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Nitrogen availability in grain sorghum under Cerrado conditions

Disponibilidade de nitrogênio em sorgo granífero nas condições de Cerrado

Disponibilidad de nitrógeno en sorgo granífero en condiciones de Cerrado

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Abstract
The objective was to evaluate the effect of the addition of increasing doses of nitrogen (N) in grain sorghum on development in sandy textured soil with low fertility in Cerrado conditions. The work was carried out at Fazenda Pântano located, in the municipality of Jataí – Goiás, Brasil. The seeds used for the experiment were the AG 1085 variety. Using five doses of N: 0 (control), 50, 100, 150 and 200 kg ha^{-1}, the source being urea, with five replications each, with a design in randomized blocks, totaling 25 experimental units. The variables evaluated were: stem length (CC), stem diameter (DC), leaf area (AF), shoot dry mass (DM), leaf nitrogen content (TN), nutrient accumulation (AC), nitrogen efficiency (NE), chlorophyll A (CLA) and chlorophyll B (CLB). The different doses of N had a significant effect for all variables except for the nitrogen content in the leaf, chlorophyll A (CLA) and chlorophyll B (CLB) contents. The dose indicated for the best development of the grain sorghum crop in the low fertility conditions studied was 150 kg^{-1} of N per hectare.
Keywords: Fertilization; Fertility; *Sorghum bicolor*.

Resumo
Objetivou-se avaliar o efeito da adição de doses crescente de nitrogênio (N) em sorgo granífero no desenvolvimento em solo de textura arenosa e de baixa fertilidade nas condições de Cerrado. O trabalho foi realizado na Fazenda Pântano, localizada no município de Jataí – Goiás, Brasil. As sementes utilizadas para realização do experimento foi à variedade AG 1085. Utilizando cinco doses de N: 0 (controle), 50, 100, 150 e 200 kg ha^{-1}, sendo a fonte a ureia, com cinco repetições cada, com delineamento em blocos ao acaso, totalizando 25 unidades experimentais. As variáveis avaliadas foram: comprimento do caule (CC), diâmetro caulinar (DC), área foliar (AF), massa seca da parte aérea (MS), teor de nitrogênio na folha (TN), acúmulo do nutriente (AC), eficiência de nitrogênio (EN), clorofila A (CLA) e clorofila B (CLB). As diferentes doses de N apresentaram efeito significativo para as todas as variáveis exceto para o teor de nitrogênio na folha, teores de clorofila A (CLA) e clorofila B (CLB). A dose indicada para o melhor desenvolvimento da cultura do sorgo granífero nas condições estudadas de baixa fertilidade foi de 150 kg^{-1} de N por hectare.
Palavras-chave: Adubação; Fertilidade; *Sorghum bicolor*.

Resumen
El objetivo de este estudio fue evaluar el efecto de la adición de dosis crecientes de nitrógeno (N) en sorgo granífero sobre el desarrollo en suelos de textura arenosa con baja fertilidad en condiciones de Cerrado. La obra fue realizada en Fazenda Pântano, ubicada en el municipio de Jataí - Goiás, Brasil. Las semillas utilizadas para el experimento fueron de la variedad AG 1085. Utilizando cinco dosis de N: 0 (testigo), 50, 100, 150 y 200 kg ha^{-1}, siendo la fuente la urea, con cinco repeticiones cada una, con un diseño en al azar bloques, totalizando 25 unidades experimentales. Las variables evaluadas fueron: longitud del tallo (LT), diámetro del tallo (DT), área foliar (AF), masa seca aérea (MS), contenido de nitrógeno foliar (NF), acumulación de nutrientes (AN), eficiencia de nitrógeno (EN), clorofila A (CLA) y clorofila B (CLB). Las diferentes dosis de N tuvieron un efecto significativo para todas las variables excepto para el contenido de nitrógeno en la hoja, clorofila A (CLA) y clorofila B (CLB). La dosis indicada para el mejor desarrollo del cultivo de sorgo granífero en las condiciones de baja fertilidad estudiadas fue de 150 kg^{-1} de N por hectárea.
Palabras clave: Fertilizando; Fertilidad; *Sorghum bicolor*.

