively impacted compared to the results with the absence of other nutrients. Furthermore, the selection of common bean cultivars at planting is another crucial factor as they can exhibit different efficiency and responsiveness in nutrient uptake depending on the degree of infestation, thereby reducing damage during the vegetative and reproductive development of plants. (Baligar et al., 2001; Canizella et al., 2015).

Owing to the significance of this crop in the dietary habits of people in various global regions, including Brazil, and the shift of its cultivation to tropical regions, particularly those with sandy soils and higher nutritional constraints, this study aimed to assess the response of four common bean cultivars grown in sandy substrate infected by *Meloidogyne incognita* to different forms of applied N sources.

Material and Methods

The experiment was conducted in a greenhouse, using pots filled with 1.0 kg of substrate in a 2:1 sand-to-soil ratio. The substrate had the following chemical attributes, as per Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA] (1997): pH in $CaCl_2$ of 5.98, soil organic matter (SOM) of 24.49 g kg^{-1}, phosphorus (P – Mehlich-1) of 194.10 mg kg^{-1}, P (Mehlich-3) of 446.46 mg kg^{-1}, K^+ (Mehlich-1) of 1.12 $cmol_c$ kg^{-1}, sodium (Na^+ - Mehlich-1) of 0.29 $cmol_c$ kg^{-1}, calcium (Ca^{2+}) of 20.39 $cmol_c$ kg^{-1}, magnesium (Mg^{2+}) of 4.08 $cmol_c$ kg^{-1}, aluminum (Al^{3+}) of 0.0 $cmol_c$ kg^{-1}, potential acidity (H+Al) of 2.47 $cmol_c$ kg^{-1}, sulfur ($S-SO_4^{2-}$) of 242.64 mg kg^{-1}, cation exchange capacity (CEC) of 28.35 cmolc kg^{-1}, remaining-P of 43.87 mg kg^{-1}, boron (B – hot water) of 0.96 mg kg^{-1}, copper (Cu – Mehlich-1) of 3.45 mg kg^{-1}, iron (Fe – Mehlich-1) of 389.85 mg kg^{-1}, manganese (Mn – Mehlich-1) of 73.48 mg kg^{-1}, and zinc (Zn – Mehlich-1) of 18.83 mg kg^{-1}.

A completely randomized experimental design was employed in a 4 × 6 factorial arrangement (cultivars and N sources), with four replicates. The study utilized common bean cultivars with an indeterminate growth habit: IDR Bem-te-vi type 'Carioca' with a medium cycle (88 days), IDR Curió type 'Carioca' with a short cycle (70 days), IDR Sabiá type 'Carioca' with a medium cycle (87 days), and IDR Tuiuiú type 'Black' with a medium cycle (88 days). Five N sources were used: ammonium nitrate (32% N), urea (40% N), ammonium sulfate (20% N), sodium nitrate (15% N), and inoculant (*Rhizobium tropici*). A control group was also included, which had no N sources and inoculant. Each N source was applied at a rate of 300 mg kg^{-1} N, divided into three applications at 10-day intervals. The substrate was autoclaved, and two-thirds of the pots were infected with approximately 5000 *Meloidogyne incognita* nematode eggs and juveniles. The remaining one-third of the pots were left uninfected to evaluate the effect of the absence of nematodes within each treatment. This arrangement resulted in eight nematode-infected pots and four nematode-free pots per treatment. Five seeds were sown in each pot, and after thinning, one uniform plant was left. Following thinning, 150 mg kg^{-1} P (phosphate monoammonium - MAP, 52% P_2O_5), 0.5 mg kg^{-1} B (H_3BO_3), 1.5 mg kg^{-1} Cu ($CuSO_4$•$7H_2O$), 2.5 mg kg^{-1} Mn ($MnSO_4$•$4H_2O$), and 5.0 mg kg^{-1} Zn ($ZnSO_4$•$6H_2O$) were applied (Moreira et al., 2011). A solution containing 200 mg kg^{-1} K (K_2SO_4, 42% K_2O and 16% S) was subsequently added in two parts, with a 20-day interval between applications.

Sixty days post-planting, plants were randomly selected from four infected pots to assess the number of nematodes in the roots (NNR), shoot fresh weight (SFW), roots fresh weight (RFW), and the NNR/RFW ratio. Upon the onset of flowering, the SPAD reading

(Minolta Camera Co., 1989) was conducted to measure the chlorophyll content. The diagnostic leaf (third and fourth leaflet from the apex) was harvested from both nematode-infected and uninfected plants to determine the total N content, according to the methodology described in Malavolta et al. (1997). At the end of the cycle, the remaining four uninfected pots were evaluated for the number of pods per plant (NPP), number of grains per plant (NGP), number of grains per pod (NGP/NPP), grain yield per pot (GY), pods weight per plant (PWP), and roots volume per plant (RV).

