NITROGEN FERTILIZATION IN SOYBEAN UNDER LOW LATITUDE AND LOW NATURAL SOIL FERTILITY

Adubação nitrogenada em soja sob condições de baixa latitude e baixa fertilidade natural do solo.

Fertilización con nitrógeno en soya en condiciones de baja latitud y fertilidad del suelo

Revista Desafios

Artigo Original
Original Article
Artículo Original

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Artigo recebido em 26/07/2021 aprovado em 16/02/2022 publicado em 11/05/2022.

ABSTRACT

In soybean, some studies have shown yield increase when nitrogen is provided through symbiotic fixation along with nitrogen fertilization. Thus, this study aimed to evaluate the effect of nitrogen fertilization on soybean cultivated at a low natural fertility area. Two experiments (field and pot) were conducted. A randomized block design was adopted, with 24 treatments and 3 replications. The treatments were arranged in a 2x12 factorial scheme, represented by two cultivars (TMG 1288RR™ and CD 251RR™) and 12 combinations of nitrogen supply (CNS). The CNS used were: without inoculant and nitrogen; only inoculant; 20; 40 and 60 kg ha^{-1} of N + inoculant; 50; 100; 150; 200; 250; 300 and 350 kg ha^{-1} of N. The doses of N were divided into three applications: 20% applied at planting, 40% at early flowering and 40% at grain-filling. The nitrogen fertilization associated with seed inoculation did not result in significant gains for crop yield. The mineral nitrogen supply affected negatively the number and mass of nodules, and positively the root mass.

Keywords: *Glycine max*, nitrogen supply, degraded areas

RESUMO

Na cultura da soja, alguns estudos têm revelado aumento de produtividade quando o nitrogênio é fornecido através da fixação simbiótica juntamente com a adubação nitrogenada. Assim, o presente trabalho foi realizado com o objetivo de avaliar o efeito da adubação nitrogenada em soja cultivada em área de baixa fertilidade natural. Foram conduzidos dois experimentos, sendo um em campo e outro em vasos. Os experimentos foram em delineamento de blocos ao acaso com 24 tratamentos e três repetições. Os tratamentos foram dispostos em um esquema fatorial 2x12, representado por dois cultivares (TMG 1288 RR e CD 251RR) e 12 combinações de fornecimento de nitrogênio (CFN). As CFN utilizadas foram: sem inoculante e sem nitrogênio, apenas inoculante, 20, 40 e 60 kg ha^{-1} de N + inoculante, 50, 100, 150, 200, 250, 300 e 350 kg ha^{-1} de N. As doses de N foram divididas em três aplicações, sendo 20% aplicada no plantio, 40% no início do florescimento e 40% no enchimento de grãos. A adubação nitrogenada em associação com a inoculação das sementes não resultou em ganhos significativos na produtividade da cultura. O fornecimento de N mineral afetou negativamente o número e peso dos nódulos e positivamente o peso das raízes.

Palavras-chave: *Glycine max, suprimento de nitrogênio, áreas degradadas*

RESUMEN

En el cultivo de la soja, algunos estudios han demostrado un aumento en la productividad cuando se suministra el nitrógeno a través de la fijación simbiotica junto con la fertilización nitrogenada. Así, el presente trabajo se realizó con el objetivo de evaluar el efecto de la fertilización con nitrógeno en soya cultivada en un área de baja fertilidad. Se realizaron dos experimentos, uno en campo y el otro en macetas. El diseño experimental utilizado fue en delineamiento bloques al azar, con 24 tratamientos y tres repeticiones. Los tratamientos se dispusieron en un esquema factorial de 2x12, siendo dos variedades (TMG 1288 RR y CD 251RR) y 12 combinaciones de suministro de nitrógeno (CSN). Los CSN utilizados fueron: sin nitrógeno y sin inoculante; sólo inoculante; 20, 40 y 60 kg ha-1 de N + inoculante; 50, 100, 150, 200, 250, 300 y 350 kg ha-1 de N. Las dosis de N se dividieron en tres aplicaciones, siendo el 20% aplicado en la siembra, el 40% al inicio de la floración y el 40% durante el llenado del grano. La fertilización nitrogenada asociada a la inoculación de las semillas no dio lugar a un aumento significativo de la productividad del cultivo. El suministro de N mineral afectó negativamente al número y peso de los nódulos y positivamente al peso de las raíces.

***Descriptores**: Glycine max, suministro de nitrógeno, zonas degradadas*

INTRODUCTION

Soybean (*Glycine max* (L.) Merril) is one of the most important oil crops worldwide due to its productive potential, its nutritional value, and its chemical composition, which explain the multiplicity of applications in human and animal feed (HIRAKURI et al., 2017).

In the Brazilian market, soybean has great relevance, as it is the main agricultural commodity. Brazil is the second-largest producer in the world, with an estimated yield of 3,522 kg/ha, occupying a cultivated area of 38.507 million hectares (CONAB, 2021).