1. Introduction

Grain sorghum (*Sorghum bicolor*) is the ninth most produced cereal in Brasil in the 2019/2020 harvest (Misosul, 2020). The total area of sorghum in this period was 835.2 thousand hectares, an increase of 14.1% in relation to the previous harvest. It is estimated that Brasil will produce 2,498.1 thousand tons in this harvest (Conab, 2020). For the 2020/21 Brazilian crop, the forecast is for 2.6 million tons produced, 4.8% higher than the previous crop, in an area of 840.5 thousand hectares, an increase of 0.6% (Conab, 2021). Compared to corn, sorghum is a crop with a lower production cost and has 95% of its nutritional value (Silva et al., 2011) and has given producers interest due to its tolerance to water stress, for cultivation in the off-season, a season marked by instabilities of rainfall, but with great potential for expanding the use of arable areas (Menezes, 2018). Sorghum has a high response to the supply of water and fertilizers, especially nitrogen fertilizers. In this crop, nitrogen accumulation occurs linearly until maturation, being the element that most limits crop productivity (Goes et al., 2011).

Nitrogen fertilization is therefore an important component of soil nutrient management since, due to its mobility, it can easily dissipate or volatilize, depending on the source used (Zheng et al., 2015). This makes it a great challenge to be able to properly recommend nitrogen rates, especially in the sandy conditions in which this work was developed. It can be observed in the literature that the recommended doses vary a lot, with authors who did not find an effect to authors who recommend up to 200 kg ha^{-1} of N per hectare.

In the study by Mortate et al. (2020) evaluating nitrogen rates in red latosol and using grain sorghum hybrid found a response up to a dose of 200 kg ha^{-1} of N. Mateus et al. (2011) observed a response of grain sorghum intercropped with grass in a no-tillage system in the region of Botucatu, SP, Brasil, in dystrophic red latosol soils in which, in the first year of cultivation, the 50-50 kg ha^{-1} N splitting provided higher sorghum productivity, and this high dose may have been obtained because it was the first year of cultivation planting. Similar observations were found by Santos et al. (2014) where they obtained in the work carried out in Sete Lagoas, MG, Brasil, in red distroferric latosol soils, the dose of N to obtain the maximum economic efficiency, considering sorghum CMSXS 7020, was of 60 kg ha^{-1}, while for CMSXS 652 the economic dose of N was approximately 40 kg ha^{-1}, and in the study by Rosolem et al. (1985) where the researchers demonstrated the response of sweet sorghum to nitrogen fertilization, in a dystrophic purple latosol in the Botucatu region, SP, Brasil, obtained the best dose of 114 kg ha^{-1} of N.

These results clearly show that the recommendation of nitrogen in this crop is not yet consolidated and needs more research to understand and adapt to the current scenario of high cost of nitrogen fertilizers and the possibility of environmental contamination by excess. In view of the above, this work aims to evaluate the effect of adding increasing doses of nitrogen to grain sorghum in sandy soil with low fertility in Cerrado conditions.

2. Methodology

This work was carried out at *Farm Pântano*, located in the municipality of Jataí – Goiás, Brasil. The reference geographic coordinates are Latitude (17°59'15.87" S) and Longitude (5°14'15.26" W). Soil preparation was done through harrowing and soil correction according to the result of the soil analysis. soil and recommendation criteria (Sousa et al., 2004).

The chemical and textural characteristics are shown below for the 0-20 cm depth: pH ($CaCl_2$) = 4.2; Ca, Mg, K, Al and Cation Exchange Capacity (CEC) (0.3; 0.1; 0.05; 0.45 and 5.2 cmolc dm^{-3} respectively); P (mel), S, Zn, B, Cu and Mn (0.8; 5.4; 0.3; 0.4; 0.7 and 10.9 mg dm^{-3}); V % = 9; Organic Matter (OM) = 16.4 g dm^{-3}; clay, silt and sand (15, 5 and 80.0%, respectively).

