BIOENG

Brazilian Journal of Biosystems Engineering (2023), 17 1194

REGULAR ARTICLE

Cotton nitrogen doses in the edaphoclimatical conditions of northeastern Brazil

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Regular Section
Academic Editor: Fernando Ferrari Putti

Statements and Declarations

Data availability
All data will be shared if requested.

Institutional Review Board Statement
Not applicable.

Conflicts of interest
The authors declare no conflict of interest.

Funding

This research did not receive external funding.

Autor contribution
CMdaS: Responsible for conducting fieldwork, data collection, scientific writing; AdeAR: Scientific writing, review, and guidance; EFdaS: Responsible for conducting fieldwork and data collection; MGdaS: Fieldwork support; SVA: Fieldwork support; SAVP: Fieldwork support.

Abstract

The study of cotton plant responses to nitrogen fertilization in different climate and soil conditions is essential for the correct management of nitrogen in this crop. Therefore, the objective of the present study was to evaluate the responses of cotton plants to nitrogen fertilization in the edaphoclimatic conditions of the Cariri region, located in the northeastern State of Ceará, Brazil. The experiment was conducted in an experimental area at the CENTEC (Centre for Technological Education) School of Technology (FATEC - Cariri campus), located in the city of Juazeiro do Norte, Ceará State. The statistical design adopted was Completely Randomized Design (CRD). The treatments were composed from the combination of four doses of nitrogen (0, 60, 120, and 180 kg ha^{-1} of N, equivalent to 0, 50, 100, and 150% of the N recommendation for the crop) with four replications. Urea was used as a nitrogen source. At 42 days after sowing, the plants were collected. Plant height, number of leaves, stem diameter, leaf area, absolute growth rate, shoot and root dry matter, total and nitrogen use efficiency were evaluated. The different doses of nitrogen significantly influenced all the analysed variables. In general, nitrogen doses greater than 120 kg ha^{-1} of N were shown to impair the growth and dry matter production of the cotton plant in the climate and soil conditions of the Cariri region, northeastern Brazil. In addition, excessive nitrogen fertilization was shown to reduce the efficiency of nitrogen use by the cotton crop.

Keywords

Gossypium hirsutum L. Soil fertility. Urea. N use efficiency.

Introduction

Cotton is one of the world's most important textile fibre crops in agriculture, planted in practically all countries and continents (USDA, 2018). World cotton production is led by the Asian continent, with India in first place, China in second, the United States in third, and Brazil in fourth (ABRAPA, 2021). In Brazil, crop production is concentrated almost entirely (sequentially in volume) in the Midwest, Northeast, and Southeast regions (ABRAPA, 2021; IBGE, 2021). In the 2020/2021 harvest, the area cultivated with cotton in Brazil totalled 1,370.6 thousand hectares, with a production of 5,798.0 thousand tons and average cotton productivity of 4,224 kg ha^{-1} fibre and core (CONAB, 2022).

Since the 2015/16 harvest, the State of Ceará (located in the northeastern region of Brazil) has shown an evolution in cotton production that represents, in addition to the aspects of volume growth, the resurgence of cotton cultivation. They are the result of actions by farmers, companies, and government agencies, consolidated and made official from 2017 with the launch of the Modernization of Cotton Culture Program created with the aim of rebuilding cotton farming in the State of Ceará (EMBRAPA, 2017).

For the cotton crop to be well established in the field, the main management technique required is fertilization with macro- and micronutrients (Aguilar et al., 2021). Among the macronutrients required by the crop, nitrogen (N) is in greater demand, requiring 60 kg ha^{-1} of N to produce 1 Mg ha^{-1} fibre (Vieira et al., 2018). The nutrient, when applied in adequate doses, has significant impacts on crop growth, boll development, yield, and fibre quality (Zhou et al., 2011; Luo et al., 2018).

Thus, the application of correct doses of N in the cotton plant is necessary (Fang et al., 2018) since the deficiency of this nutrient results in lower photosynthetic rate, premature senescence of the plants, and lower productive potential (Dong et al., 2012). Meanwhile, high doses of N cause excessive vegetative development and reductions in yield, fibre percentage, and N use efficiency (Rochester, 2011; Devkota et al., 2013; Du et al., 2016; Li et al., 2017).