This legume is grown all over Brazil, but the largest areas of cultivation and production are concentrated in the regions South, Southeast, and Midwest. Soybean cropping has been expanding to the Brazilian North and Northeast regions due to the adaptive success of improved cultivars, studies of mineral nutrition, adoption of the no-tillage system, and resistance to pests and diseases (ROCHA et al., 2018).

The state of Tocantins has a great potential for the development of soybean culture because of water availability, high radiation, production flow logistics, flat terrain, and adoption of new technologies (soil and nutrients management, integrated pest management, integrated production systems, adapted cultivars, biological nitrogen fixation, among others) (EMBRAPA, 2019).

According to Saturno et al. (2017), nitrogen is the most important element for biomass increase. The soybean has a high demand for N due to its high protein content. This nutrient is essential to achieve high yields. In soybean cropping, the nitrogen is mainly supplied by biological fixation, through symbiosis with *Bradyrhizobium* bacteria (RENGEL et al., 2018; NOMURA et al., 2019).

Biological nitrogen fixation was one of the major drivers for large-scale cultivation of soybean in Brazil, wherein bacteria in contact with soybean roots penetrate and create an infection thread inside the cortex, where they multiply, and form nodules. This process results in the transformation of N_2 into ammonia (NH_3), a form plants can assimilate, through the enzyme hydrogenase, which presents in certain groups of bacteria, in addition to being the cheapest source of N (HUNGARY et al., 2015).

There is a strong positive correlation between seed production and nitrogen absorption in soybean (ROTUNDO et al., 2014). Most of the assimilated nitrogen is exported to the grains. The highest demand for nitrogen occurs between stages R1 (beginning of flowering) and R6 (maximum volume of grains), conversely, Bahry et al. (2013) report that the capacity for symbolic N_2 fixation begins to decrease rapidly after the R5 growth stage, which corresponds to the stage of greatest demand for protein synthesis.

Inoculating microorganisms, such as *Bradyrhizobium* spp., promotes several benefits for soybean cropping, from an economy with mineral fertilizers to the promotion of morphological improvements in the roots, better absorption of water and nutrients, enabling the best development of the plant and the formation of quality grains, in addition to yield (NOMURA et al., 2019).

Thus, the present study was carried out given the scarcity of studies involving the nitrogen supply via nitrogen fertilization in soybean cropping under low latitude conditions.

MATERIAL AND METHODS

Two experiments (one in field conditions and one in pots) were installed In February 2014 in the experimental station of the Federal University of Tocantins (UFT), Gurupi Campus - TO (11°43' south latitude, 49°04' west longitude, and altitude of 280 meters). The local climate is humid B1WA'a' with moderate water deficiency, rainy summer, and dry winter. The average annual temperature is 29.5 °C, and the average annual precipitation is 1804 mm.

The chemical and physical analysis of the soil of the experiments presented the following characteristics: Ca+Mg = 0.86 (cmol/dm³), Ca = 0,71 (cmol/dm³), Mg = 0,15 (cmol/dm³), Al = 0.1 (cmol/dm³), H+Al = 4.79 (cmol/dm³), K = 0.04 (cmol/dm³), CTC(T) = 5.68 (cmol/dm³), SB = 0.9 (cmol/dm³), CTC(t) = 1 (cmol/dm³), K = 13.85 (mg/dm³), P(Mel) = 1.35 (mg/dm³), V (%) = 15.76, (m (%)) = 10.05, (organic matter (%)) = 1.2, organic matter = 12.02 (g/dm³), pH in $CaCl_3$ = 4.3, pH in H_2O = 5.52, Sand = 571.22 (g/Kg), Silt = 31.07 (g/Kg), and Clay = 397.72 (g/Kg).

The experiments were conducted in a randomized block design with 24 treatments and three replications. The treatments were arranged in a 2 x 12 factorial scheme, represented by two cultivars (TMG1288RR™ and CD251RR™) and 12 nitrogen supply combinations.

The nitrogen supply combinations used in each of the experiments were as follows: T1 - Without inoculant and nitrogen (Sia); T2 - only inoculant; T3 - 20 kg ha^{-1} of N + Inoculant; T4 - 40 kg ha^{-1} of N + Inoculant; T5 - 60 kg ha^{-1} of N + Inoculant; T6 - 50 kg ha^{-1} of N; T7 - 100 kg ha^{-1} of N; T8 - 150 kg ha^{-1} of N; T9 - 200 kg ha^{-1} of N; T10 - 250 kg ha^{-1} of N; T11 - 300 kg ha^{-1} of N and T12 - 350 kg ha^{-1} of N. Each dose of N was divided into three applications: 20% applied at planting, 40% at the beginning of flowering, and 40% in grain-filling. The ammonium sulfate was used as nitrogen source. The mineral N fertilization was split to avoid losses through leaching and volatilization, as well as making nitrogen available during all stages of plant development.