The data underwent a homogeneity and normality test, followed by an analysis of variance (ANOVA), an F test, and a comparison using the Scott–Knott test with a 5% error probability. The nematode population data were transformed using the $\sqrt{x+0,5}$ equation.

Results and Discussion

Significant differences were observed in all evaluated variables across different bean cultivars, irrespective of the nitrogen (N) sources, as well as in the interaction between cultivars and N sources (Table 1). The IDR Curió cultivar had the highest SFW, RFW, and lowest NNR, whereas the IDR Bem-te-vi cultivar demonstrated the highest NNR and NNR/RFW ratio. The IDR Sabiá and IDR Tuiuiú cultivars recorded the lowest averages for RFW and SFW, respectively. These findings align with those of Simão et al. (2005), who reported distinct responses among cultivars to *Meloidogyne* in common bean plants. They also support the results of Walber et al. (2003), which suggested distinct multiple tolerances in different common bean accessions to species and races of root-knot nematodes.

Table 1
Shoot fresh weight (SFW), root fresh weight (RFW), root nematode number (NNR), and NNR/RFW ratio of four common bean cultivars and nitrogen sources (N) within each cultivar as well as the average of cultivars

Cultivars/N Sources	SFW	RFW	NNR	NNR/RFW
	g	g	n	
IDR Bem-te-vi	15.91c	8.60b	202.50a	5462.22a
IDR Sabiá	19.82b	5.79c	158.52c	4845.83b
IDR Tuiuiú	15.61 c	9.06b	173.19b	3848.05c
IDR Curió	30.72a	11.25a	86.45d	942.33d
Average	20.52	8.68	155.17	3774.61
		IDR Bem-te-vi		
Control	7.56c	4.97c	94.64e	1801.67d
Ammonium sulphate	31.84a	17.64a	402.01a	9256.67a
Sodium nitrate	10.93c	13.58b	218.34b	3524.00c
Ammonium nitrate	11.67c	6.52c	136.58d	2947.33c
Inoculant	16.27b	4.33c	190.61c	8505.67a
Urea	17.20b	4.51c	172.82c	6738.00b

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IDR Sabiá				
Control	14.83c	4.53c	122.03c	3312.00b
Ammonium sulphate	29.99b	7.45b	222.78a	6694.33a
Sodium nitrate	15.24c	4.62c	176.13b	6834.67a
Ammonium nitrate	16.10c	4.53c	164.14b	6220.33a
Inoculant	10.23d	2.46c	76.50c	2732.33b
Urea	33.53a	11.05a	189.51b	3281.33b
IDR Tuiuiú				
Control	7.66c	4.83d	65.00d	904.00d
Ammonium sulphate	16.65b	7.38c	191.44c	5026.33a
Sodium nitrate	12.77b	10.93b	233.30b	5017.33a
Ammonium nitrate	24.30a	15.49a	257.51a	2131.33c
Inoculant	8.57c	3.64d	112.19d	3748.67b
Urea	24.72a	12.08a	179.70c	2845.00c
IDR Curió				
Control	33.26b	9.60b	66.39c	460.33b
Ammonium sulphate	41.20a	9.72b	51.03c	272.33b
Sodium nitrate	24.36c	17.13a	58.48c	204.00b
Ammonium nitrate	22.82c	15.01a	86.05b	494.67b
Inoculant	24.88c	9.23b	175.52a	3348.00a
Urea	37.86a	6.80b	75.20b	874.67b
Average				
Control	15.83c	6.01c	87.01d	1619.50d
Ammonium sulphate	29.42a	10.55a	216.82a	5312.42a
Sodium nitrate	15.82c	11.56a	171.56b	2948.42
Ammonium nitrate	18.72b	10.39a	154.31b	4303.85b
Inoculant	14.99c	4.91c	138.71c	4583.67b
Urea	28.33a	8.61b	154.31c	3434.00c
F-Test				
Cultivar (A)	161.470*	46.027*	310.883*	138.19*
N Sources (B)	523.323*	51.538*	150.837*	37.891*
A × B	100.609	108.70*	99.609*	20.611*
CV (%)	11.61	18.26	7.73	20.03

Notes. Values followed by different letters within the same column and treatment are differentiated by the Snott–Knott test ($p \leq 0.05$). The original NNR data underwent transformation using the equation $\sqrt{x + 0,5}$.