For the depth of 20 to 40 cm, the result of the soil analysis showed the following result: pH ($CaCl_2$) = 4.01; Ca, Mg, K, Al and CEC (0.2; 0.1; 0.04; 0.65 and 4.4 cmolc dm^{-3} respectively); P (mel), S, Zn, B, Cu and Mn (0.8; 6.9; 0.3; 0.5; 0.8 and 12.0 mg dm^{-3}); V % = 8; OM = 14.2 g dm^{-3}; clay, silt and sand (15.7 and 78.0%, respectively). It can be observed that according to the data from the soil analysis, the soil has a sandy texture and acid pH. Organic matter, potassium and CEC are low and phosphorus is very low.

Liming was carried out 90 days before planting to raise the base saturation to 50%, using a dolomitic limestone with a relative power of total neutralization (PRNT) of 85% and the amount applied was 2.5 t ha^{-1}. The experimental plots were formed by a square of 3x3 m, with a distance between plots of three meters and three meters between blocks. The spacing used was 0.5 m between rows, to obtain a population of 140 thousand plants per hectare. The planting was carried out on 02/01/2018. The seeds used for the experiment were of the AG 1085 variety and five doses and five replications of N fertilization were evaluated, using a randomized block design, totaling 25 experimental units.

To evaluate the effect of nitrogen rates, the following rates were used: 0 (control), 50, 100, 150 and 200 kg ha^{-1}, the source being urea (45% N). For all doses 50% of the nitrogen dose was applied in the furrow at planting and the remainder of each treatment was applied in top dressing when the plants had six leaves in the late afternoon and wet soil to reduce loss by ammonia volatilization. Twenty days after planting, there was an attack by the fall armyworm (*Spodoptera frugiperda*) and the control was carried out with the application of Karate Zeon 250 CS® insecticide, applying 30 mL ha^{-1} of the product with the aid of a sprayer that was attached to the tractor.

The variables evaluated were: stem length (SL), stem diameter (SD), leaf area (LA), shoot dry mass (DM), leaf nitrogen content (LN), nutrient accumulation (NA), nitrogen efficiency (NE), chlorophyll A (CLA) and chlorophyll B (CLB). All analyzes performed were performed when the plants were in their physiological stage 5 known as booting. To determine the shoot dry mass, three plants from each plot were randomly harvested with the help of scissors. The samples were separated in the experimental area, placed in paper bags, identified and taken to the laboratory for drying in an oven with forced air circulation for 72 hours at 65 °C and then weighed.

The length of the stem was measured with the help of a millimeter tape, being measured the height of the plant neck until the insertion of the last leaf, in three plants of the plot. The stem diameter was measured using a digital caliper in the region of the plant neck (0.05 m from the ground) in three plants in the plot. For the determination of the leaf area from the leaf, the method described by (Sans; Pellegrin, 1998) was used, in which the total length and the average width of the leaves are measured and through the equation "LF = 0.7811 X 14.964 ," where LF is the leaf area and x is the length multiplied by the width in cm^2 where data were collected from three leaves of each plot.

To perform the analysis of chlorophyll A and B content, the ChlorofiLOG® measuring device was used, where measurements were taken of three leaves of each plot in the morning. The nitrogen content of the leaves was performed by collecting three leaves per plant, collected at random, in the central third of the plant according to recommendation by Sousa et al. (2004) and sent to a specialized laboratory. The quantification of nutrient accumulation was performed with the aid of the formula $NA = \frac{DM \times NC}{1000}$, where NA is the nutrient accumulation (kg ha^{-1}); DM is the shoot dry mass (kg ha^{-1}); NC is the nutrient content (g kg^{-1}) (Perin *et al.,* 2004). As for the nutrient application efficiency, the formula "NE =" "ATN treatment – AC control" /"AC treatment" "*x* 100" was used, where NE is the nutrient application efficiency (%); ATN is the accumulation of treatment nutrients (kg ha^{-1}); ACN is the accumulation of control nutrients (kg ha^{-1}) (Leal *et al.*, 2015). The regression analysis of variance was used to evaluate the effect of nitrogen doses on all analyzed variables where the data obtained were submitted to the SISVAR statistical software (Ferreira, 2011).