Field experiment

The experimental plot was composed of four lines of 5 meters in length with spacing between rows of 0.45 meters. The two central rows were harvested, except for 0.50 m from the end of each row, resulting in a useful area of 3.6 m^2. After a previous analysis of the soil, liming was initially carried out, using two tons of Filler dolomitic limestone/ha, which was immediately incorporated into the soil. At 30 days after correction, plowing, harrowing, and furrowing operations were performed.

Sowing and fertilization were performed manually. Planting fertilization was carried out using 700 kg ha^{-1} of simple superphosphate. At planting, the seeds were inoculated (except for the treatment with *Bradyrhizobium japonicum* strains using the product

Biomax® Premium Turfa - Soybean – Strains: SEMIA 5079 + SEMIA 5080), with a dosage of 60 grams for each 50 kg of seeds. The sowing density was carried out to obtain 14 plants/m.

The control of pests, diseases, and weeds was carried out as necessary. Top-dressing fertilization with potassium chloride was performed 15 days after seedling emergence at a dose of 100 kg ha^{-1}.

Based on the useful area of the plot, the following agronomic characteristics were obtained: Number of seeds per pod (NSP) - number of seeds, obtained at maturation, in 10 competitive plants in the useful area; Number of pods per plant (NPP) - number of pods, obtained at maturation, in 10 competitive plants in the useful area; Mass of 100 seeds in grams (M100) - mass, in grams, obtained from a sample of 100 seeds per plot; Grain yield (YIELD) - production, in kg/ha, after the humidity correction to 12%.

Pot experiment

The experimental plot consisted of three eight-liters pots filled with the same soil as the field experiment. In each pot, five seeds of each cultivar were sown. Ten days after emergence, thinning was performed, leaving only two plants per pot. Planting fertilization was carried out using 700 kg ha^{-1} of simple superphosphate.

Top-dressing fertilization with potassium chloride was performed 10 days after emergence, at a dose of 100 kg ha^{-1}, according to soil analysis and corrective fertilization indication. The control of pests, diseases, and weeds was carried out as necessary.

At harvest, the plants in each experimental plot were cut at the point of cotyledon insertion, near to the stem base. The roots were gently washed under running water to remove all undesirable material, but not removing the nodules.

Then, the nodules were removed and counted. Subsequently, the root and the nodules were placed in a paper bag and dried in an oven for 72 h at 65 °C until reaching constant mass. Finally, the variables number of nodules (NN) and mass of nodules (WN) were obtained.

Statistical analysis

Regression analyzes were performed for combinations of mineral nitrogen supply, associated or not with the use of the inoculant, with the significance of the angular coefficients of the equations determined by the Student's t-test, at 5% of significance.

Comparisons were also made of the combinations of mineral nitrogen supply versus nitrogen via inoculation, with the following contrasts being established: Contrast 1: (Inoculated) x (I+20, I+40, I+60 kg of N ha_{-1}; Contrast 2: (Inoculated, I+20, I+40, I+60 kg of N ha^{-1}) x (50, 100, 150, 200, 250, 300, 350 kg N ha^{-1}; and Contrast 3: (Inoculated) x (50, 100, 150, 200, 250, 300, 350 kg N ha^{-1}), whose indexes are shown in Table 1. Then, the Scheffé test was applied at the 5% significance, as this test does not require orthogonality and there is no maximum number of contrasts to be analyzed (PIMENTEL-GOMES, 1976).

RESULTS AND DISCUSSION

The summary of the analysis of variance (ANOVA) of the evaluated characteristics is shown in Table 2. The ANOVA results showed significant differences for cultivars (CULT) for the characteristics grain yield (YIELD), mass of 100 grains (M100), and root mass (RM).

For the combinations of nitrogen supply (CNS), only the characteristics number of seeds per pod (NSP) and mass of nodules (NM) were not significant. Thus, for the characteristics that showed significant differences, contrasts were established between the combinations for each of the genotypes.

The CULT x CNS interaction showed a significant difference for grain yield (YIELD), root mass (RM), number of nodules (NN), and mass of nodules (NM), indicating a differential behavior of cultivars when compared to nitrogen supply combinations. For these characteristics, regression models were adjusted for each genotype.

The coefficients of variation (Table 2) were considered low, ranging from 3.58 to 17.34% for all the characteristics evaluated. The contrasts for the characteristics root mass (RM) and number of nodules (NN), for both cultivars, are shown in Table 3.

All the contrasts established for both cultivars, with mineral nitrogen supply, associated or not with inoculation, resulted in higher root mass (RM), being this increase significant.

Table 1. Indexes used in the different treatments for contrasts: contrast 1: (Inoculated) x (I+20, I+40, I+60 kg of N ha^{-1}), contrast 2: (Inoculated, I+20, I+40, I+60 kg of N ha^{-1}) x (50, 100, 150, 200, 250, 300, 350 kg N ha^{-1}) and contrast 3: (Inoculated).

