Nitrogen fertilization strategies in the cultivation of Cactus pear in Brazilian Savannah localities

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ABSTRACT

This study aimed to evaluate the agronomic parameters and the chemical composition of the cactus pear variety Doce (*Nopalea cochenillifera*) in different Brazilian savannah localities, subjected to different nitrogen fertilization strategies. A randomized block design was used in this experiment, with a 2× 4 × 2 factorial arrangement with five replications. The factors corresponded to two application frequencies of nitrogen fertilization (30 days and 30/60 days), four nitrogen doses (0, 100, 200, 400 kg ha^{-1} $year^{-1}$), and two cactus pear cultivation localities, with Locality 1 corresponding to the municipality of Curimatá and Locality 2 corresponding to the municipality of Riacho Frio. After one year of cultivation, there was no interaction (P>0.05) for frequency × doses × locality, doses × locality, and frequency × doses. The means observed for fresh and dry matter production varied from 57.0 to 68.0±2.9 t ha^{-1} and from 2.4 to 3.7±0.2 t ha^{-1}, respectively. There was an interaction (P<0.05) between frequency × locality for fresh matter production, dry matter production, water-use efficiency, water accumulation, and carrying capacity. For the chemical composition, there was an interaction (P<0.01) between frequency × dose for the mineral content matter. Fertilization splitting associated with the highest nitrogen application dose resulted in better performance for the cactus pear variety of Doce grown in the Brazilian savannah region.

Keywords: *Biomass, Cactaceae, Nopalea cochenillifera, Phenotypic characteristics, Urea application*

INTRODUCTION

Water deficit and the seasonality of forage production in the Brazilian savannah, as a consequence of the rainfall regime, constitute one of the main hindrances to animal production for interfering directly with the availability of forage for animal feeding. The cactus pear presents great use potential in animal feeding, given its water-use efficiency, especially highlighted in regions with prolonged drought periods (Grünwaldt *et al*.2015). In this scenario, cactus pear production is one of the strategies for the coexistence of cattle rising in the Cerrado, especially in the food deficit period (Nascimento *et al*. 2020).

Aiming to potentialize the productive capacity of this crop, the use of nitrogen fertilization was recommended after 30 days of planting (Souza *et al*. 2017). Nitrogen application in cactus pear planting improves the production yield, the chemical composition, and the protein content of the plant, besides being responsible for changes in the establishment and persistence of cultivated plants (Fragoso *et al*.2016). This fact improves the yield of cactus pear production, consequently improving animal performance. During maintenance fertilization, nitrogen application is essential to ensure productivity, and the non-adoption of these technologies is considered one of the principal degradation triggers of areas destined for food production in cattle raising (Gurgel *et al.* 2020).

Studies on the forms of application of nitrogen fertilization are still scarce and divergent regarding the recommendation of doses and frequencies, and the subject is little-known for the cactus pear crop (Cunha *et al*. 2012; Souza *et al*. 2017), especially for the Brazilian savannah region. For the efficient use of nitrogen fertilization in this crop, it is of utter importance to establish fertilization protocols that may guarantee a high production, aiming at supplying food for the livestock. Furthermore, studies that determine the agronomic potential of the cactus pear regarding the responses of nitrogen fertilization need to be developed in regions with scarce information (Nascimento *et al*. 2020).

Given the above observations, the cactus pear is an alternative to increase food production destined for animal production in savannah regions, especially in localities with prolonged drought periods. However, fertilization for this crop demands studies applied in localities that present productive barriers, such as climatic restrictions (Edvan *et al.* 2020). This study hypothesizes is that splitting of nitrogen fertilization associated with a higher nitrogen dose in the cactus pear cultivar Doce (*Nopalea cochinillifera*) provides better performance, regardless of the savannah environment locality. This study was performed aiming at evaluating the growth, production, and chemical composition of the cactus pear variety Doce (*Nopalea cochenillifera*), in two savannah localities, under different frequencies and doses of nitrogen fertilization.

MATERIAL AND METHODS

Location of the study and edaphoclimatic conditions

The experiment was perform in two Cerrado (Brazilian savannah) localities in the state of Piauí, Brazil, with Locality 1 corresponding to the municipality of Curimatá and Locality 2 corresponding to the municipality of Riacho Frio. Locality 1 is locate at the geographic coordinates 10° 02' 11" S latitude and 44° 18' 22" W longitude, with an elevation of 328 meters. Locality 2 is locate at the geographic coordinates 10° 07' 31" S latitude and 44° 57' 09 " W longitude, with an elevation of 400 meters. Both sites are located in environments with the predominance of seasonal forests in savanna fields on the Brazilian Cerrado region, as described by Batalha (2011). The study region presents a BSh climatic classification, with summer rains and dry winters, according to the 1936 Köppen classification described by Alvares *et al*. (2013).