3. Results and Discussion

The different N doses had a significant effect on the following variables: shoot dry mass (DM), stem length (SL), stem diameter (SD), leaf area (LA), nitrogen accumulation (NA) and nitrogen efficiency (NE) (Table 1). The nitrogen doses used in this work did not influence the levels of chlorophyll A (CLA), chlorophyll B (CLB).

Table 1. Effect of nitrogen rates on grain sorghum under field conditions in Southwest Goiás, Brasil. Mean squares table.

Parameters	QM	Regression (V%)	CV (%)
DM (kg ha^{-1})	374.802466	Linear** Quadrat**	2,69
SL (cm)	80.358544	Linear** Quadrat**	6.64
SD (cm)	0.171350	Linear** Quadrat*	9.18
LA (cm^2)	16439.937586	Linear** Quadrat**	3.36
TN (g kg^{-1})	6.353600	NS NS	3.56
NA (kg ha^{-1})	13840.059734	Linear** Quadrat**	5.71
NE (%)	4195.559906	Linear** Quadrat**	9.65
CLA (ICF)	7.534400	NS NS	9.74
CLB (ICF)	1.105600	NS NS	24.28

Note: NS: not significant; *: Significant (P < 0.05); **: Significant (P < 0.01). Quadrat = quadratic; DM = shoot dry mass; SL = stem length; SD = stem diameter; LA = leaf area; NT = nitrogen content in the leaf; NA = nitrogen accumulation; NE = nitrogen efficiency; CLA= chlorophyll A and CLB= chlorophyll B. Source: Authors (2018).

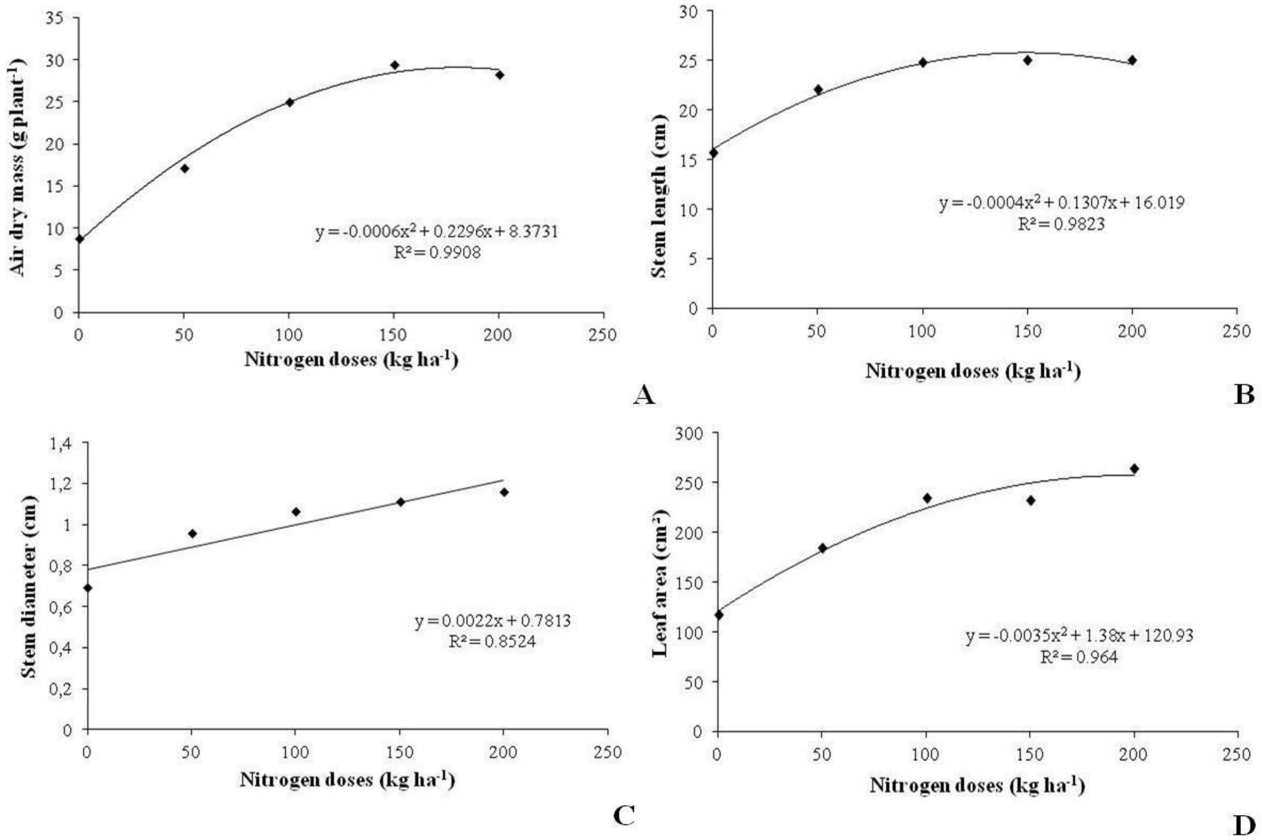
It can be verified that the maximum point of nitrogen dose for shoot dry mass in this work was at the dose of 191.3 kg ha^{-1} and obtained a dry mass of 30.33 g plant^{-1}. Maia et al., 2017 when working with different doses of nitrogen fertilization (80, 120, 160 kg/ha^{-1}) in hybrid sorghum SS-318 did not obtain an increase in the production of dry mass of the area with increasing doses of nitrogen , where the averages were 16.40; 18.06 and 15.37 g plant^{-1}, in which it was observed that doses above 80 kg ha^{-1} are not economically viable for the farmer. However, the results of the present work showed that with the increase of the dose, gains in shoot dry mass were obtained. This fact can be explained by the difference in the variety of the crop used, which presents greater mass production in the shoot.