Therefore, it is extremely important to carry out research in different regions of Brazil, aiming at the elaboration of

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https://doi.org/10.18011/bioeng.2023.v17.1194
Received: 31 December 2022 / Accepted: 21 April 2023 / Available online: 11 May 2023

recommendations for nitrogen fertilization for the cotton crop based on the results of regional research, thus allowing the application of correct amounts of this nutrient. In this context, the objective of the present study was to evaluate the responses of cotton to nitrogen fertilization in the edaphoclimatic conditions of the Cariri region, located in the northeastern State of Ceará, Brazil.

Materials and methods

Location and characterization of the experimental area

The experiment was conducted in an open-air environment from May to July 2022 in an experimental area at the CENTEC (Centre for Technological Education) School of Technology (FATEC - Cariri campus), located in the city of Juazeiro do Norte, Ceará State, Brazil – with geographic coordinates 07°12'47” S, 39°18'55” W. The city is located at an altitude of 377 meters and has a climate ranging from Tropical Semi-Arid to Tropical Semi-Arid Mild, with an average temperature of 24 to 26 ºC, where the rainy season goes from January to May. The average annual rainfall is 925 mm. The quarter January, February, and March is considered the rainiest period (Lima and Ribeiro, 2012). Within the Köppen climate types (Köppen and Geiger, 1928), one can identify as predominant in Juazeiro do Norte the climate class BSW'h', that is, Semi-arid climate, with a short rainy season starting in the summer and reaching its peak in the summer-autumn transition.

The soil classes present in the city are: Neosol Quartizarenic, Litholic Neosol, Fluvial Neosol, Red-Yellow Argisol, and Red-Yellow Latosol (FUNCEME, 2012).

Experimental design and treatment description

The statistical design adopted was the Completely Randomized Design (CRD). The treatments were composed from the combination of four doses of nitrogen (0, 60, 120, and 180 kg ha^{-1} of N, equivalent to 0, 50, 100, and 150% of the N recommendation for the cotton crop) with four replications. The experimental unit was represented by a 7 L plastic pot containing the plant. The reference dose (100% of the N recommendation for the crop) corresponded to 120 kg ha^{-1} of N (Ferreira and Carvalho, 2005) for cotton with 75 000 plants per hectare.

Characterization of the used soil

The soil used in the research was collected in the experimental area of FATEC Cariri, at a depth of 0 to 20 cm, being first sieved. After that, the pots were filled. At the lower end of each vase, a layer of 2 cm of gravel was placed. The chemical and physical characterization of the used soil is shown in Table 1, below.

Table 1. Chemical and physical characterization of the soil used in the experiment.

Chemical characteristics												
ECse	pH	C	OM	P	V	Ca	Mg	K	Na	SB	T	H+Al
dS m^{-1}	-	----g/kg---		mg/dm^3	%	--------------------cmol$_c$/dm^3----------------------						
0.15	6.0	1.7	3.0	7.0	58	1.90	0.70	0.20	0.03	2.83	4.91	2.08

Physical characteristics								
Ds	Dp	P_T	Total sand	Thick sand	Thin sand	Silt	Clay	Texture class
---kg/dm^{-3}-----		%	------------------------g/kg--					
1.48	2.86	48.2	850.60	499.20	351.40	8.65	140.7	Loamy sand

ECse - electrical conductivity of the saturation extract; pH - potential of hydrogen; C - carbon; OM - organic matter; P - phosphorus; V - base saturation; Ca - calcium; Mg - magnesium; K - potassium; Na - sodium; SB - sum of exchangeable bases; T - cation exchange capacity; Ds - soil density; Dp - particle density; P_T - total porosity.

Culture selection

The crop that was selected for this experiment was the cotton cultivar BRS 433FL B2RF. The seeds were purchased at the Experimental Field of Embrapa Algodão, located in Barbalha, Ceará State, Brazil.