The experiment was performing from November 2015 to November 2016, and the average meteorological data of both localities in the experimental period were described in Table 1. Data were obtained from the network of stations of the National Institute of Meteorology (2019), Estação Bom Jesus. OMM Code: 81987. Located in the study region.

Table 1. Meteorological data of the experimental area in the months from November 2015 to November 2016.

Place	T Min[a] (°C)	T Max[b] (°C)	RH (%)[c]	Rainfall (mm)[d]
Curimatá	21.4	33.4	40.6	97.28
Riacho Frio	22.6	34.5	41.5	96.85

[a]Minimum temperature, annual mean; [b]Maximum temperature, annual mean; [c]Relative air humidity, annual mean; [d]Cumulative annual rainfall

The localities in which the experiment were conducted belong to tropical environment microregions of the southern Cerrado of Piauí, Brazil. Figure 1 exhibits the map of the state of Piauí, Brazil, highlighting the evaluated microregions, considering the distance between Localities 1 (Curimatá) and 2 (Riacho Frio).

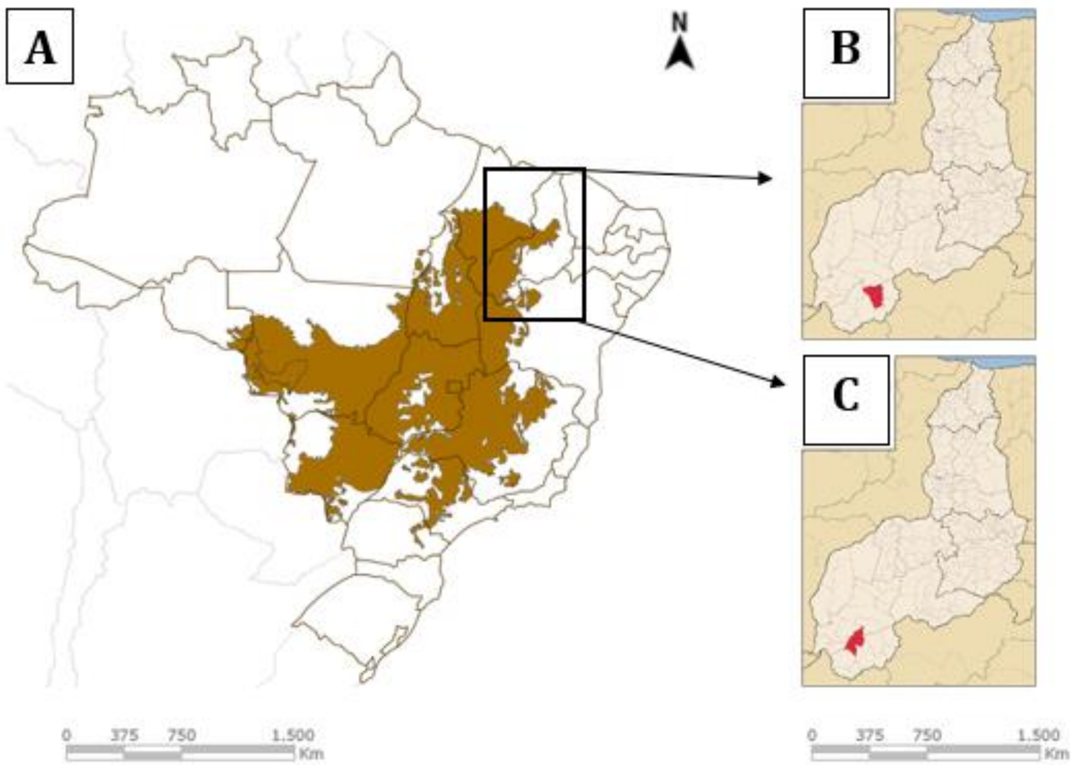


Figure 1. Map of the Brazilian Cerrado region (A) and of the state of Piauí, highlighting in red the municipalities of Curimatá (B) and Riacho Frio (C) in savannah fields.

The spacing used for planting the cactus pear variety Doce (*Nopalea cochinillifera*) was 1.5 m x 0.1 m, with a total number of 66.133 plants ha^{-1} in 4.5 m x 5.0 m plots, spaced with a 1-m non-cultivated area, with a total of 144 plants. The plots consisted of 4.5 m x 1.2 m with 36 cactus cladodes, evaluating two useful plants per plot for the growth analyses and analyzing the entire plot to estimate the forage mass production.

Treatments and experimental design

The experimental design used in this study was in randomized blocks in a 2 x 4 x 2 factorial arrangement with five replications. The factors corresponded to two application frequencies of nitrogen fertilization (full application at 30 days and split application at 30/60 days), four nitrogen doses (0, 100, 200, 400 kg ha^{-1} year^{-1}), and two cactus pear cultivation localities (Locality 1 – Curimatá, Piauí, Brazil and Locality 2 – Riacho Frio, Piauí, Brazil).