For the stem length, the maximum point was at the dose of 163.3 kg ha^{-1}, which obtained a stem length of 26.69 cm at this dose. Pereira et al. (2014 working with nitrogen rates in the fertilization of grain sorghum BR 304 in the municipality of Baraúna, RN, Brasil, in cambisol soils, observed that plant height had no significant effect by the F test (P < 0.10) and no regression model fitted the observed data with nitrogen rates (0, 30, 60, 90 and 120 kg ha^{-1}). However Albuquerque et al. (2020) when evaluating nitrogen fertilization management with doses of 16, 32, 48, 64 kg of N ha^{-1} in grain and silage sorghum cultivars in semiarid regions observed that the increase in nitrogen fertilization provided increases in plant size regardless of the group of cultivars, corroborating the data obtained in the present work.

The regression analysis of variance showed for stem diameter, the data obtained were significant for the linear and quadratic model, and the largest stem diameter was found at the dose of 150 kg ha^{-1}. Goes et al. (2011) working with grain sorghum AG 1040 in the off-season in a dark red latosol and applied two nitrogen sources (urea ammonium sulfate), with five doses of nitrogen being applied (0, 20, 40, 60 and 80 kg ha^{-1}), did not have a significant effect of nitrogen sources on the stem diameter, however they reached an average of 1.6 cm in diameter in relation to the N applied with the urea source. When comparing this value to that obtained in the present work, it is possible to verify that the average value obtained by Goes et al., (2011) was higher, probably due to the difference between the varieties used.