Experiment conduction

Sowing was performed by placing three seeds per pot, 2 cm deep. At 8 days after sowing (DAS), thinning was performed, leaving one plant per pot.

Nitrogen fertilization (0, 60, 120, and 180 kg/ha of N, equivalent to 0, 50, 100, and 150% of the N recommendation for the crop) and potassium (50 kg ha^{-1} the K_2O) were split, with 25% applied at thinning and the remainder applied in two equal portions at 15 and 25 days after thinning. At sowing, 7.7 g of single superphosphate was applied per pot. The sources of nitrogen and potassium used were urea (45% N) and potassium chloride (60% K_2O and 48% Cl), respectively.

Irrigation was done daily (manually), being carried out slowly until the water drained from the pot, thus reaching field capacity in all pots.

Analysed variables

At 42 DAS, the plants were collected. At this time, the crop was in the vegetative phase, the period between the emission of the first definitive leaf and the anthesis of the first flower

(Soares et al., 2020). Measurements were taken of plant height, stem diameter, number of leaves, and leaf area. The measurement of plant height (PH) was determined from a graduated ruler expressed in centimetres and the diameter of the stem with the aid of a digital calliper. To obtain the number of leaves (NL), only the leaves that were photosynthetically active were considered. The leaf area (LA) was obtained using the equation proposed by Fideles et al. (2010): $y = 0.7254\,(X)^{2,08922}$, where X is the length of the main vein resulting in the total leaf area in cm².

The different parts of the plants (roots, stems, leaves, and bolls) were separated, packed in paper bags, and placed to dry in an oven with forced air circulation, keeping the temperature in the range of 65 to 70°C. After drying, each sample was weighed on an analytical balance, thus obtaining the root dry matter (RDM), shoot dry matter (SDM), and total dry matter (TDM).

Based on plant height data, the absolute growth rate (AGR) was obtained using data collected at 15 and 42 DAS, and applied in Equation 1 proposed by Benincasa (2003):

$$AGR = \frac{PH_2 - PH_1}{T_2 - T_1} \qquad (1)$$

Where AGR is the absolute growth rate in relation to height (cm day^{-1}); PH_2 - PH_1 shows the variation of plant growth in height between two consecutive samples taken at times T1 and T2 (days); and T1 - T2 is the time interval between evaluations, in days, without considering values pre-existing prior to this variation.

From the relationship between the total dry matter and the total N applied (TDM/Napplied), the N use efficiency (NUE) was obtained.

The data obtained were submitted to analysis of variance (ANOVA) and, when significant by the F test, the effects of different nitrogen doses were submitted to regression analysis. The equations that best fit the data were chosen based on the highest coefficient of determination (R^2). Statistical analyses were performed using the SISVAR® statistical software, version 5.3 (Ferreira, 2010) and graphs were generated using Excel.

Results and discussion

Different nitrogen doses significantly influenced plant height ($p < 0.01$), stem diameter ($p < 0.01$), number of leaves ($p < 0.01$), leaf area ($p < 0.01$), and absolute growth rate ($p < 0.01$), as showcased in Table 2.

Table 2. Summary of analysis of variance for plant height (PH), stem diameter (SD), number of leaves (NL), leaf area (LA), and absolute growth rate (AGR) of cotton plants grown under different nitrogen doses in the soil and climate conditions of the Cariri-Ceará region, northeastern Brazil.

VS	Mean square					
	DF	PH	SD	NL	LA	AGR
N Dose	3	211.89**	13.48**	295.89**	7542.92**	0.304**
Residue	12	16.64	1.16	12.31	255.56	0.021
Total	15	-	-	-	-	-
CV (%)		10.65	14.23	15.05	12.19	12.94

VS = Variation source; DF = Degree of freedom; CV= Coefficient of variation; **,* = Significant at 1% and 5%, respectively, ns = not significant.

As observed in Figure 1A, the height of the plants showed a quadratic response in relation to the applied N doses. The maximum height (44.94 cm) was obtained with an estimated dose of 114.03 kg ha^{-1}. At 120 days after planting, Main et al. (2013) obtained, in the same culture, the maximum height at the dose of 134 kg ha^{-1} of N. Meanwhile, Zaman et al. (2021), in a field experiment carried out in Pakistan, found that the height of cotton plants in the maximum tested dose (197 kg ha^{-1} of N) presented an increase of 22.1% when compared to the non-application of nitrogen.