Soil correction and fertilization

Before implanting the experiment, soil samples was collected for analysis and chemical characterization based on a representative soil sample collection at the 0-20 cm depth in areas destined for the experiment in Localities 1 and 2. The soil sample was sent to the Laboratory of Soils of the Campus Professora Cinobelina Elvas (CPCE) of the Federal University of Piauí (UFPI), located in the municipality of Bom Jesus, Piauí, Brazil.
The results of the soil analysis are shown in Table 2.

Table 2. Soil chemical analysis of the two forage cactus growing locations.

Curimatá												
pH*	P	K	Na	Ca	Mg	Al	H+Al	SB	t	T	V	M
H_2O	-----mg/dm³-----			------------cmol/dm³----------							------%------	
5.2	4.3	86.3	-	1.0	0.6	0.2	2.3	1.8	0.2	4.1	44.1	9.9
Riacho Frio												
pH*	P	K	Na	Ca	Mg	Al	H+Al	SB	t	T	V	M
H_2O	-----mg/dm³-----			------------cmol/dm³----------							------%------	
5.0	9.0	93.0	-	1.6	0.8	0.4	4.1	2.6	0.2	6.7	39.	13.2

*pH in water; phosphorus (P); potassium (K); calcium (Ca); magnesium (Mg); aluminum (Al); hydrogen + aluminum (H+Al); sum of bases (SB); effective CEC (t); CEC at pH 7.0 (T); base saturation (V); aluminum saturation (M).

The Soil correction was not required as soil chemical analysis did not reveal high acidity levels and presented adequated SB values for the cactus pear crop. Planting fertilization consisted of an application of 75 kg phosphorus ha^{-1} as single superphosphate (18% P_2O_5) and 40 kg potassium ha^{-1} as potassium chloride (48% K_2O). Fertilization was performed according to soil analysis, considering the cactus pear as an N-demanding crop and performing fertilization according to the recommendations by Martha Junior *et al*. (2007). After 30 days of planted, urea was used as a nitrogen source (45% CH_4N_2O) at the doses of 0, 100, 200, and 400 kg N ha^{-1} year^{-1}, being applied according to each treatment, regarding the fertilization frequency (30 and 30/60 days after planting) and the nitrogen doses.

Plant sampling and evaluation

The data was evaluated regarding growth, fresh matter (FMP) and dry matter production (DMP), nitrogen-use efficiency (NUE), water-use efficiency (WUE), water accumulation

(WAC), and carrying capacity (CCAP). The cactus pear plants were cut after one year of planting using a 10-inch stainless steel Tramontina® machete, cutting the cladodes above the mother cladode while preserving the mother plant (matrix) to keep the perennial character of the crop, according to the proposed by Santos *et al*. (2010) for irrigated cactus pear. The growth, production, and chemical composition evaluations of the cactus pear varieties were performed at harvest.

The following morphometric observations were made for the growth characteristics of the plants: the number of cladodes, obtained by counting; plant height, measured with a metric tape (in cm) from the soil surface to the apex of the highest cladode; and cladode length (horizontal part of the cladode) and width (vertical part of the cladode), measured in the central region of the cladodes with a metric tape (100 cm), which was also used to determine the perimeter of the cladode. A digital caliper with a 0.05 mm precision measured the thickness of the cladodes, with all measurements made in the middle third of the cladodes.

At harvest, the collected material was weighed in the field to obtain the FMP. Afterward, a sample with about 2 kg of fresh matter was removed to perform the laboratory analysis and the dry mass determination, by which the material was ground, weighed, and taken to a forced-air oven at 55 – 60ºC until constant weight (Method INCT-CA G-003/1). Soon afterward, the dried samples were weighed to determine the DMP, ground in a Thomas Wiley® benchtop cutting mill with a 1.0 mm mesh sieve, and finally stored in sealed containers to perform the chemical laboratory analyses.

The WUE (kg DM mm^{-1}) was estimated by the division of the DMP in t ha^{-1} by the amount of rainfall accumulated throughout the experimental period. The WAC, in t ha^{-1}, was estimated by the FMP in t ha^{-1}, multiplying the water percentage of the plant that was calculated by the dry matter content (DM) subtracted from 100, after which the result was divided by 1000 (MACÊDO *et al*., 2018). The NUE given as (kg DM/kg N) was determined by relating the dry matter yield with the N dose.

A simulation of the CCAP was performed for the cactus pear varieties, using as parameters one hectare to confine sheep for 90 days, a known DMP (t ha^{-1}), and considering sheep with an average live weight (LW) of 25 kg (PV) consuming 3% of LW × 60% GP in the diet based on dry matter, with 40% of concentrate composition. The following formula was used: carrying capacity = (DMP t ha^{-1}) / (individual consumption × 90 days of confinement), in which the carrying capacity = the number of animals.