Significant variations in yield components were observed among common bean cultivars in response to different N sources (Table 1). The application of ammonium sulfate in IDR Bem-te-vi resulted in the highest average for SFW, RFW, NNR, and NNR/RFW. Conversely, lower SFW yield was observed when sodium nitrate ($NaNO_3$) was applied, and lower RFW values were only observed with the use of inoculant, lower NNR, and urea. However, for the NNR/RFW ratio, a smaller population of nematodes was identified when ammonium nitrate was used (Table 1). Zambolim and Ventura (2016) noted that in legumes, the ammonium ($N\text{-}NH_4$) application reduces nematode-induced injuries and egg numbers, thereby controlling population growth. Ammonium, due to its toxicity, is rapidly incorporated into carbon skeletons produced by photosynthesis, thereby forming amino acids and amides essential for plant metabolism. This process decreases the amount of soluble carbohydrates available as food for pathogens, thereby enhancing plant resistance (Pípolo et al., 1993; Malavolta, 2006; Marschner, 2012).

On an average, the inoculant treatment among cultivars was similar to that of the control. Data from the IDR Curió was excluded as this cultivar demonstrated greater tolerance to phytonematodes, exhibiting higher SFW, RFW, and NNR/RFW. This cultivar was nearly double that of other cultivars (Table 1). A positive correlation was also observed between the SFW and RFW with the original NNR data ($\hat{y} = 9734.8 + 2763.0^{*}x$, r = 0.66 and $\hat{y} = 8246.0 + 5862.2^{*}x$, r = 0.76, $p \leq 0.05$). Regarding N sources, urea and ammonium sulfate were similar and had the highest SFW yield; in contrast, the RFW of the two nitric sources and ammonium sulfate did not differ statistically (Table 1). This result indicates that even with a high N infection, the increase in roots volume (RV) can mitigate the negative impact of phytonematodes. In the case of ammonium sulfate, its composition includes 22-24% sulfur (Fageria, 2014), an essential nutrient in plant metabolism (Malavolta, 2006; Marschner, 2012). The presence of sulfur (S) may contribute to a beneficial effect on SFW yield, as reported by Huebner et al. (1983) in the use of urea as a N source and by Fageria et al. (2011) with ammonium sulfate in rice (*Oryza sativa* L.).

Generally, the application of ammonium sulfate yielded the highest averages in terms of SFW, NNR, and NNR/RFW. Conversely, the use of the inoculant resulted in the lowest RFW, SFW, and NNR due to a smaller RV, thereby reducing the benefits of biological N fixation (Table 2). However, the application of sodium nitrate (Chile saltpeter) led to the highest NNR and lowest NNR/RFW (Table 1). Xavier et al. (2020), in a study on corn plants (*Zea mays* L.), observed that appropriate N fertilization can effectively control soil phytoparasites, which otherwise hinder plant development.

Table 2
Number of pods per plant (NPP), number of grains per plant (NGP), number of grains per pod (NGP/NPP), pod weight per plant (PWP), root volume (RV), and grain yield (PG) of four common bean cultivars and nitrogen (N) sources within each cultivar as well as the average of cultivars