For the LA the maximum point was obtained at the dose of 197.1 kg ha^{-1} with a leaf area of 256.95 cm^2 per plant. Ferreira et al. (2020) working with a biostimulant in the treatment of seeds (0, 3, 6, 9 and 12 mL ha^{-1}) in the presence and absence of nitrogen for the cultivation of grain sorghum “Fox” in typical orthic quartzarenic neosol soils observed an increase in leaf area , due to the fact that the supply of nitrogen in amounts increased the chlorophyll content of the leaf, being more efficient in the interception of solar radiation, increasing the leaf area of the plant, corroborating with data obtained in the present work. However Dessougi et al. (2021), when evaluating the effects of nitrogen fertilization at doses of 0, 50 and 100 kg ha^{-1} for two varieties of sweet sorghum, observed differences for leaf area only in the flowering and anthesis stages. Factor that can be explained by the availability of nitrogen in the initial stages of growth, since the fertilizer was all applied at the time of planting. The regression analysis of variance showed a linear and quadratic effect for the application of nitrogen rates on the morphological variables in the grain sorghum crop, better fitting the quadratic model as shown in (Figure 1).

Figure 1. Effect of the addition of nitrogen doses applied to the cultivation soil on the vegetative development of grain sorghum under field conditions in Southwest Goiás, Brasil. Averages of 5 observations. (**A**) DM = dry matter CV% = 2.69; (**B**) SL = stem length, CV% = 6.64; (**C**) SD = stem diameter, CV% = 9.18 and (**D**) LA = leaf area, CV% = 3.36.



Source: Authors (2018).

In the present work, the average N contents found in the leaves varied between 38.7 and 41g kg^{-1}. Pereira et al. (2014) evaluated grain sorghum BR 304 in haptic cambisol soils fertilized with five different doses of N 0, 30, 60, 90, and 120 kg ha^{-1}

and observed that the N content in the leaves had a significant effect, where values ranging from 23.95 to 33.93 g kg^{-1} were obtained, obtaining an increase of 30% when compared to the control with the lowest dose applied. In general, the average N contents found in the leaves obtained in this work were higher than the value presented by Pereira et al. (2014), however, their doses were lower than the doses used in the present work. When observing the reference values for the N content in plant tissues according to Ribeiro et al. (1999), the expected content for the sorghum crop is 23-29 g kg^{-1}, therefore the values obtained in the present work were higher.

It can be verified that the maximum point for N accumulation in the dry mass was at the rate of 180.5 kg ha^{-1} of nitrogen with an accumulation of 181.5 kg ha^{-1}. Castro et al. (2015) working with two sorghum hybrids and making applications in planting and nitrogen coverage, and in this work an increasing increase in accumulation was also observed with increasing nitrogen doses.

Sorghum shows a decreasing behavior in the efficiency of N uptake as the amounts of nitrogen available to plants increase (Fernandes *et al.*, 1991), which is different from the results found in the present study, where it can be verified that the maximum point for efficiency it was at the rate of 150.6 kg ha^{-1} of nitrogen, with an efficiency of 73.63%. Sigua et al. (2018) when evaluating the combined effects of N fertilization, supplemental irrigation on sorghum biomass, absorption and use efficiency of three levels of N application (0.85 and 170 kg N ha^{-1}) testing in two sorghum varieties (Dekalb A571 and Pioneer 84P80) obtained better results of use efficiency and nitrogen uptake when the sorghum cultivar varieties when they were supplemented with 85 kg N ha^{-1} was about 40.8% compared to with the efficiency of 35.8% of the plots that were fertilized with 170 kg N ha^{-1}.

The regression analysis of variance showed no linear or quadratic effect for the application of nitrogen rates on leaf nitrogen content (g kg^{-1}) in sorghum. The average nitrogen content found in this work for all treatments was 39.25 g kg^{-1} as shown in (Table 2).

Table 2. Effect of the addition of nitrogen doses applied to the crop soil on the foliar nitrogen content of grain sorghum under field conditions in Southwest Goiás, Brasil.