The increment of nitrogen fertilization provided increases in the diameter of the stem of the plants up to the estimated dose of 109.83 kg ha^{-1} of N, obtaining a maximum value of 8.56 mm (Figure 1B), which corresponds to an increase of 42.75% when compared to the value obtained in plants that did not receive nitrogen fertilization. In surveys conducted under conditions of climate, soil, and evaluation times different from the present study, Rigon et al. (2011), Simões et al. (2021) and Aguilar et al. (2021) found that nitrogen doses did not significantly affect plant stem diameter.

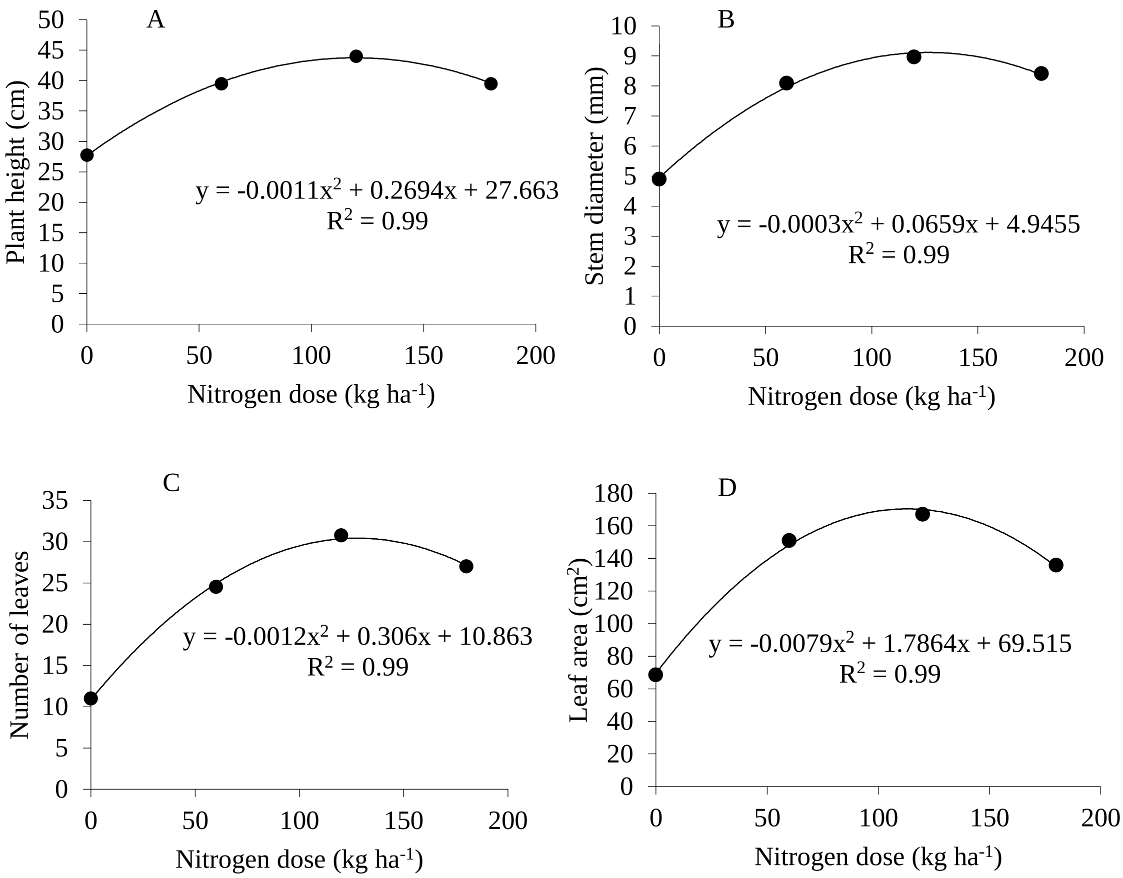

Figure 1. Plant height (A), stem diameter (B), number of leaves (C), and leaf area (D) of cotton plants cultivated under different doses of nitrogen.