Chemical composition analysis of plants

In the plant samples collected at harvest in each locality, the chemical composition was analyzed according to the recommendations by the AOAC (1990) regarding the dry matter (method 967.03), ash (method 942.05), crude protein (method 981.10), and ethereal extract contents (method 920.29). The neutral detergent fiber (NDF) and the acid detergent fiber (ADF) were determined using the methods by Van Soest et al. (1991) with the modification proposed by Senger et al. (2008) for autoclave use. The autoclave temperature was adjusted to 110 °C for 40 min. The analyses were performed in the Laboratory of Animal Nutrition (LANA) of the CPCE/UFPI.

Statistical Analysis

The data obtained were subjected to analysis of variance, comparing the means of the application frequency of the nitrogen fertilizer and the localities using Tukey's test, and the levels of nitrogen fertilization by linear regression analysis, both with $P<0.05$ of significance. The data were analyzed using the statistical software SISVAR, version 5.0 (Ferreira, 2011).

RESULTS AND DISCUSSION

The hypothesis that the splitting of nitrogen fertilization associated with a higher nitrogen dose would provide the cactus pear with better performance, regardless of the locality, was not entirely accepted. Both localities showed positive responses to nitrogen fertilization and its splitting. However, these localities showed different answers regarding the development and production of the cactus pear, corroborating the answer by Edvan *et al.* (2020). The fact can be explained by conditions intrinsic to the cultivation environments, presenting equally different responses and interactions for specific crops. Therefore, the microclimate, soil, management, and issue regarding the choice of the variety should be determining factors for the implantation of the cactus pear crop, consequently influencing its productive success.

Agronomic parameters

No interaction was observed ($P>0.05$) for the frequencies × doses × localities, doses × localities, and frequency × damount for any of the studied variables (Table 3). There was an interaction for frequencies x localities for fresh matter production (FMP), dry matter production (DMP), water-use efficiency (WUE), water accumulation (WAC), and carrying capacity (CCAP). The frequencies of nitrogen fertilization presented effects ($P<0.05$) on the FMP, DMP, WUE, WAC, CCAP, and NUE variables, whereas, for the nitrogen doses, there was a significant effect on the number of cladodes, cladode length, cladode perimeter, plant height, FMP, DMP, WUE, WAC, CCAP, and NUE. The different localities significantly affected the number of cladodes, cladode length, cladode perimeter, cladode thickness, plant height, FMP, DMP, WUE, WAC, and CCAP.

The nitrogen fertilization frequency of 30/60 days influenced the agronomic responses of the cactus pear, resulting in higher values for locality 2 (Riacho Frio) regarding the FMP, DMP, WUE, WAC, and CCAP variables (Table 4).

Table 3. Discrimination in the analysis of variance for the agronomic parameters of the cactus pear under frequencies and doses of nitrogen application in different localities of the Brazilian savannah.

Variables	*P – value*						
	Freq[g]	Dose[h]	Loc[i]	Freq × Dose	Dose x Loc	Freq × Loc	Freq × Dose × Loc
Number of cladodes	0.90^{ns}	<0.04*	<0.01*	0.66^{ns}	0.64^{ns}	0.64^{ns}	0.95^{ns}
Thickness (mm)	0.70^{ns}	0.15^{ns}	<0.01*	0.41^{ns}	0.15^{ns}	0.95^{ns}	0.36^{ns}
Length (cm)	0.24^{ns}	0.01^{*}	<0.01*	0.97^{ns}	0.06^{ns}	0.91^{ns}	0.89^{ns}
Perimeter (cm)	0.57^{ns}	0.04*	<0.01*	0.67^{ns}	0.06^{ns}	0.15^{ns}	0.56^{ns}
Width (cm)	0.31^{ns}	0.33^{ns}	0.06^{ns}	0.41^{ns}	0.36^{ns}	0.21^{ns}	0.36^{ns}
Height (cm)	0.95^{ns}	0.02*	<0.01*	0.89^{ns}	0.34^{ns}	0.80^{ns}	0.73^{ns}
FMP[a] (t ha^{-1})	0.02*	<0.01*	0.02*	0.69^{ns}	0.39^{ns}	0.02*	0.68^{ns}
DMP[b] (t ha^{-1})	<0.01*	<0.01*	0.05*	0.33^{ns}	0.24^{ns}	0.01*	0.71^{ns}
WUE[c] (kg DM mm^{-1})	0.01*	0.02*	0.02*	0.43^{ns}	0.26^{ns}	0.04*	0.91^{ns}
WAC[d] (t ha^{-1})	0.03*	<0.01*	0.02*	0.71^{ns}	0.39^{ns}	0.02*	0.64^{ns}
CCAP[e] (animals ha^{-1})	0.01*	0.02*	0.02*	0.43^{ns}	0.26^{ns}	0.04*	0.91^{ns}
NUE[f] (kg of DM kg N^{-1})	0.03*	<0.01*	0.19^{ns}	0.07^{ns}	0.25^{ns}	0.16^{ns}	0.98^{ns}

FMP[a]: fresh matter production; DMP[b]: dry matter production; WUE[c]: water-use efficiency; WAC[d]: water accumulation; CCAP[e]: carrying capacity; NUE[f]: nitrogen-use efficiency; Freq[g]: frequencies of nitrogen application; Dose[h]: nitrogen doses; Loc[i]: localities evaluated in the study *significant at 5%.