Cultivars/N Sources	NPP	NGP	NGP/NPP	PWP	RV	GY
	n	n		g	cm^3	g
IDR Bem-te-vi	2.1c	7.7d	3.5b	3.1c	4.9c	2.5c
IDR Sabiá	3.0a	11.8b	3.9a	3.6b	4.7c	2.7b
IDR Tuiuiú	2.6b	9.7c	3.6b	2.9c	6.3b	2.3c
IDR Curió	3.3a	13.7a	4.1a	4.2a	7.2a	3.4a
Average	2.8	10.7	3.8	3.5	5.8	2.7
IDR Bem-te-vi						
Control	2.0b	3.7c	1.8c	0.8c	3.0b	0.6e
Ammonium sulphate	3.7a	10.0a	5.0a	5.5a	8.4a	4.5a
Sodium nitrate	2.0b	9.3b	4.7a	2.8b	2.5b	2.5b
Ammonium nitrate	2.3b	6.7b	2.9b	5.3a	4.3b	4.3a
Inoculant	1.3b	4.0c	3.2b	1.3c	3.2b	1.1d
Urea	1.3b	4.7c	3.7b	2.8b	7.8a	1.9c
IDR Sabiá						
Control	1.3b	3.3d	2.7b	0.5e	3.8b	0.2e
Ammonium sulphate	2.0b	11.0c	6.8a	3.7b	11.1a	3.0b
Sodium nitrate	2.0b	6.7d	3.3b	2.1d	3.2b	1.5d
Ammonium nitrate	3.7a	10.0c	2.8b	2.9c	2.6b	2.2c
Inoculant	4.7a	23.7a	5.2a	6.1a	3.3b	4.7a
Urea	4.3a	16.3b	3.8b	5.7a	4.2b	4.8a
IDR Tuiuiú						
Control	2.7b	9.3b	3.7a	2.5b	3.3c	1.9b
Ammonium sulphate	2.3b	7.7b	3.4a	2.2b	5.7b	1.7b
Sodium nitrate	2.0b	7.3b	3.7a	2.1b	5.7b	1.6b
Ammonium nitrate	2.0b	6.7b	3.3a	2.1b	11.6a	1.7b
Inoculant	2.0b	7.0b	3.5a	2.3b	3.7c	2.1b
Urea	4.7a	20.0a	4.3a	6.4a	7.6b	4.8a
IDR Curió						
Control	4.7b	19.0b	4.1b	4.7b	3.5d	3.7b
Ammonium sulphate	2.3c	15.3c	6.6a	4.6b	11.5a	3.7b
Sodium nitrate	2.0c	5.3d	2.7c	1.5e	6.4c	1.1e
Ammonium nitrate	3.0c	8.7d	2.9c	3.6c	7.7b	2.8c
Inoculant	2.0c	8.3d	4.2b	2.7d	5.0c	2.0d
Urea	6.0a	25.3a	4.2b	8.3a	9.2b	6.9a

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Average						
Control	2.7b	8.8d	3.0c	2.1e	3.4c	1.6e
Ammonium sulphate	2.6b	13.0b	5.2a	4.0b	9.2a	3.3b
Sodium nitrate	2.0c	7.2d	3.6c	2.1e	4.4c	1.7e
Ammonium nitrate	2.8b	8.0d	3.0c	3.5c	6.5b	2.8c
Inoculant	2.5b	10.8c	4.0b	3.1d	3.8c	2.5d
Urea	4.1a	16.6a	4.0b	5.8a	7.2b	4.6a
F-Test						
Cultivar (A)	16.288*	25.140*	2.713NS	54.647*	15.706*	54.049*
N Sources (B)	19.136*	31.728*	17.270*	211.012*	37.573*	219.235*
A × B	14.870*	24.374*	5.334*	86.876*	8.469*	96.045*
CV (%)	20.01	20.39	17.77	9.49	22.13	9.53

Note. Values followed by different letters within the same column and treatment are differentiated by the Snott–Knott test ($p \leq 0.05$).

Table 2 presents the results for each cultivar in terms of NPP, NGP, NGP/NPP, PWP, RV, and GY. Except for the NGP/NPP ratio for the effect of cultivars (C), the variables NPP, NGP, NGPI, PWP, VR, and GY had a significant effect of sources (S) and a significant interaction for C × S. The highest values of NPP, NGP, NGPI, PWP, and GY were observed when urea was applied in the presence of nematodes, significantly differing from other nitrogen sources. In treatments both with and without the presence of phytonematodes, urea application proved to be the most effective across an average of four cultivars. Urea application also resulted in the lowest loss in GY of the common bean plant (Table 3). This result supports the findings of Fageria et al. (2011), Moreira et al. (2017), and Moraes et al. (2017), who reported that urea demonstrated the greatest efficiency in increasing GY in rice (*Oryza sativa* L.), soybean, and sunflower (*Helianthus annus* L.), respectively, when compared to other N sources. Among the cultivars, the NPP, NGP, and NGP/NPP ranged from 1.3 to 6.0, 3.7 to 25.3, and 1.8 to 6.6, respectively, depending on the cultivar. The IDR Curió cultivar generally presented the highest values (Table 2). Baligar et al. (2001) suggested that these variables in plants are influenced not only by nutritional factors but also by the genetic effects of the cultivars.