Regarding the number of leaves (Figure 1C), the highest value found (30.37) was obtained by applying an estimated dose of 127.5 kg ha^{-1} of N. In the Potiguar semi-arid region, in an experiment conducted under field conditions, Tartaglia et al. (2020) found that the highest number of cotton leaves were obtained at the maximum tested dose (200 kg ha^{-1} of N). On the other hand, Rigon et al. (2011), in an experiment carried out in a greenhouse and using lower nitrogen doses compared to the present study, found that nitrogen fertilization did not significantly affect the number of plant leaves in any of the evaluated periods (20, 40, 60, 80, and 100 days after emergence).

As seen in Figure 1D, the increasing doses of nitrogen promoted a significant expansion in the cotton leaf area up to the estimated dose of 113.06 kg ha^{-1} of N, where a maximum leaf area of 170,5 cm^2 was found. Right away, there was a decrease of 20.32% from the maximum point to the highest dose (180 kg ha^{-1} of N). In a study carried out with the same crop but under field conditions in semi-arid Afghanistan, Nooriet al. (2018) observed that at 30, 60, 90, and 120 DAS, the maximum leaf area values were found at the dose of 210 kg ha^{-1} of N. According to Wu et al. (2023), the application of nitrogen at the appropriate dose not only increases the number of leaves, but also the leaf area, light interception, photosynthetic activity, and fibre quality.

Nitrogen fertilization provided an increase in absolute growth rate (AGR) up to an estimated dose of 110 kg ha^{-1} of N, obtaining a maximum value of 1.33 cm/day, followed by a reduction to a dose of 180 kg ha^{-1} of N (Figure 02). Differently, Kumar et al. (2022), in an experiment carried out in an area with clayey-silty soil and arid climate in India, found that nitrogen fertilization significantly increased the relative growth rate up to the maximum tested dose of 225 kg ha^{-1}, with increases of 9.75% compared to the treatment without nitrogen application.

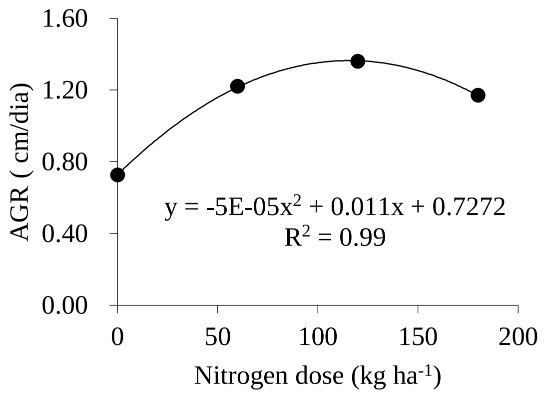

Figure 02. Absolute growth rate (AGR) of cotton plants cultivated under different nitrogen doses.

The increase in plant height, stem diameter, number of leaves, leaf area, and absolute growth rate up to the estimated nitrogen dose of 114.03, 109.83, 127.5, 113.06, and 110 kg ha^{-1} of N, respectively, probably occurred due to the functions that this element plays in the growth and development of plants, which acts in cell division and elongation, and also plays an important role in chlorophyll, protein, hormones, nucleic acids, and in the synthesis of vitamins (Aragão et al., 2012; Souza et al., 2016; Vieira et al., 2016; Souza et al., 2017; Medeiros et al., 2018).

Different nitrogen doses significantly influenced root dry matter ($p < 0.01$), shoot dry matter ($p < 0.01$), total dry matter ($p < 0.01$), and nitrogen use efficiency ($p < 0.01$) as shown in Table 3.

Table 3. Summary of analysis of variance for root dry matter (RDM), shoot dry matter (SDM), total dry matter (TDM), and nitrogen use efficiency (NUE) of cotton plants grown under different nitrogen doses in the soil and climate conditions of the Cariri-Ceará region, northeastern Brazil.