Treatment	Number of contrasts		
	1	2	3
I	-3	-1	-7
I+20	1	-2	0
I+40	1	-2	0
I+60	1	-2	0
50	0	1	1
100	0	1	1
150	0	1	1
200	0	1	1
250	0	1	1
300	0	1	1
350	0	1	1

I: Inoculated, I+20: Inoculated + 20 kg of N ha^{-1}, I+40: Inoculated + 40 kg of N ha^{-1}, I+60: Inoculated + 60 kg of N ha^{-1}, 50: 50 kg N ha^{-1}, 100: 100 kg N ha^{-1}, 150: 150 kg N ha^{-1}, 200: 200 kg N ha^{-1}, 250: 250 kg N ha^{-1}, 300: 300 kg N ha^{-1} e 350: 350 kg N.

Table 2. Summary of the analysis of variance of four agronomic characteristics evaluated with 12 different combinations of nitrogen supply (CNS) and two cultivars (CULT) of soybeans, in the 2013/2014 growing season, in Gurupi, Tocantins.

SV	DF	Mean square						
		YIELD	M100	NPP	NSP	RM	NN	WN
CULT	1	148699 *	24.39*	39.35	0.009	43.555*	10.12	31.6
BLOCKS	2	28172.0	0.520	24.10	0.001	3.1666	7.055	51380*
CNS	11	524345.1*	2.321*	159.5*	0.009	19.515*	708.6*	277.2
CULT X CNS	11	67173.33*	1.092	23.30	0.011	34.222*	23.36*	3968*
ERROR	46	24930.93	0.780	19.23	0.008	1.1521	2.49	120.54
CV (%)	8.43	8.44	14.54	3.58	14.98	14.89	17.34	17.34
Mean	1872.75	10.46	30.15	2.60	7.16	10.59	63.32	63.32

Grain yield (kg ha^{-1}); M100: Masst of 100 grains (grams); NPP: Number of pods per plant; NSP: Number of seeds per pod; RM: Root mass; NN: Number of nodules; NM: Nodules mass. *Significant at 5% probability by the F-test.

Hungary et al. (2015) and Bulegon et al. (2016) reported that there might be a response to seed inoculation in areas with few years of soybean cropping since in these areas the existing *Bradyrhizobium* populations can compete for infection sites, which confirm the finding of this present study. Conversely, Nomura et al. (2019) found no statistically significant differences between treatments without and with *Bradyrhizobium* inoculation.

Table 3. Contrast means for root mass (RM) and number of nodules (NN) for two soybean cultivars in the 2013/2014 growing season, in Gurupi, Tocantins.

Contrasts	RM		NN	
	TMG 1288	CD 251	TMG 1288	CD 251
Contrast 1	3.8*	2.7	-36.9*	-70*
Contrast 2	58.9	18.5*	-42.94*	-61.5*
Contrast 3	47.3*	9.3*	-191.94*	-265.5*

Contrast 1: (Inoculated) x (I+20, I+40, I+60 kg of N ha^{-1}), Contrast 2: (Inoculated, I+20, I+40, I+60 kg of N ha^{-1}) x (50, 100, 150, 200, 250, 300, 350 kg N ha^{-1}), Contrast 3: (Inoculated) x (50, 100, 150, 200, 250, 300, 350 kg of N ha^{-1}). *Significant contrast at 5% probability by the Scheffé test.

As for the number of nodules (NN), all contrasts studied for both cultivars, with mineral nitrogen supply, associated or not with inoculation, reduced the number of nodules.

According to Miyasaka (1981), nitrogenous compounds incorporated into the soil close to the rhizosphere impair the formation of bacterial infection thread. Glyan'ko et al. (2009) state that under high mineral nitrogen concentration conditions in the environment, the plant starts to recognize *Rhizobium* as a pathogen, restricting nodulation.

The contrasts for grain yield (YIELD), mass of 100 seeds (M100), and number of pods per plant (NPP) for two soybean cultivars are shown in Table 4.

Table 4. Contrast means for grain yield (YIELD), mass of 100 grains (M100), and number of pods per plant (NPP) for two soybean cultivars in the 2013/2014 growing season, in Gurupi, Tocantins.

Contrast	YIELD		M100		NPP	
	TMG 1288	CD 251	TMG 1288	CD 251	TMG 1288	CD251
Contrast 1	405	1551	9.69	2.97	9.81	25.5
Contrast 2	8561*	9772*	50.3*	47.02	145.3*	161*
Contrast 3	2717	5638*	34.42	8.12	63.58	93.3*

Contrast 1: (Inoculated) x (I+20, I+40, I+60 kg of N ha^{-1}), Contrast 2: (Inoculated, I+20, I+40, I+60 kg of N ha^{-1}) x (50, 100, 150, 200, 250, 300, 350 kg N ha^{-1}), Contrast 3: (Inoculated) x (50, 100, 150, 200, 250, 300, 350 kg N ha^{-1}). *Significant contrast at 5% probability by the Scheffé test.