Table 3
Percentages of chlorophyll content (SPAD index), root volume (RV), total N content in the diagnostic leaf, and common bean grain yield (GY) in the treatment without phytonematode

Cultivars/N sources	Chlorophyll (SPAD)	RV	Total N	GY
		Percentage (%)		
IDR Bem te vi	34.0	27.3	-4.9	41.4
IDR Sabiá	15.7	18.2	13.7	46.4
IDR Tuiuiú	26.2	14.4	6.3	31.3
IDR Curió	26.9	12.4	-32.1	10.1
		IDR Bem-te-vi		
Control	80.0	34.3	11.4	81.9
Ammonium sulphate	23.0	10.3	-48.5	18.7
Sodium nitrate	19.6	38.0	12.3	46.0
Ammonium nitrate	19.4	35.6	-56.7	10.0
Inoculant	57.7	25.8	18.1	65.3
Urea	-0.8	19.7	-5.0	62.0
Average	34.0	27.3	-4.9	41.4
		IDR Sabiá		
Control	22.4	23.1	8.6	89.9
Ammonium sulphate	17.1	11.9	18.3	37.9
Sodium nitrate	-30.6	4.0	14.2	65.5
Ammonium nitrate	34.8	9.3	25.7	51.4
Inoculant	23.4	10.7	18.6	18.0
Urea	12.1	15.3	-4.1	15.6
Average	15.7	12.4	13.7	46.4
		IDR Tuiuiú		
Control	47.3	25.9	8.8	19.0
Ammonium sulphate	23.5	11.8	-30.0	52.7
Sodium nitrate	10.6	20.9	35.4	58.3
Ammonium nitrate	40.3	6.7	25.2	29.6
Inoculant	23.8	13.2	-60.1	14.5
Urea	9.1	7.7	11.8	13.5
Average	26.2	14.4	6.3	31.3
		IDR Curió		
Control	-1.0	26.4	1.7	10.2
Ammonium sulphate	3.4	13.1	-28.4	22.0
Sodium nitrate	36.6	13.2	-104.8	72.3
Ammonium nitrate	61.7	18.4	-19.2	34.4
Inoculant	48.6	29.6	-42.8	28.8

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Urea	8.4	8.6	-25.3	8.6
Average	26.9	18.2	-32.1	29.4
		Average		
Control	41.1	27.4	7.6	50.3
Ammonium sulphate	16.7	11.8	-16.8	32.8
Sodium nitrate	10.2	19.0	2.7	60.5
Ammonium nitrate	38.8	17.5	2.0	31.4
Inoculant	39.3	19.8	-5.3	31.7
Urea	6.8	12.8	-4.1	24.9
Average	26.2	18.1	-2.0	38.6

Note. Δ = 100 – [(value obtained from the infected plant × 100)/value obtained from the uninfected plant].

Within each cultivar, the application of ammonium sulfate in the IDR Bem-te-vi cultivar infected with phytonematode substrate resulted in the highest averages for NPP, NGP, NGPI, NGP/NPP, RV, and GY. Conversely, the sole use of the inoculant showed the opposite effect, except for RV, which recorded its lowest value with the application of sodium nitrate (Table 2). In the IDR Sabiá cultivar, ammonium sulfate application resulted in a higher NGP/NPP, RV, and a lower NPP, indicating varying responses between cultivars. For the IDR Tuiuiú cultivar, urea application elicited the best response, with the highest averages of NPP, NGP, NGP/NPP, PWP, and GY (Table 2), whereas ammonium nitrate recorded the lowest values. Amide and ammoniacal sources have greater efficiency than nitric sources because a large part of the nitrate (NO_3^-) absorbed by the roots has to be converted into ammonium (NH_4^+), and the process of sequential action of the enzymes nitrate reductase and nitrite reductase is energy-dependent. Furthermore, a portion of the NO_3^- in this process is retained in the vacuole and only becomes available for use in plant metabolism at a later stage (Malavolta, 2006; Marschner, 2012; Fageria, 2014).

Among the cultivars, IDR Bem-te-vi exhibited the most significant disparity in SPAD unit and RV between non-infected and nematode-infected soil (Table 3). In contrast, IDR Sabiá had the lowest SPAD unit and highest N-total and GY. For IDR Curió, plants infected with nematodes had the highest levels, registering a 32.1% increase when cultivated in soil without nematodes (Figure 2). Concerning the N sources within each cultivar, the control treatments and seeds with inoculant displayed the most substantial differences. This phenomenon suggests that, irrespective of the N sources, the application of N fertilizer mitigates the adverse impact of nematodes on chlorophyll content (SPAD unit), RV, total N, and GY of common beans (Table 3). Dias et al. (2021) reported that the absence of N in soil infected with root-knot nematodes is a primary factor in reducing GY. Conversely, both Pereira et al. (2018) and Dias et al. (2021) suggested that N application, even at varying stages of plant development, does not alter chlorophyll levels compared to that in unfertilized plants.