Table 4. Cactus pear characterization regarding the frequency of nitrogen application in different cultivation localities in the Brazilian savannah.

	Frequencies of nitrogen application		EPM[f]
	30 days	30/60 days	
	FMP[a] (t ha^{-1})		
Curimatá	57.1Aa	52.0Ab	4.5
Riacho Frio	57.2Ab	76.0Aa	
	DMP[b] (t ha^{-1})		
Curimatá	2.5Aa	2.7Ab	1.2
Riacho Frio	2.3Ab	4.4Aa	
	WUE[c] (kg DM mm^{-1})		
Curimatá	4.1Aa	4.3Ab	1.0
Riacho Frio	4.2Ab	5.8Aa	
	WAC[d] (t ha^{-1})		
Curimatá	52.6Aa	52.9Ab	4.2
Riacho Frio	53.1Ab	70.4Aa	
	CCAP[e] (animals ha^{-1})		
Curimatá	154.7Aa	161.3Ab	39.5
Riacho Frio	158.6Ab	217.5Aa	

FMP[a]: fresh matter production; DMP[b]: dry matter production; WUE[c]: water-use efficiency; WAC[d]: water accumulation; CCAP[e]: carrying capacity; EPM[f]: mean standard error Means followed by different uppercase letters in the columns and lowercase letters in the rows are statistically different at 5% of probability by Tukey's test.

The effects observed for the productive variables are possibly due to the effects of nitrogen in increasing the cellular content, potentializing growth and cell multiplication, increasing the WAC and WUE, as already observed in previous studies (Nascimento *et al*. 2020). The highest values found for these variables in Locality 2 can be explained by the influence that the cultivation environment causes on the biomass production of this crop, as described by Edvan *et al*. (2020) in their study with the environmental adequacy of cactus pear varieties. These authors report that the variety Doce shows positive responses for the production variables when grown in this locality. Besides that, Rocha et al. (2017) evaluating the WUE and WAC in different genotypes of cactus pear in Petrolina-PE, observed that the genotype that presented the highest efficiency in the use and accumulation of water, was the most productive, demonstrating that the efficiency in the use of available resources is directly related to the productivity of the culture. Similar values of the cactus pear genotype Doce Miúda of 7.4 and 7.7 kg DM mm-1 were found by Silva et al. (2014) for the variable WUE, evaluating indicators of water and nutrients use efficiency of cactus pear clones under rainfed conditions.

Nitrogen also presents a marked effect on the morphogenic and structural responses of plants, with pronounced effects on plant cell division (Farias *et al*. 2019), promoting the increase of the total number of appendices and increasing the fresh matter production of the plant, as observed with the increase in the number of cladodes. Another factor for this result is that the cactus pear variety Doce is characterized as a plant of more numerous and narrow cladodes, is a fact that may be a precursor for plants to present cladodes that grow vertically, shaping the plants to be taller and narrower (Edvan *et al*. 2020).

For plant height, whose values are considered low even for the cactus pear variety Doce (known in some regions as ‘Palma Doce Miúda’ or small sweet cactus pear), these can be explained by the dense planting, which was above 66,000 plants per hectare. The higher plant growth in response to growing nitrogen doses can be explained by the effect of nitrogen, which stimulates the expansive capacity of the plant and increases its vigor and cell division, as observed by Cunha *et al*. (2012) in works with growing doses of nitrogen fertilization, verifying significant differences regarding the growth variables of the cactus pear crop.

The cladode width was not influenced by (P>0.05). This fact can be explained by the increase in the number of cladodes due to the greater nitrogen availability. Thus, the higher need for nutrient translocation to new cladodes (drains), influences the characteristics related to the development of the cladodes (Lemaire e Chapman, 1996; Nascimento et al., 2020)

The nitrogen doses promoted an increasing linear effect (P<0.01) for the number of cladodes, length, perimeter, height, FMP, DMP, WUE, and CCAP (Table 5). The number of cladodes varied from 6.6 to 8.9±0.4 for the 0 and 400 kg N ha^{-1} $year^{-1}$doses, respectively.