For contrast 1 (C1 = -3T1 + 1T2 + 1T3 + 1T4), i.e. C1 = (inoculated) versus (I + 20, I + 40, I + 60 kg of N ha^{-1}), considering all the characteristics and both cultivars, there was no significant difference in the N supplied to the plants only by the symbiotic route compared to the mineral N associated with the symbiosis, despite greater gains with the addition of mineral nitrogen.

Zuffo et al. (2019) evaluated the response of soybean to sources and doses of N, associated with the inoculation of *Bradyrhizobium japonicum*. The authors reported that fertilization did not increase the yield components and the protein content of the grains, regardless of the environment, the sources, and doses of N in the application.

In the present study, there was no significant benefit or damage to the plants using mineral N after seed inoculation, even though a reduction in the number of root nodules (NN) was observed with fertilization. This may be because nitrogen fertilization, despite the negative effect on NN, provided a greater root mass (RM) (Table 3), which resulted in a larger explored area of soil and, finally, in greater absorption of nutrients.

For contrast 2 (C2 = -1T1 - 2T2 - 2T3 - 2T4 + T5 + T6 + T7 + T8 + T9 + T10 + T11), i.e. C2 = (Inoculated, I + 20, I + 40, I + 60 kg of N ha^{-1}) versus (50, 100, 150, 200, 250, 300, 350 kg N ha^{-1}), there was a superiority of the group involving mineral N supply in relation to the inoculated group (with or without mineral N), for all characteristics, except for mass of 100 seeds (M100) for the cultivar CD251.

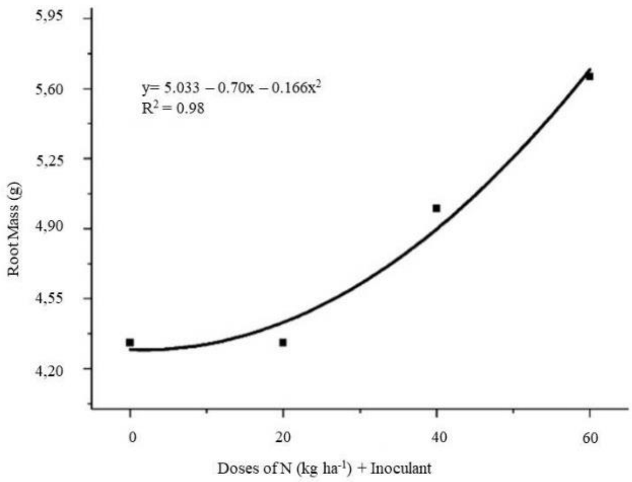
In contrast 3 (C3 = -7T1 + T2 + T3 + T4 + T5 + T6 + T7 + T8), i.e. C3 = (inoculated) versus (50, 100, 150, 200, 250, 300, 350 kg N ha^{-1}), no significant gains were detected when N was provided via symbiosis with the group that received mineral N for the cultivar TMG1288. In contrast, for the cultivar CD 251, the mineral N was superior to the N of the symbiotic fixation, for YIELD and NPP.

The heavier roots (RM) of only-fertilized treatments probably in greater absorption of nutrients from the soil, which in turn increased the mass of 100 seeds (M100) and the number of pods per plant (NPP), reflecting in the grain yield (YIELD) (Table 3).

The regression models for the characteristics root mass (RM), number of nodules (NN), mass of nodules (NM) and grain yield (YIELD), which showed significant interaction between cultivars and the combinations of mineral nitrogen supply, associated or not with inoculation, are shown in Figures 1 to 6.