Different responses to the impact of yield components on GY were observed among the common bean cultivars (Table 4), which indicates that the four common bean cultivars respond differently to the applied N sources. In the treatment involving phytonematodes, a positive correlation was observed between the GY of the IDR Bem-te-vi and IDR Curió cultivars and the SFW, RFW, NPP, and NGP. However, no correlation was found between the GY of the IDR Sabiá and IDR Tuiuiú cultivars and the SFW and RFW (Table 4). The absence of correlation between RV and GY could be attributed to an increase in phytonematode infestation, which leads to plant death and subsequent loss of root volume. These observed relationships between GY and yield components align with the results of previous studies (Fageria et al., 2008) and support the findings of Canizella et al. (2015), who reported significant variations in GY with yield components in the common bean crop.

Table 4
Correlation of grain yield (GY) with the yield components of the four common bean cultivars, irrespective of the nitrogen (N) source used

Correlation	Equation	r
	IDR Bem-te-vi	
GY × SFW	$\hat{y} = 8.754 + 2.871x$	0.54*
GY × RFW	$\hat{y} = 3.159 + 2.179x$	0.62*
GY × NNR	$\hat{y} = -284.280 + 20414.000x$	0.59*
GY × SPAD	$\hat{y} = 13.470 + 4.223x$	0.67*
GY × NPP	$\hat{y} = 1.074 + 0.416x$	0.71*
GY × NGPI	$\hat{y} = 1.296 + 2.577x$	0.75*
GY × NGP	$\hat{y} = 2.543 + 0.395x$	0.51^{NS}
GY × RV	$\hat{y} = 2.934 + 0.767x$	0.46^{NS}
GY × Total N - Leaf	$\hat{y} = 18.304 + 0.419x$	0.30^{NS}
	IDR Sabiá	
GY × SFW	$\hat{y} = 14.455 + 1.957x$	0.38^{NS}
GY × RFW	$\hat{y} = 4.076 + 0.624x$	0.35^{NS}
GY × NNR	$\hat{y} = 25939.000 + 558.370x$	0.06^{NS}
GY × SPAD	$\hat{y} = 22.691 + 0.491x$	0.18^{NS}
GY × NPP	$\hat{y} = 1.393 + 3.735x$	0.80*
GY × NGPI	$\hat{y} = 1.592 + 0.222x$	0.91*
GY × NGP	$\hat{y} = 2.786 + 0.413x$	0.53*
GY × RV	$\hat{y} = 5.594 + 0.590x$	0.34^{NS}
GY × Total N - Leaf	$\hat{y} = 17.611 + 0.849x$	0.64*

continue...

continuation...

	IDR Tuiuiú	
GY × SFW	$\hat{y}$ = 8.708 + 2.966x	0.49^{NS}
GY × RFW	$\hat{y}$ = 12.770 – 0.473x	0.06^{NS}
GY × NNR	$\hat{y}$ = 43019.00 – 3632.300x	0.19^{NS}
GY × SPAD	$\hat{y}$ = 20.079 + 2.264x	0.51^{NS}
GY × NPP	$\hat{y}$ = 0.739 + 0.804x	0.92*
GY × NGPI	$\hat{y}$ = 0.186 + 4.073x	0.96*
GY × NGP	$\hat{y}$ = 2.966 + 0.283x	0.48^{NS}
GY × RV	$\hat{y}$ = 5.660 + 0.261x	0.10^{NS}
GY × Total N - Leaf	$\hat{y}$ = 18.946 + 0.181x	0.13^{NS}
	IDR Curió	
GY × SFW	$\hat{y}$ = 21.475 + 2.757x	0.66*
GY × RFW	$\hat{y}$ = 16.200 – 1.475x	0.71*
GY × NNR	$\hat{y}$ = 14373.000 – 1576.600x	0.29^{NS}
GY × SPAD	$\hat{y}$ = 14.073 + 2.255x	0.50^{NS}
GY × NPP	$\hat{y}$ = 0.916 + 0.720x	0.84*
GY × NGPI	$\hat{y}$ = 1.473 + 3.634x	0.90*
GY × NGP	$\hat{y}$ = 3.207+ 0.266x	0.35^{NS}
GY × RV	$\hat{y}$ = 3.557 + 0.344x	0.20^{NS}
GY × Total N - Leaf	$\hat{y}$ = 25.496 – 0.683x	0.47^{NS}
	Average	
GY × SFW	$\hat{y}$ = 11.393 + 3.343x	0.54*
GY × RFW	$\hat{y}$ = 8.925 + 0.146x	0.04^{NS}
GY × NNR	$\hat{y}$ = 25767.000 + 1709.900x	0.08^{NS}
GY × SPAD	$\hat{y}$ = 18.631 + 1.878x	0.42^{NS}
GY × NPP	$\hat{y}$ = 0.945 + 0.666x	0.81*
GY × NGPI	$\hat{y}$ = 0.998 + 3.561x	0.87*
GY × NGP	$\hat{y}$ = 2.832 + 0.352x	0.48*
GY × RV	$\hat{y}$ = 4.642 + 0.411x	0.22^{NS}
GY × Total N - Leaf	$\hat{y}$ = 19.316 + 0.238x	0.17^{NS}