Table 5. Effect of the nitrogen doses on the agronomic parameters of the cactus pear grown in the Brazilian savannah.

Variáveis	Nitrogen doses kg N ha^{-1} $year^{-1}$ 0	100	200	400	*P - value* Linear	R^{2f}	EPM[g]
Number of cladodes	6.6	7.1	7.7	8.9	0.01*	99.8	0.4
Length (cm)	13.3	13.7	14.2	15.0	<0.01*	87.0	0.2
Perimeter (cm)	31.7	32.4	33.1	34.4	0.01*	75.6	0.5
Height (cm)	39.4	41.3	43.2	46.9	<0.01*	95.1	1.3
FMP[a] (t ha^{-1})	57.0	59.8	62.5	68.0	0.04*	76.3	2.9
DMP[b] (t ha^{-1})	2.4	2.7	3.1	3.7	0.01*	40.1	0.2
WUE[c] (kg DM mm^{-1})	4.1	4.4	4.7	5.3	0.01*	57.5	0.2
WAC[d] (t ha-1)	52.9	55.4	57.9	62.8	0.06[ns]	-	2.7
CCAP[e] (animals ha^{-1})	154.2	165.0	175.7	197.2	0.01*	57.6	9.2

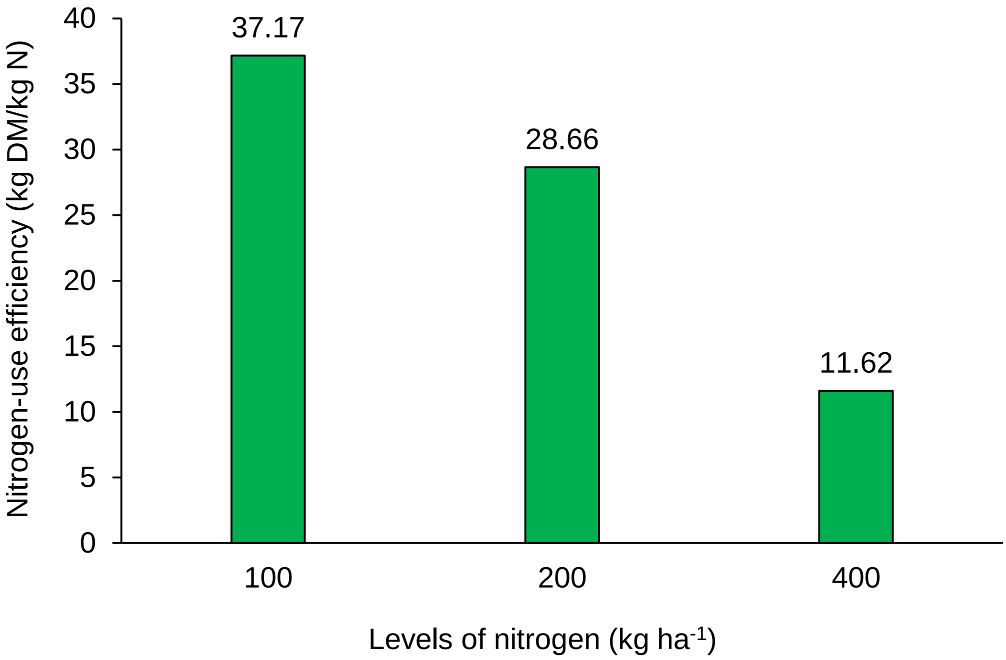
FMP[a]: fresh matter production; DMP[b]: dry matter production; WUE[c]: water-use efficiency; WAC[d]: water accumulation; CCAP[e]: carrying capacity; R^{2f}: determination of coefficient (Demonstrate the reliability of the equation). EPM[g]: standard error of the mean *significant at $P<0.05$.

Despite the increase of forage mass production by the cactus pear variety Doce to the increase of the nitrogen doses, the productions obtained were below the average of other regions. Cunha *et al*. (2012) reported an FMP production of 197 t ha^{-1} $year^{-1}$ with a 300 kg^{-1} N ha^{-1} $year^{-1}$ fertilization. The lower result obtained in the present study may be related to the climatic factors of the cerrado region, which presents hot days with low humidity and also hot nights. Making it difficult to carry out photosynthetic processes. Due to their CAM metabolism, cacti possess a physiological adaptation that allows performing photosynthetic processes in such a way that stomata open at night since the temperatures are milder, allowing lower water loss. The good performance of the cactus pear requires cooler nights associated with high air humidity (Edvan *et al*. 2020), and in the Brazilian savannah region, in the driest season of the year, nights are hotter and with low relative air humidity, often below 20%. This fact compromises the development and production of cactus pear in the region.