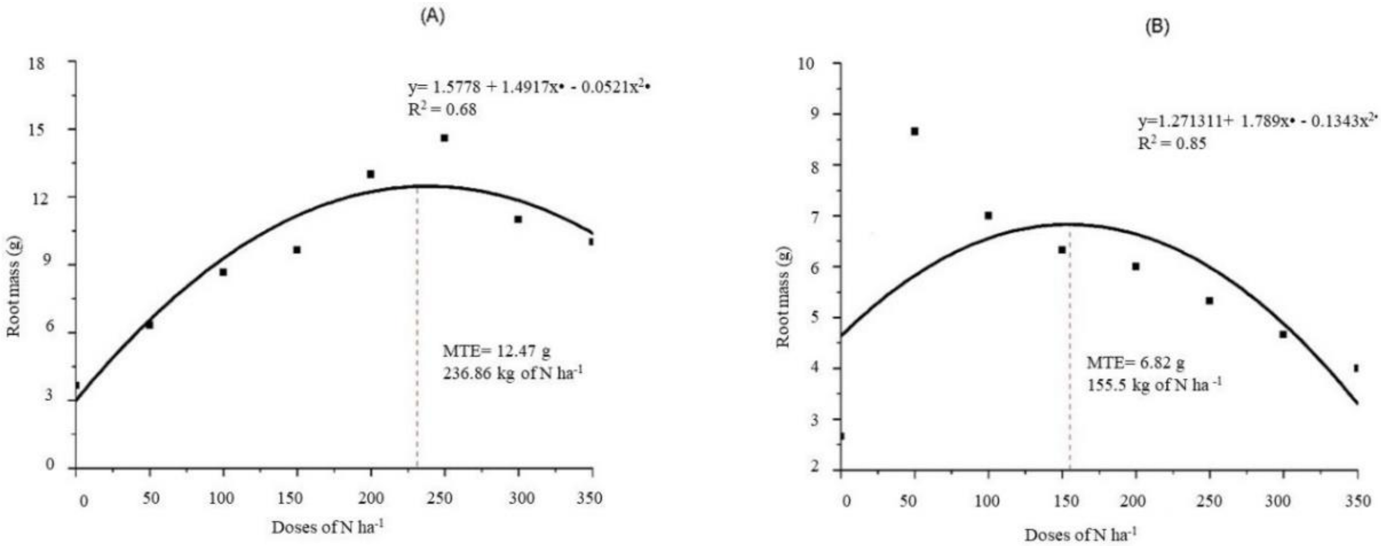
Increasing doses of nitrogen, after seed inoculation, resulted in an increase in RM for cultivar TMG1288 (Graphic 1). For the cultivar CD251, it was not possible to adjust an orthogonal polynomial to the data.

Graphic 1. Root mass of cultivar TMG1288 (A) as a function of nitrogen doses + inoculant, in the municipality of Gurupi - Tocantins. *Significant contrast at 5% probability by the Scheffé-test.



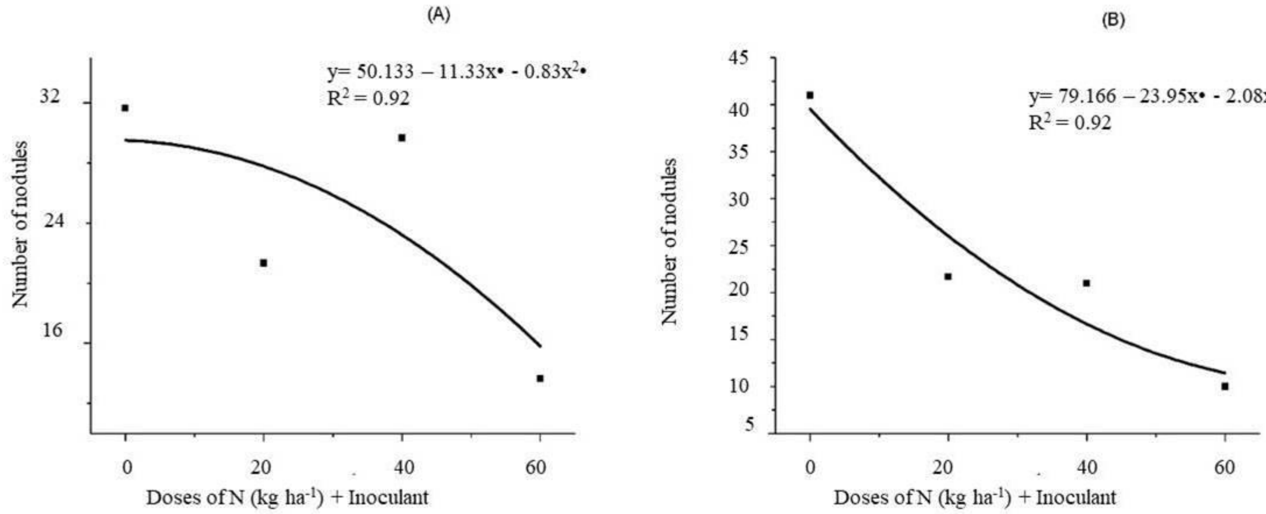
Considering only the effect of the mineral N supply (without seed inoculation) for RM, the two cultivars were influenced by the nitrogen doses, with the quadratic model being the best fit (Graphic 2). The maximum technical efficiency (MTE) of 12.47 (g) was obtained with the estimated dose of 236.86 kg of N ha^{-1} for cultivar TMG1288RR (Grafic 2A). For the cultivar CD251 (Figure 2B), the MTE was 6.82 (g) obtained with the estimated dose of 155.5 kg of N ha^{-1}

Graphic 2. Root mass of cultivars TMG1288RR (A) and CD251 (B) as a function of nitrogen doses, in the municipality of Gurupi - Tocantins. MTE: maximum technical efficiency. *Significant contrast at 5% probability by the Scheffé-test.