* Significant and NS not significant for $p \leq 0.05$.

Among the N sources, the control and inoculant treatments exhibited the lowest SPAD units, with the highest values observed in the application of ammonium sulfate and urea (Figure 1). Among the cultivars, the IDR Curió displayed the lowest values, showing a significant statistical difference from the other cultivars (Figure 2). In terms of foliar N content, the lowest levels were found in the control and with the application of ammonium nitrate (Figure 1). Conversely, among the cultivars, the highest foliar content was found in the IDR Curió cultivar, which significantly differed from the other studied cultivars (Figure 2). Despite these differences between sources and cultivars, the leaf contents of plants grown in soil infected by the phytonematode fall below the 30.0- to 50 g kg^{-1} range, which Reuter and Robinson (1997) suggest as adequate for common beans.

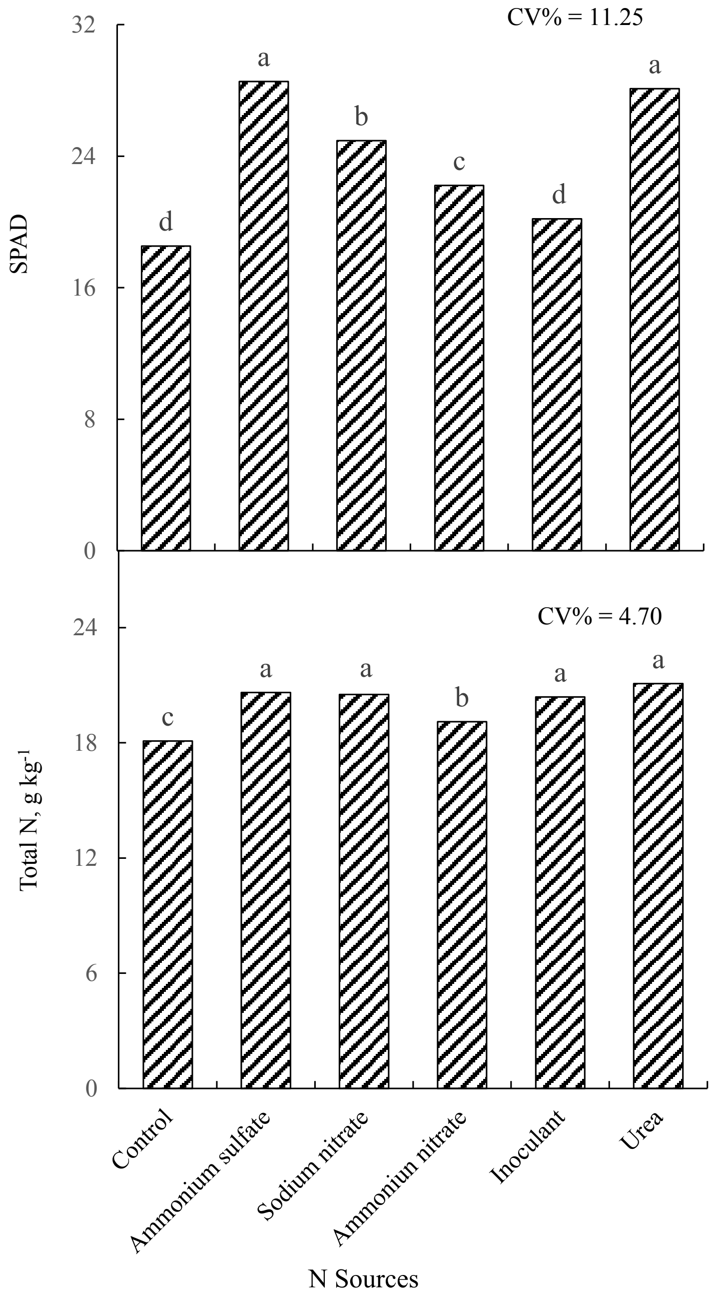

Figure 1. Leaf chlorophyll content (SPAD) and total N as a function of nitrogen sources (N) in the average of common bean cultivars. Values followed by different letters within the same column and treatment are differentiated by the Snott–Knott test ($p \leq 0.05$).