The application of growing nitrogen doses resulted in an increase of the values of cladode length and perimeter, which varied from 13.3 to 15±0.2 cm and from 31.7 to 34.4±0.5 mm, respectively. For the FMP and DMP, the nitrogen doses demonstrated a variation of the means from 57.0 to 68.0±2.9 t ha^{-1} and from 2.4 to 3.7±0.2 t ha^{-1}, respectively, also increasing the WUE values (4.1 to 5.3±0.2).

Regarding the nitrogen doses, the effect observed for the WUE regarding the highest nitrogen doses may be related to the higher plant production resulting from nitrogen fertilization. In this manner, the plant possesses sufficient available nutrients for greater development, consequently using water more efficiently. Therefore, the increase in plant yield potentializes the use efficiency of renewable water resources (Rocha *et al.* 2017). Furthermore, the CAM metabolism of the cactus pear is an intrinsic factor to the crop, ensuring greater water-use efficiency, with reports of its efficiency by more than 11 times compared to plants with C3 and C4 metabolism (Han e Felker, 1997). Larcher (1986) reports greater water-use efficiency of cacti compared to legumes and grasses, according to the photosynthetic metabolism (Legumes 700-800, Grasses 250-359, Cacti 100-150 kg of water/kg DM).

The carrying capacity (CCAP) is associated to the increase in the DMP, a fact that occurs due to its association with plant production, resulting in a feeding capacity that varies from 154 to 197±9.2 sheep per ha^{-1} for 90 days. The higher forage mass production of the cactus pear and the higher water-use efficiency due to the greater nutrient availability, besides the adaptability to the cultivation environment, are factors that provide an increase in animal production per hectare (Mokoboki *et al*. 2016). This result contributes to affirmed that this species can be used for animal feeding in savannah regions under prolonged drought periods, showing to be a promising feeding alternative for the livestock in the region.
For the nitrogen-use efficiency (NUE), a higher value was observed for the nitrogen application frequency of 30/60 days (Figure 2).



$y = 45.6860 - 0.0851^{*}x$
$R^2 = 80.60$
$P<0.01$

Frequencies of nitrogen application
30 days = 23.3±1.6b
30/60 days = 28.3±1.6b

Figure 2. Nitrogen-use efficiency of the cactus pear for different levels of nitrogen fertilization in the Brazilian savannah.

The dose of 100 kg N ha^{-1} resulted in a higher NUE compared to the doses of 200 and 400 kg N ha^{-1}. It is seen that the dose of 400 kg N ha^{-1} resulted in a lower NUE, equivalent to 25.55 Kg DM/ kg N.

Urea is a nitrogen source prone to losses by volatilization and leaching, affecting absorption and assimilation and, consequently, the NUE applied to the soil (Cunha et al. 2012). The splitting of fertilization (i.e., 30/60 frequency) presents a direct effect on the reduction of losses through the availability of nitrogen at lower amounts, allowing it to be readily absorbed by the plant and resulting in less nitrogen available in the soil solution for possible losses or transformations. This effect can be confirmed by the results obtained in this study for the growth and agronomical variables.

Furthermore, we can affirm that the doses of 100 and 200 kg ha^{-1} $year^{-1}$ were more efficient due to the lower use of nitrogen fertilization with the productive gain. The maximum N efficiency at the lowest nitrogen dose may be associated to the higher assimilation rate and the lower susceptibility with nutrient losses by leaching or volatilization (Araújo Filho *et al*. 2013). The higher NUE observed for these doses may also be related to the better use of available resources, greater economic and financial efficiency, lower potential for soil acidification, and few negative effects to the environment due to the lower nitrogen loss for transformations and later contamination of the atmosphere (Nascimento *et al*. 2020).

Locality 2 showed higher values for the cladodes number, with a mean of 9.72±1.1, whereas locality 1 showed a mean of 5.56±1.1 (Table 6). The cactus pear variety Doce grown in locality 2 showed higher values of cladode thickness (9.3±0.26), length (15.9±0.29), perimeter (36.6±0.59), width (8.9±1.02), and plant height (53.1±1.3).

Table 6. Growth characteristics of the cactus pear grown in different localities of the Brazilian savannah.

	Number of cladodes	Thickness (mm)	Length (cm)	Perimeter (cm)	Width (cm)	Height (cm)
Curimatá	5.56B	7.9B	12.2B	29.2B	6.2A	32.1B
Riacho Frio	9.72A	9.3A	15.9A	36.6A	8.9A	53.1A
EPM[a]	1.01	0.26	0.29	0.59	1.02	1.3

EPM[a]: mean standard error Means followed by different letters in the columns are statistically different by Tukey's test at $P<0.05$ of probability.

The best results for the agronomic traits of the cactus pear obtained in Locality 2, compared to Locality 1, confirm the recommendation for the planting restriction of cactus pear in Locality 1, as described by Edvan et al. (2020). These authors observe a dry biomass production of <10 t ha^{-1} $year^{-1}$ for the cactus pear grown in this locality. However, long-term evaluations are required before fully condemning cactus pear cultivation in this savannah area. The contrary occurs for Locality 2, as the authors recommend its use due to the higher growth and production observed in their evaluations.