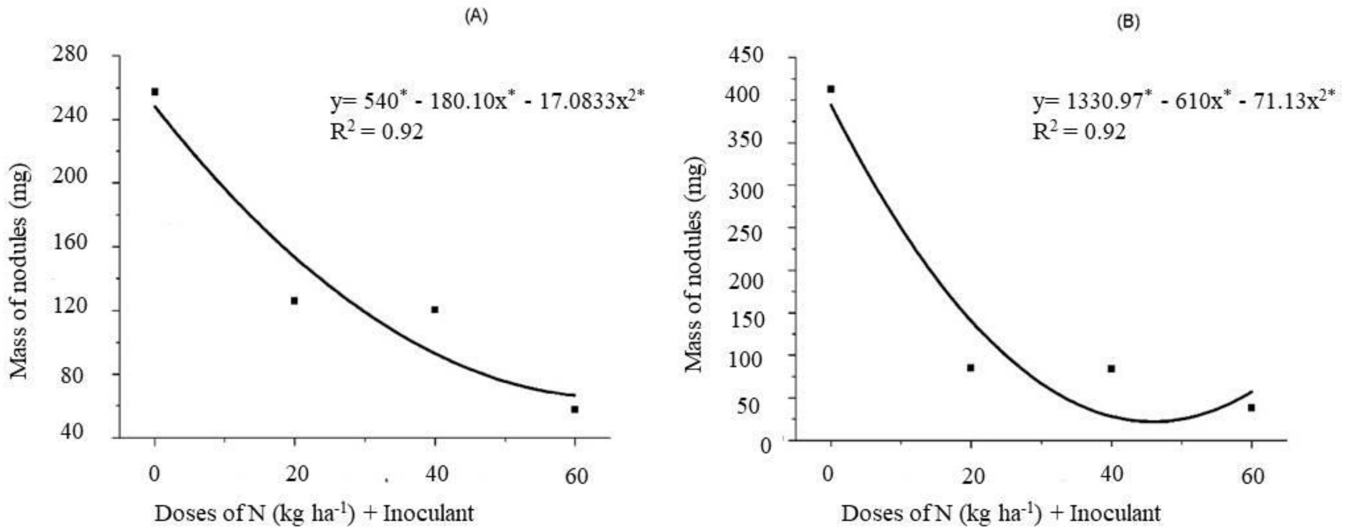


For the characteristics number of nodules (NN) (Graphic 3) and nodule mass (NM) (mg) (Grphic 4), there was a decrease as the N doses increased after seed inoculation, regardless of the cultivar. These results agree with Kaschuk et al. (2016); Zuffo et al. (2019), who pointed out the negative effects of increasing doses of mineral N on nodulation and nodule mass since the biological nitrogen fixation is closely related to the nodular mass (PADOVAN et al. 2012).

Graphic 3. Number of nodules (NN) of cultivars TMG1288RR (A) and CD251 (B) as a function of nitrogen doses + inoculant in the municipality of Gurupi - Tocantins. MTE: maximum technical efficiency. *Significant contrast at 5% probability by the Scheffé-test.



Graphic 4. Mass of nodules of cultivars TMG1288RR (A) and CD251 (B) as a function of nitrogen doses + inoculant in the municipality of Gurupi – Tocantins. MTE: maximum technical efficiency. *Significant contrast at 5% probability by the Scheffé-test.



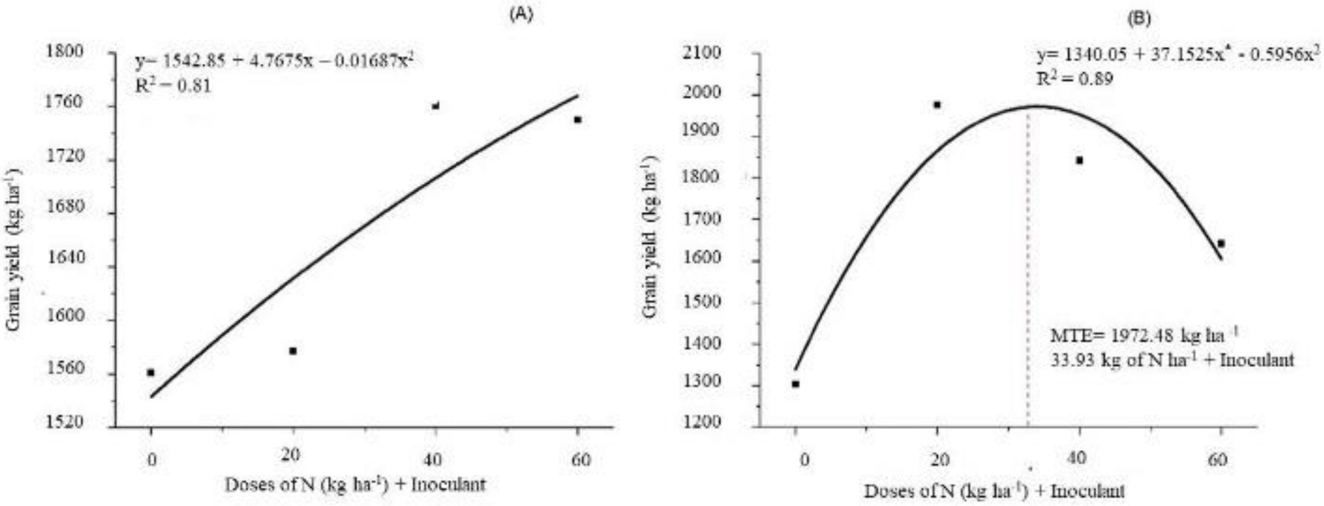
According to Embrapa (2011), the application of nitrogen fertilizer reduces the bacteria efficiency in fixing atmospheric N, decreasing the number of nodules per plant. Thus, N doses should be lower than 20 kg ha^{-1} when formulated N-containing fertilizers are more economical than those without N.