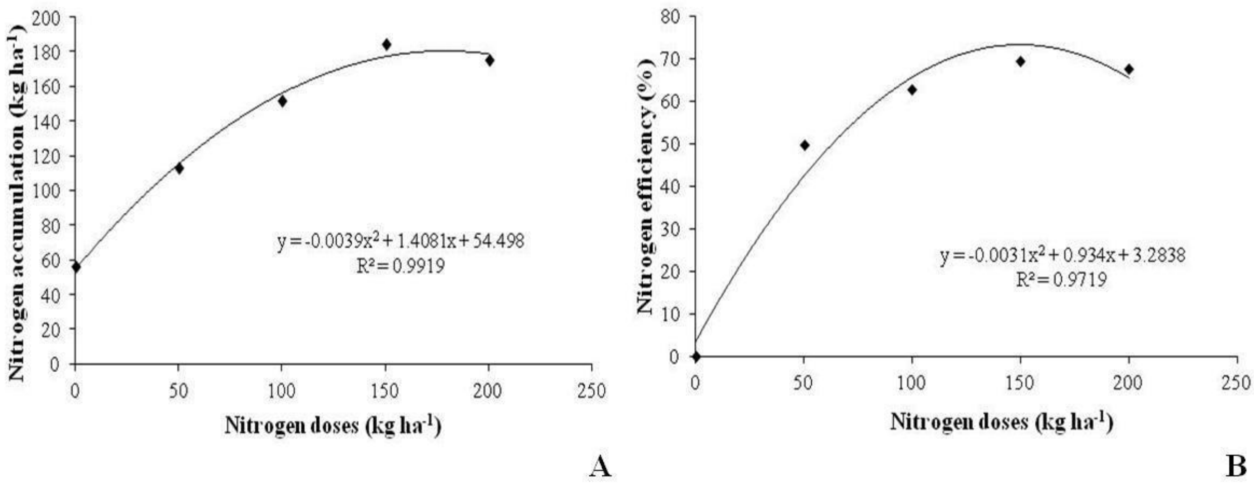
Nitrogen doses (kg ha^{-1})	**Leaf nitrogen content (g kg^{-1})**
0	39.4
50	41.0
100	37.9
150	39.1
200	38.7

Source: Authors (2018).

Zamani et al. (2020) when evaluating the growth and biochemical responses of different sorghum genotypes with nitrogen fertilization having salinity as a stress factor, with high, medium and low stress tolerance varieties and with N applications in the dosages of 0, 75, and 150 kg N ha^{-1} observed a positive effect of N fertilization on chlorophyll B concentration for high tolerance genotypes.

The highest concentrations of chlorophyll a and b were found with application of 150 kg N ha^{-1} for genotypes more tolerant to stress. The regression analysis of variance showed a linear and quadratic effect for the application of nitrogen rates on the accumulation of N in the NA and on the NF in the use of nitrogen (%) in the sorghum crop, adapting better to the quadratic effect as shown in (Figure 2).

Figure 2. Effect of the addition of nitrogen doses applied to the crop soil on the accumulation of N in the dry mass and on the efficiency of nitrogen use in grain sorghum crop under field conditions in Southwest Goiás. Averages of five observations. (**A**) NA = Nitrogen accumulation, CV% = 5.71; (**B**) NE = Nitrogen efficiency, CV% = 9.65.



Source: Authors (2018).

The regression analysis of variance did not show a linear or quadratic effect for the application of nitrogen rates on the chlorophyll A and Chlorophyll B Falker chlorophyll index (FCI) content in the sorghum crop, as shown in (Table 3). The chlorophyll A index found in this work for all treatments was 26.32 ICF and the chlorophyll B index was 5.62 FCI.

Table 3. Effect of the addition of nitrogen doses applied to the cultivation soil on the chlorophyll A and B content, of grain sorghum under field conditions in Southwest Goiás, Brasil.

Nitrogen doses (kg ha^{-1})	Chlorophyll A	Chlorophyll B
	FCI*	
0	25.3	5.2
50	25.1	5.4
100	27.0	5.5
150	26.1	5.6
200	28.1	6.4

Note: FCI* = Falker chlorophyll index. Means of five observations. Source: Authors (2018).

4. Conclusion

Nitrogen application had a positive influence on grain sorghum, not influencing leaf N content and chlorophyll A and B contents. The best dose response in grain sorghum crop development was at a concentration of 150 hg^{-1} N per hectare.

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