VS	Mean square				
	DF	RDM	SDM	TDM	NUE
N Dose	3	1.64**	166.28**	200.72**	329.71**
Residue	12	0.12	8.01	9.74	6.90
Total	15	-	-	-	-
CV (%)		22.03	19.87	19.71	13.53

VS = Variation source; DF = Degree of freedom; CV= Coefficient of variation; **,* = Significant at 1% and 5%, respectively, ns = not significant.

The maximum RDM (2.64 g) was obtained when an estimated dose of 138.5 kg ha^{-1} of N was applied, and from this value, there was a decrease (Figure 3A). In a 2-year field experiment conducted in China, Wu et al. (2022) verified that the application of 272 kg ha^{-1} of N maximized the cotton root dry matter. Meanwhile, Chen et al. (2020), evaluating the influence of different nitrogen doses (0, 120, 240, and 480 kg ha^{-1} of N) in a transgenic cotton cultivar under field conditions, found that the application of 240 kg ha^{-1} of N promoted an increase of 36.06% in root dry matter compared to the treatment without nitrogen application.

For shoot dry matter (Figure 3B), a maximum value of 20.59 g was obtained at the estimated dose of 113 kg ha^{-1} of N, which corresponds to an increase of 305.31% when compared to the value obtained in plants that did not receive nitrogen fertilization. In two varieties of cotton (FiberMax 910 and FiberMax 96) grown in a greenhouse, Araújo et al. (2013) found that the highest doses of N (750 and 1000 mg dm^{-3} of soil) provided greater accumulation of dry matter in the aerial part. In an experiment carried out under field conditions in China, Chen et al. (2020) observed that nitrogen fertilization significantly increased the dry matter of the aerial part of cotton plants. The application of a dose of 240 kg ha^{-1} of N promoted an increase of 38.32% in shoot dry matter compared to the treatment without nitrogen application.