Cattelan and Hungary (1994) concluded that a well-nodulated soybean root would present between 15 and 30 nodules at flowering, which is similar to the observed in this study. The same authors also highlight that a soybean plant with good nodulation presents between 100 and 200 mg of nodular mass during flowering.

There was an increase in grain yield (PG) of cultivar TMG1288RR (Graphic 5A) as the doses of N increased. The yield surplus of cultivar TMG1288RR as a function of doses of nitrogen + Inoculant probably occurred in function of the increase in the number of pods per plant (Table 3), mass of 100 seeds (Table 3), and root mass (Table 3).

For the cultivar CD251 (Graphic 5B), the grain yield as a function of nitrogen doses + inoculant, presented adjustment of the quadratic model and maximum technical efficiency (MTE) of 1972.48 kg ha^{-1} obtained with the estimated dose of 33.93 kg of N ha^{-1} (Figure 5), decreasing from that point. This drop in yield coincides with the decrease in the number of nodules (NN) (Graphic 3B) and mass of nodules (Figure 4B), which also occurred markedly around 30 kg of N ha^{-1}.

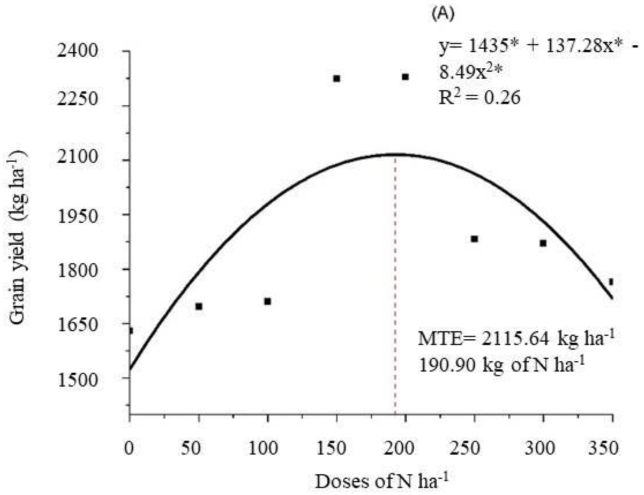
Graphic 5. Grain yield of cultivars TMG1288RR (A) and CD251 (B) as a function of nitrogen doses + inoculant in the municipality of Gurupi – Tocantins. MTE: maximum technical efficiency. *Significant contrast at 5% probability by the Scheffé-test.



As for the use of only mineral N, despite the low magnitude of the mathematical models in explaining the variations of grain yield as a function of N doses (Graphic 6), for both cultivars, the most representative model was quadratic. For the cultivar TMG 1288RR (Graphic 6A), the maximum technical efficiency (MTE) was 2115.64 kg ha^{-1} at the dose of 190.90 kg N ha^{-1}. For CD 251 (Graphic 6B), the estimated dose of 194.44 kg of N ha^{-1} resulted in maximum technical efficiency (MTE) of 2366 kg ha^{-1}.

Petter et al. (2012) reported gains in yield in soybean cultivars applying N doses at the R1 stage (beginning of flowering). In addition to increasing grain yield, N application can also increase protein levels. Klarmann (2004) found a positive relationship between the nitrogen application and yield increase. However, some results have shown that the application of nitrogen fertilizers does not improve grain yield and harvesting (KORBER et al. 2017; ZUFFO et al. 2018).

Graphic 6. Yield of commercial cultivars, TMG1288 (A) and CD251 (B) as a function of nitrogen doses + inoculant in the municipality of Gurupi – Tocantins. MTE: maximum technical efficiency. *Significant contrast at 5% probability by the Scheffé-test.



CONCLUSION

The nitrogen fertilization in association with seed inoculation did not result in significant gains in crop yield. The mineral N supply affected negatively the number and mass of nodules, and positively the root mass.

Todos os autores declararam não haver qualquer potencial conflito de interesses referente a este artigo.

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