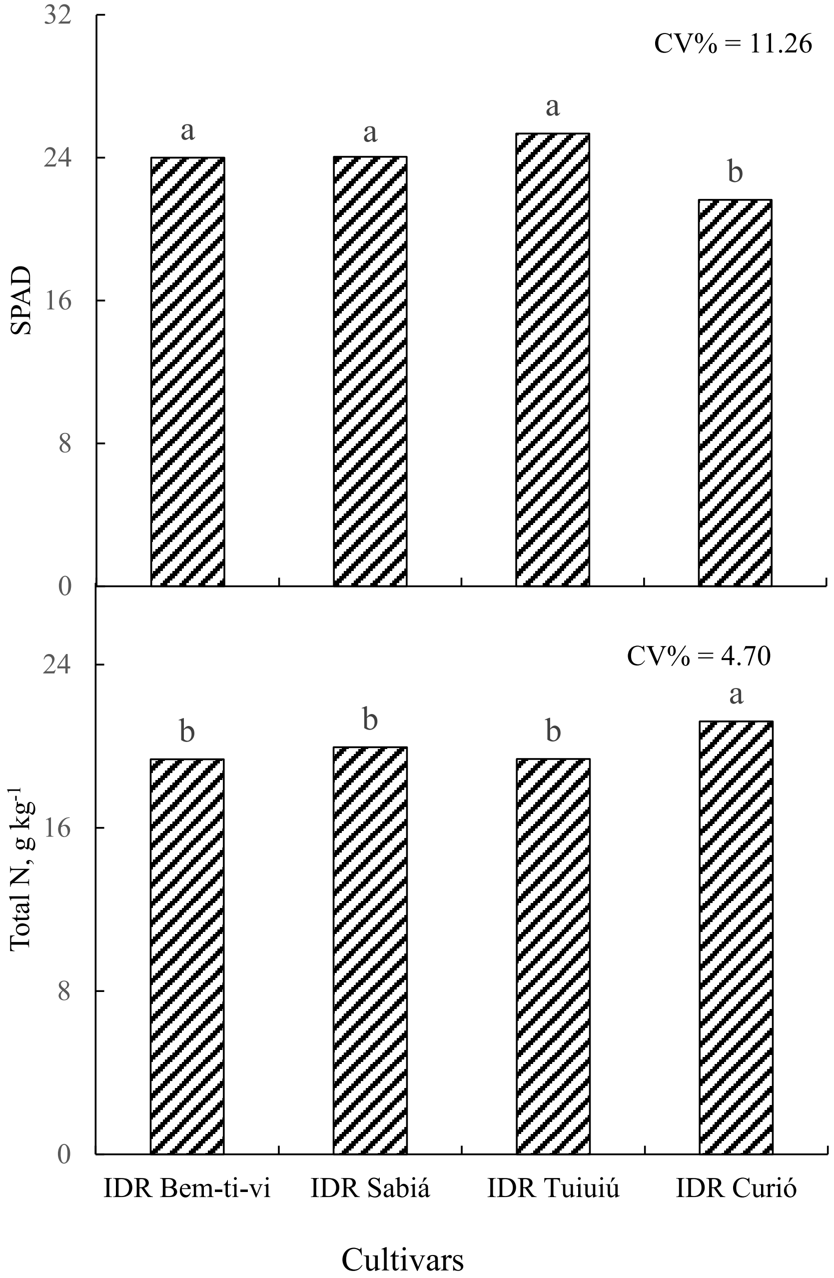

Figure 2. Leaf chlorophyll content (SPAD) and total N of common bean cultivars on the average of nitrogen (N) sources. Values followed by different letters within the same column and treatment are differentiated by the Snott–Knott test ($p \leq 0.05$).

Conclusions

The presence of *Meloidogyne incognita* in the substrate led to a 38.6% reduction in the GY of common beans, irrespective of the cultivars and N sources used.

The cultivar IDR Curió presented the most significant productivity loss. With regard to N sources, nitric sources proved to be the least efficient, and the absence of roots due to pathogen attack impairs the efficiency of the inoculant.

The application of urea or ammonium sulfate to the soil in three separate instances was the most effective in mitigating the nematode's negative impact on plant development and common bean GY.

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