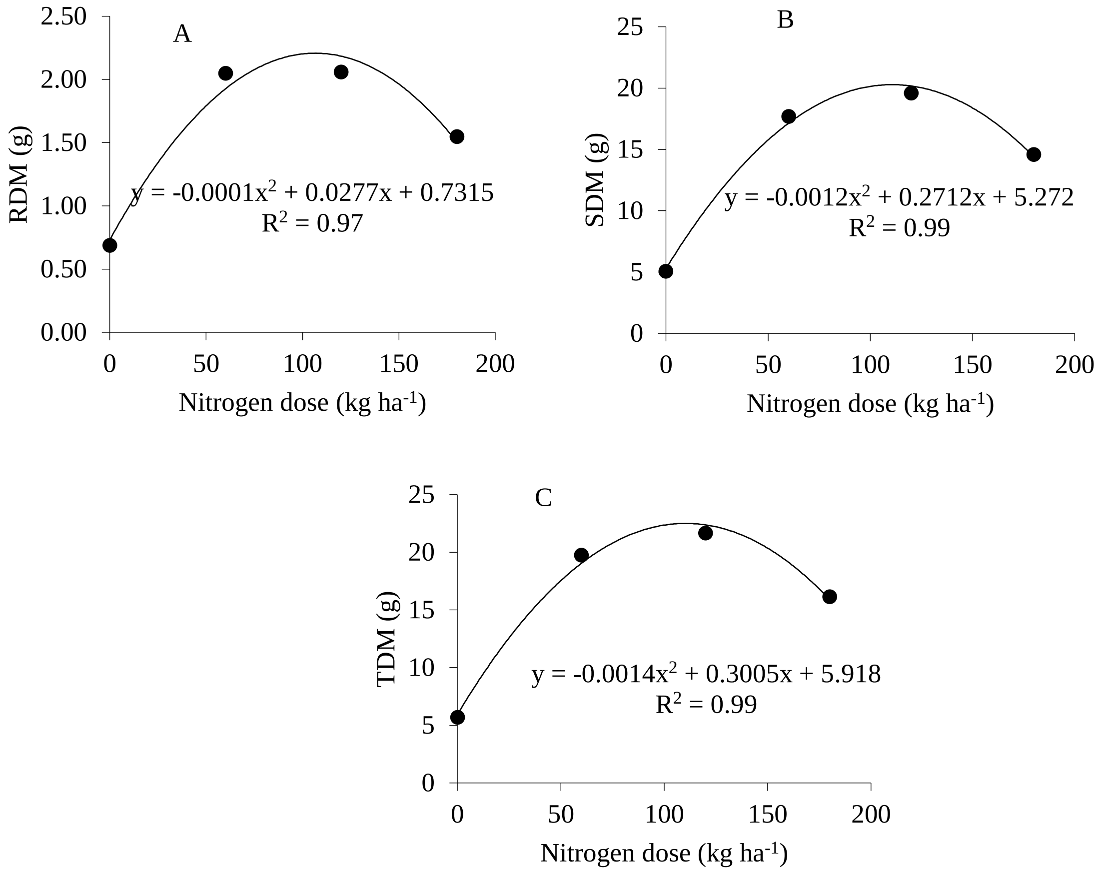

Figure 03. Root dry matter (A), shoot dry matter (B), and total dry matter (C) of cotton plants cultivated under different nitrogen doses.

The total dry matter of the plants increased up to the estimated dose of 107.32 kg ha^{-1} of N, reaching a maximum value of 22.04 g. From this dose, there was a decrease of 26.76% when compared to the value obtained at the dose of 107.32 kg ha^{-1} of N, and with the one obtained at the dose of 180 kg ha^{-1} of N (Figure 3C). Wassie et al. (2022), in an experiment carried out under field conditions with the same crop in Ethiopia, observed that the maximum value of total dry matter, at the end of the plant cycle, was obtained at a dose of 92 kg ha^{-1} of N.

The absence of nitrogen fertilization reduced all the evaluated growth parameters and the dry matter of the plants. This possibly occurred as a result of the poor nutritional status of the plants, resulting in damage to cell expansion (Zubairu et al., 2017).

The excessive application of N (180 kg ha^{-1} of N) provided decreases of 50.4% in N use efficiency in cotton crop compared to the N dose recommended for the crop (Figure 04). Similarly, Tartaglia et al. (2020) verified that N use efficiency in the coloured cotton crop decreased with the increase in nitrogen doses (0, 50, 100, 150, and 200 kg ha^{-1} of N). The application of 200 kg ha^{-1} of N reduced nitrogen use efficiency by 43.5%. The excessive application of nitrogen in cotton plants, in addition to promoting a reduction in productivity, causes a reduction in N use efficiency and an increase in environmental pollution (Tartaglia et al., 2020; Khan et al., 2021; Niu et al., 2021; Huang et al., 2022; Javed et al., 2022a,b; Kumar et al., 2022; Wang et al., 2022).

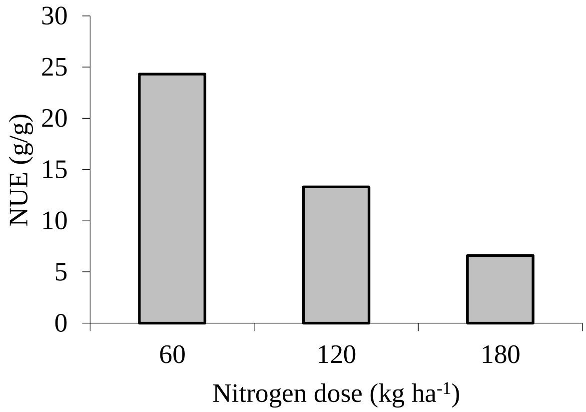

Figure 04. Nitrogen use efficiency in cotton plants cultivated under different nitrogen dose.

Conclusions

In general, nitrogen doses greater than 120 kg ha^{-1} of N were shown to impair the growth and dry matter production of the cotton plant in the climate and soil conditions of the Cariri region, located in the northeastern State of Ceará, Brazil. Excessive nitrogen fertilization reduces the efficiency of nitrogen use by the cotton crop.

Acknowledgments

The authors would like to thank the Foundation for Development and Technological Support of Ceará State (FUNCAP) for granting the Scientific Initiation fellowship to the first author of the manuscript.

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