The results of the interaction between frequencies and doses of N application obtained for the chemical composition can be related to the mobilization of minerals that are available for the structural composition of the plant, which, through splitting and difference between doses, can be more available in the soluble fraction of the soil and consequently available for absorption by plants (Cunha *et al*. 2012; Nascimento *et al*. 2020).

Chemical composition

For the chemical composition, there was an interaction between the frequencies and doses of nitrogen application for the MM content (Table 7). For the remaining chemical composition variables, no effect of the interaction was observed.

Table 7. Discrimination of the analysis of variance for the chemical composition of the cactus pear under frequencies and doses of nitrogen application in different localities of the Brazilian savannah.

	P – value							
Variable	Freq	Dose	Loc	Freq x Dose	Dose x Loc	Freq x Loc	Freq x Dose x Loc	General Mean
DM[a]	0.55[ns]	0.83[ns]	0.61[ns]	0.11[ns]	0.06[ns]	0.50[ns]	0.86[ns]	6.6
MM[b]	0.15[ns]	0.13[ns]	<0.01*	<0.01 *	0.08[ns]	0.70[ns]	0.79[ns]	12.95
EE[c]	0.12[ns]	0.21[ns]	0.14*	0.89[ns]	0.81[ns]	0.65[ns]	0.52[ns]	1.09
NDF[d]	0.87[ns]	0.95[ns]	<0.01*	0.96[ns]	0.36[ns]	0.85[ns]	0.73[ns]	37.0
ADF[e]	0.78[ns]	0.26[ns]	<0.01*	0.77[ns]	0.40[ns]	0.96[ns]	0.81[ns]	18.22

DM[a]: dry matter; MM[b]: mineral matter (ash); EE[c]: ethereal extract; NDF[d]: neutral detergent fiber; ADF[e]: acid detergent fiber *significant at *P*<0.05.

Effects were only observed (P<0.05) for the influence of the locality on the contents of MM, EE, NDF, and ADF. Locality 1 showed higher values for the MM, NDF, and ADF, with means that varied from 14.39 to 11.52±0.70, from 39.99 to 34.02±1.64, and from 24.69 to 11.76±1.46, respectively (Table 8).

Table 8. Chemical composition characteristics of the cactus pear grown in different localities of the Brazilian savannah.

	MM[b]	EE[c]	NDF[d]	ADF[e]
Curimatá	14.39A	0.96A	39.99A	24.69A
Riacho Frio	11.52B	1.22A	34.02B	11.76B
EPM[a]	0.70	0.17	1.64	1.46

MM[b]: mineral matter (ash); EE[c]: ethereal extract; NDF[d]: neutral detergent fiber; ADF[e]: acid detergent fiber EPM[a]: mean standard error Means followed by different letters in the column are statistically different at *P*<0.05 by Tukey's test.

The higher chemical composition values verified for Locality 1 may be related to the lower number of cladodes produced in that locality (Table 5), which relates to the dilution of compounds in the plant. N has effects on the metabolic rate of the plant, increasing the morphogenic processes. Higher N doses directly affect the structural variables and, consequently, the chemical composition (Gurgel *et al.* 2020). Therefore, the higher number of cladodes verified in Locality 2 was responsible for the lower chemical composition contents, given the greater need for nutrient mobilization to form new cladodes. Batista *et al*. (2003) reported that the variations in the mineral matter are probably the consequence of different edaphoclimatic and management conditions to which the cactus pear is subjected, as described in the present study, in which Locality 1 showed higher values.

CONCLUSIONS

The cactus pear variety Doce, grown in the Brazilian savannah, responds increasingly to the main production parameters up to the dose of 400 kg N ha^{-1} $year^{-1}$. For the frequency of nitrogen application, the best option is the split application with 30/60 days.

The cultivation of the cactus pear variety Doce can be encouraged in the Brazilian Savannah region, although it presents a better performance in the locality of Riacho Frio, Piauí, Brazil.

CONSENT FOR PUBLICATION

This research study does not contain any individual person's data in any form (including any individual details, images or videos).

AVAILABILITY OF SUPPORTING DATA

All data generated or analyzed during this study are included in this published article.

COMPETING INTERESTS

The research has no financial or commercial purpose that must be interpreted as a potential conflict of interest in the future.

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AUTHOR CONTRIBUTIONS

Conceptualization, RLE, and SSRM; methodology, KSN, TGJG and SVS; formal analysis, RLE; investigation, KSN, TGJG, MOR, LFRC and TGJG; resources, KSN; data curation, writing-original draft preparation, KSN and TGJG; writing-review and editing, KSN and RLE.

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